SPOT PRICES AND FORWARD PREMIA ON THE MISO EXCHANGE

Kevin Jones

ABSTRACT

This paper explores information contained in the basis for wholesale electricity on the Midcontinent IndependentSystem Operator (MISO) electricity exchange. Utilizing Fama and French's (1987) approach, the basis is found to have predictive power on changes in real-time (spot) prices but provides only limited evidence of a time-varying forward premium. This result contradicts Huisman and Kilic's (2012) theory that the basis in an electricity marketwhich relies primarily on storable forms of power for electricity production (such as MISO) should contain information on both changes in spot prices and provide evidence of a time-varying forward premium.

Keywords: Electricity Derivatives, Forward Premiums, Basis

Kevin Jones, PhD, University of Houston-Downtown, joneske@uhd.edu

1. INTRODUCTION

The Midcontinent Independent System Operator (MISO) is a regional transmission operator (RTO), whichis responsible for managing the transmission and delivery of electricity across the US and Canada. Beginning in 2013, MISO expanded to the Southern US to cover parts of Texas, Louisiana, Arkansas, and Mississippi. The MISO footprint is divided into regional eight hubs which cover 15 states and one Canadian province, making it geographically the largest RTO in the United States (Fig. 1).

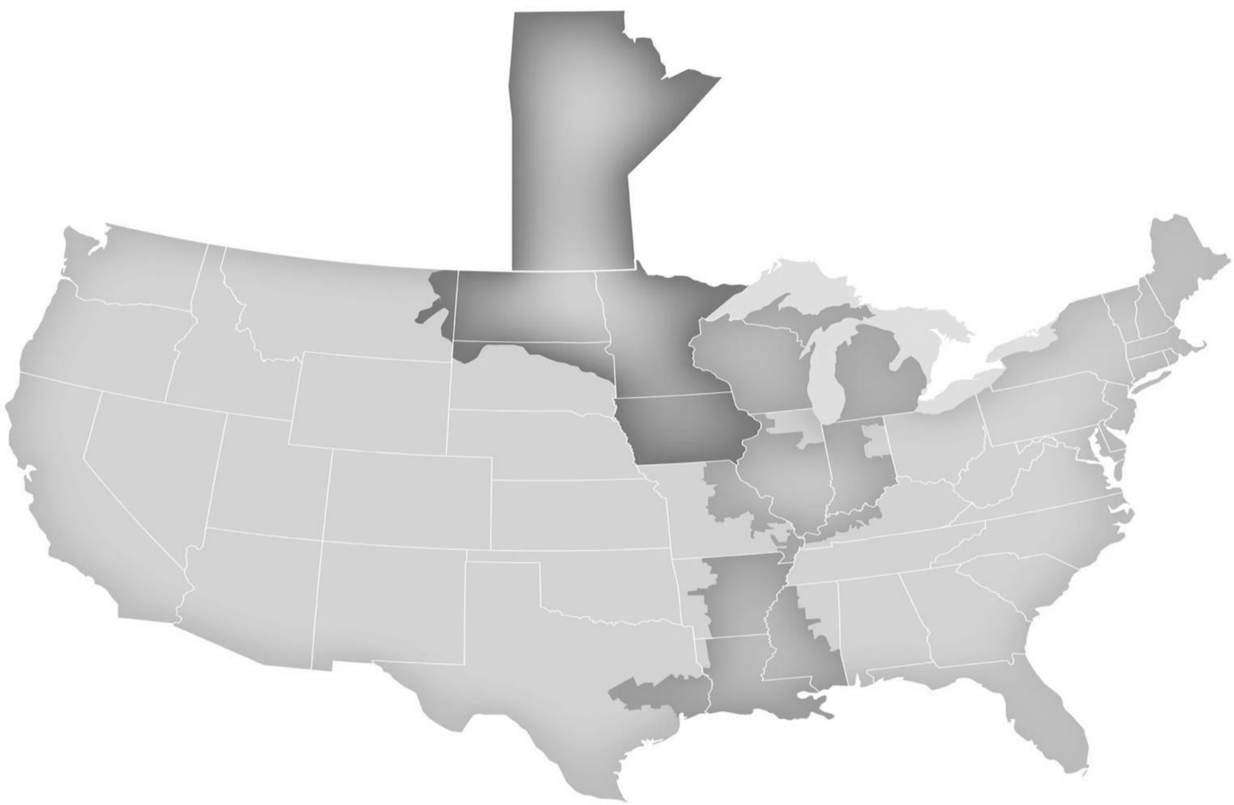

Figure 1: MISO Geographic Footprint. (MISO 2021a)

MISO also manages a wholesale electricity market which allows registered market participants to trade spot (real-time) and forward (day-ahead) contracts. MISO's wholesale electricity market is one of the largest in the United States, with over 450 registered market participants and more than $20 billion in annual energytransactions (MISO 2021b

Several authors have found the existence of significant forward premiums in various wholesale electricity markets across the world (Longstaff & Wang 2004, Lucia & Torro 2008, Viehmann 2011, Redl & Bunn 2012, Handika & Trück 2013). However, this is the first study to use the basis (defined as the difference between the forward price observed in time *t* for delivery in time *t+1* and the spot price in time *t*) in forecasting both real-time price changes and to determine the existence of time-varying forward premiums on the MISO exchange. The basison the MISO market has explanatory power in terms of future spot price movements but provides only limited support for the existence of a time-varying forward premium. This result contradicts Huisman and Kilic's (2012) theory that suggests electricity markets which predominantly use storable forms of energy in electricity generationexhibit time-varying forward premiums.

