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An intra-day analysis of electricity forward premia

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About the Presenter

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Previous studies

- Kun Li et al. “The Significance of Calendar Effects in the Electricity Market”, *Applied Energy*, 2019, volume 235, pages 487-494. (DOI: 10.1016/j.apenergy.2018.10.124)

- Kun Li et al. “Principal Component Analysis of Price Fluctuation in the Smart Grid Electricity Market”, *Sustainability*, 2018, volume 10, issue 11, 4019. (DOI: 10.3390/su10114019)

Motivation

- An extended model based on Bessembinder & Lemmon (2002) with theoretical proof in behavioral finance.
- Include risk factors that account for significant forward premium in the multi-line electricity market.
- Conduct an empirical test in the Pennsylvania–New Jersey–Maryland (PJM) wholesale electricity market.

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Three options to have electric power

When have the electricity power at day t+1

1. buy at the spot price at day t, and hold it to day t+1.
2. buy at the forward price at day t for day t+1.
3. buy at the spot price at day t+1 directly.

Three options to have electric power

- The settled price
  - $F_{t,t+1}$ *is the forward price observed on day t for delivery on day t+1;*
  - S_t *is the spot price on day t*
  - S_{t+1} *is the spot price on day t+1*

	day t	day t+1
Option 1	S_t	
Option 2	$F_{t,t+1}$	$F_{t,t+1}$
Option 3		S_{t+1}

Three options to have electric power

- The settled price, and the estimated value for transaction
  - $E_t[S_{t+1}]$ *is the estimated spot price on day t+1 given information available on day t*
  - u is the inventory cost, and y is the convenience yield

	day t	day t+1
Option 1	S_t	$S_t e^{r_f+u-y}$
Option 2	$F_{t,t+1}$	$F_{t,t+1}$
Option 3	$E_t[S_{t+1}]$	S_{t+1}

Efficient Market

- Perfect Hedge: all three options have the same value at day t+1,

$$S_t e^{r_f+u-y} = F_{t,t+1} = S_{t+1}$$

- According to Fama (1970), Pindyck (2001), Hull (2006), at day t, we should also have

$$E_t[S_{t+1}] = S_t$$

- at day t,

$$E_t[S_{t+1}] = S_t$$
$$E_t[S_t e^{r_f+u-y}] = S_t$$
$$S_t E_t[e^{r_f+u-y}] = S_t$$

- Offset S_t

$$E_t[e^{r_f+u-y}] = 1$$
$$e^{r_f+E(u)-E(y)} = 1$$

- So the arbitrage-free condition

$$r_f + E(u) - E(y) = 0$$

- So the arbitrage-free condition

$$r_f + E(u) - E(y) = 0$$

- Rewritten into the generalized format of APT multifactor model about opportunity cost, inventory cost, and non-monetary benefits of holding an asset.

$$r = r_f + E(u) - E(y)$$

Or

$$r_i = r_f + \beta_1 u_i + \beta_2 y_i + e_i$$

Forward Premium

- Bessembinder & Lemmon (2002), Longstaff & Wang (2004), Haugom & Ullrich (2012)
- The ex ante (day t) forward premium as

$$FP^{EA} = F_{t,t+1} - E_t[S_{t+1}]$$

- The alternative ex post (day t+1) forward premium

$$FP^{EP} = F_{t,t+1} - S_{t+1}$$

Forward Premium

- The ex post forward premium

$$FP^{EP} = F_{t,t+1} - S_{t+1}$$
$$= \left(F_{t,t+1} - E_t[S_{t+1}]\right) + \left(E_t[S_{t+1}] - S_{t+1}\right)$$
$$= FP^{EA} + FE_{t,t+1}$$

- Where $FE_{t,t+1} = E_t[S_{t+1}] - S_{t+1}$ is the forecast error, and $E_t[S_{t+1}] - S_{t+1}$ is a function of r_f, u and y.
- So the forward premium FP^{EP} is a function of r_f, u and y.

Bessembinder & Lemmon (2002)

- Equilibrium Forward Price

$$F_{t,t+1} = E_t[S_{t+1}] + b\,Var(S_{t+1}) + c\,Skew(S_{t+1})$$

- Input $FP^{EA} = F_{t,t+1} - E_t[S_{t+1}]$ and $FP^{EP} = FP^{EA} + FE_{t,t+1}$

$$FP^{EP} = b\,Var(S_{t+1}) + c\,Skew(S_{t+1}) + FE_{t,t+1}$$

- So we need to include variables related to $FE_{t,t+1}$.