2. PRIOR RESEARCH

The classic model described by Keynes (1930) expresses the relationship between the forward price for agiven commodity and its expected future spot price as follows:

$$F_{t,+1} = E_t(S_{t+1}) - RP, \qquad (1)$$

where $F_{t,t+1}$ is the forward price for a given commodity in time *t* for delivery in time *t+1*, $E_t(S_{t+1})$ is the expected(forecasted in time *t*) spot price in time *t+1*, and *RP* is the risk premium. In this framework, the risk premium represents compensation forward contract buyers receive for accepting the price risk of the underlying commodityat expiration. Keynes postulates in equilibrium, $F_{t,+1}$ will fall below $E_t(S_{t+1})$ by an amount equal to the risk premium, a phenomenon he refers to as normal backwardation.
Kaldor (1939) builds on Keynes' approach by explaining the dynamic between forward and spot prices with what became known as the cost of carry model. Formally, it can be expressed as:

$$F_{t,+1} - S_t = S_t i_{t,t+1} + C_{t,t+1} - Y_{t,t+1}, \quad (2)$$

where S_t represents the current (time *t*) spot price for a given commodity, $S_t i_t$ is the interest that could be earnedfrom investing S_t dollars from time *t* to *t+1*, $C_{t,t+1}$ is cost of storing the commodity from time *t* to *t+1* and $Y_{t,t+1}$ is the convenience yield received from holding the commodity from time *t* to *t+1*. In other words, the return earnedby a person who simultaneously purchases an asset in the spot market in time *t* and sells a forward contract on that asset in time *t* for delivery in time *t+1* should equal the costs of foregone interest and storage, less any gains earned from holding the asset from *t* to *t+1*.

In their seminal work, Fama and French (1987) define the basis as the difference between the futures price observed in time *t* for delivery in time *t+1* and the spot price in time *t*, which is the left-hand side of Equation 2. The authors then perform the following regressions to evaluate the information contained in the basis with respect to spot price changes and the ex-post forward premium for several futures contracts:

$$S_{t+1} - S_t = \alpha_1 + \beta_1(F_{t,t+1} - S_t) + \varepsilon_{1,t} \qquad (3)$$

$$F_{t,+1} - S_{t+1} = \alpha_2 + \beta_2(F_{t,t+1} - S_t) + \varepsilon_{2,t}, \qquad (4)$$

where $(F_{t,t+1} - S_{t+1})$ represents the realized forward premium. It is important to note that under rational expectations, the sum of the intercept, coefficient, and error term in Equation 3 should equal $(S_{t+1} - S_t)$.

Therefore, significant β_1 estimates suggest that the basis has predictive power for future spot price changes. If rational expectations hold, it's also the case that the forward premium as defined in Equation 4 is the inverse of the risk premium shown in Equation 1. Fama and French find that for commodities with high storage costs, such as livestock, the basis tends to contain information about spot price changes (significant estimates of β_1) but does not show evidence of a time-varying forward premium (insignificant estimates of β_2). For commodities with lower storage costs, the basis tends to provide evidence of time-varying forward premiums but has low forecasting power on spot price changes. Of the 21 commodities tested, only two (plywood and orange juice) yield significantestimates for both $\beta 1$ and $\beta 2$.

While the cost of carry model (as shown in Equation 2) seems difficult to apply to wholesale electricity markets given the challenges of storing electricity, the factors of production may be physically stored or traded in highly liquid, financially settled futures markets to mitigate the risk of being long or short in wholesale electricity. Power exchanges that primarily use storable forms of energy sources like coal or natural gas in electricity generation provide market participants with a means to indirectly store wholesale electricity. Thus, the storability of the factors of production may play a role in the ability of the basis to forecast spot prices and on the existence oftime-varying forward premiums in electricity markets.

Huisman and Kilic (2012) investigate this possibility by studying two European wholesale electricity markets: Nord Pool and the Amsterdam Power Exchange. Nord Pool's footprint relies mainly on hydropower, which is difficult to store and has no active futures markets. Conversely, the main source of power for generators on the Amsterdam Power Exchange is natural gas, which is both easily storable and actively traded in futures markets. The authors employ Equations 3 and 4 on each power exchange and find that the basis has forecasting power for both markets, but only the Amsterdam exchange shows evidence of a time-varying forward premium. To further understand their findings, the authors then compare the variance of spot price changes to the variance of the forward premium for each exchange. While the variance for spot price changes is larger than the variance of the forward premium for both markets, the authors find this difference is only statistically significant on the Nord Pool exchange. This implies that basis variation is low relative to the variation of spot prices on Nord Pool, which can lead to insignificant estimates of β_2 in Equation 4. The authors attribute the high spot price variation on Nord Pool in part to the storability issues surrounding hydropower.