Data

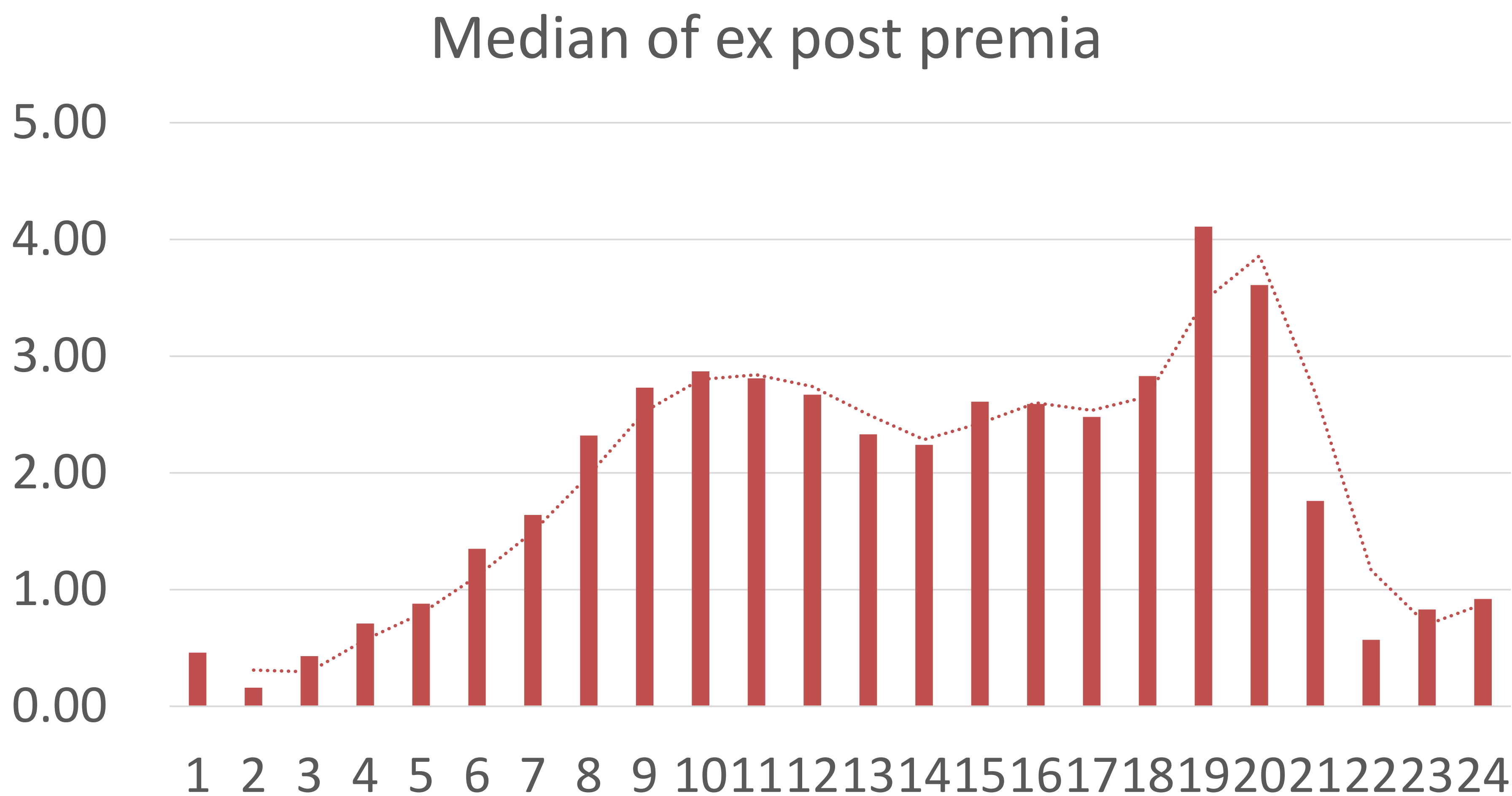
- the wholesale Pennsylvania, New Jersey and Maryland (PJM) electricity market
- Covers 13 states and Washington D.C.
- 12,000 transmission lines (Pnodes) in areas served by PJM
- Market clearing price: for each Pnode, Hourly locational marginal price (LMP) , for both forward and spot prices, between 2013-16

Summary statistics: ex post premia

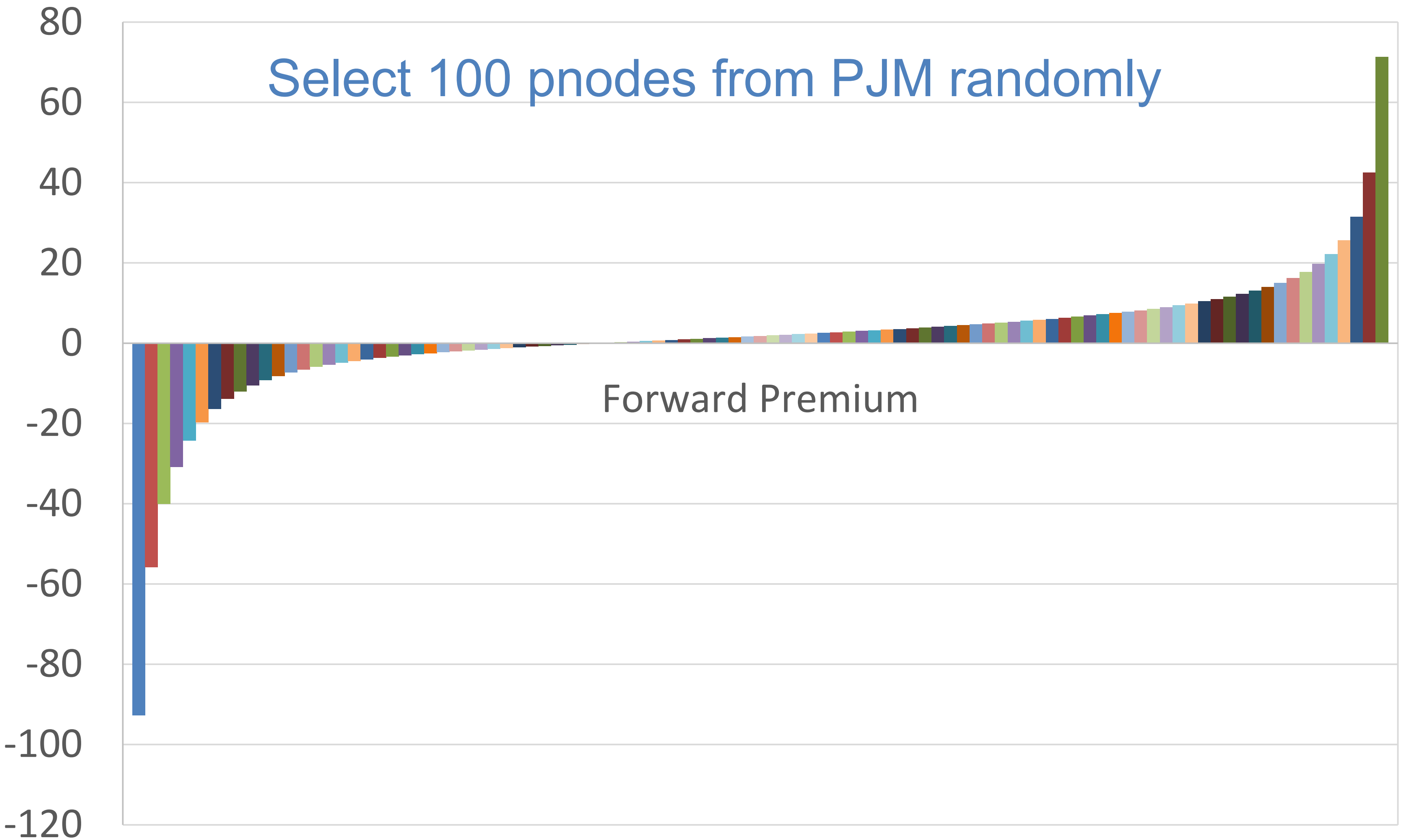
Over 390 million observations

mean	p50	sd	min	max	t-statistic
0.77	1.63	34.91	-4508	2272	437.18

ex post premia by Hour-of-the-day



Forward premia in percentile



Cross-sectional Analysis

- Typical B-L Model: for each Pnode x at hour h

$$FP_{t,t+1}^{EP} = a_x + a_h + b\,Var(S_{t+1}) + c\,Skew(S_{t+1})$$

- Revised Model: add congestion cost and marginal loss as $FE_{t,t+1}$

$$FP^{EP} = a_x + a_h + b\,Var(S_{t+1}) + c\,Skew(S_{t+1}) + d\,Congestion_{t+1} + e\,Marginal_{t+1}$$

Empirical Results

	B-L	Revised
$Var(S_{t+1})$	-0.21	-0.30
$Skew(S_{t+1})$	0.03	0.01
$Congestion_{t+1}$		0.44
$Marginal_{t+1}$		-0.07
Num	3,500,400	3,500,400
R	0.0426	0.3291

Implications

- Congestion: corresponds to u, since the inventory cost can be adjusted due to the different settled prices on date t or t+1
- Marginal: corresponds to y, since the transmission loss is mainly due to the producers' motivations and locations.
- These results are consistent with B-L model (2002).

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Summary

- We theoretically explain the components of the forecast error in B-L, and prove them as the critical conditions for the model.
- Use PJM dataset to testify the theoretical proof
  - Suggest qualified measures for empirical tests