The aim of this study is to evaluate the information contained in the basis regarding both the forward premium and real-time (spot) price changes on the MISO exchange as shown in Equations 3 and 4. To my knowledge, this is the first paper to employ the methodology described in Fama and French (1987) to the largest wholesale electricity market in the United States. While several forms of energy are used in the production of electricity within the MISO footprint, 71% of MISO's electricity is generated with gas and coal (MISO 2021b). Basedon the theory proposed by Huisman and Kilic (2012), the heavy reliance on storable factors of production within the MISO footprint should result in the basis containing information on spot price changes and providing evidence of a time-varying risk premium.

The rest of the paper is organized as follows. Section 3 details the data and methodology used in the research. Section 4 discusses the results, while Section 5 provides a summary and conclusion.

3. METHODOLOGY

The market-clearing price for day-ahead (forward) and real-time (spot) electricity is known as the locational marginal price (LMP). LMPs are quoted in terms of US dollars per megawatt hour ($/MWh) and represent the cost of supplying the last incremental amount of energy at a given node within the transmission grid (MISO 2021a). MISO uses a weighted average process to aggregate nodal LMPs to hub level LMPs. MISO then calculates and reports 24 day-ahead and real-time hub level LMPs daily for each of its eight hubs: Arkansas (AR), Illinois (IL), Indiana (IN), Louisiana (LA), Michigan (MI), Minnesota (MN), Mississippi (MS), and Texas (TX). Thesample used in this study consists of 24 hourly real-time and day-ahead price series for each day, on the eight MISO hubs from 1/1/2018-12/31/2020. Therefore, each of the hourly day-ahead and real-time price series contains 1096 hub level LMPs. LMP data is available on MISO's website, www.misoenergy.org.

As previously stated, the goal of this study is to apply the methodology described in Fama and French (1987) to determine the information contained in the basis for wholesale electricity on the MISO exchange.

Specifically, the basis, real-time price changes, and ex-post forward premiums are calculated for each hour of the day, on each of the eight MISO hubs during the sample period. Equations 3 and 4 are then estimated via OLS with heteroscedasticity and autocorrelation-consistent (Newey-West) standard errors. Statistically significant estimates of β_1 suggest that the basis can be used to forecast real-time price movements. If MISO market participants use coal and natural gas futures markets to indirectly store electricity as theorized by Huisman and Kilic (2012), estimates of β_2 should be statistically significant.

It's important to note that the methodology used in this paper differs substantially from the one used by Huisman and Kilic (2012) in a few ways. Huisman and Kilic's (2012) sample consists of 69 monthly futures contracts for both the Nord Pool and Amsterdam power markets. The authors assume that delivery occurs the first trading day of delivery month. To determine the basis and ex-post forward premium, the authors use day- ahead prices for electricity to be delivered on the futures contract settlement day (by calculating the arithmetic mean day-ahead price) as a proxy for the spot price for electricity. Instead of using proxies for spot prices, this study uses actual hub level real-time prices in the calculation of the realized forward premium and basis.
Additionally, this study treats each hour of the day in both the real-time and day-ahead market as its own time series. Treating electricity delivered on a given day as a homogenous commodity prohibits the examination of inter-day patterns that may exist regarding the risk premium and the ability to forecast spot prices.

4. RESULTS

Tables 1-8 show the coefficients obtained from the OLS regressions of Equations 3 and 4. Consistent with the findings of Huisman and Kilic (2012), β_1 is positive and statistically significant for 186 of the 192 (96.88%) hourly time series in the sample. Four of the 6 insignificant β_1 estimates occurred on one hub (Mississippi) and all six occurred between the hours of 1:00-9:00. In general, the basis (and subsequently the day-ahead price) explains a large portion of the variance in real-time prices across the exchange. The average coefficient of determination, R^2 (β_1), across all 192 hourly hub level regressions is 48%.

Evidence of a time-varying forward premium (significant estimates of β_2), however, is limited at best. Of the 192 total regressions of the basis on realized forward premiums, only 59 (30.73%) provide evidence of a time- varying premium. Furthermore, the largest number of significant β_2 estimates on any hub is 11 (Louisiana), which suggests that time-varying forward premiums do not exist on any MISO hub for most of the day. Forward premiums are slightly more common on the four southern hubs. The average number of hours exhibiting time- varying forward premiums on each of the southern hubs (AR, LA, MS, TX) is 7.75 while the average on the northern hubs is 7. Even though there are not widespread time-varying forward premiums on the MISO exchange as Huisman and Kilic's (2012) indirect storage theory suggests, the data reveals an inter-day pattern in forward premiums. Time-varying forward premiums tend to be most frequently found between the hours of 12:00-22:00.This could be the result of hedging pressure during these peak demand hours on the exchange. The lack of persistent time-varying premiums contradicts Huisman and Kilic's (2012) perfect indirect storability theory regarding fossil fuel-dominated electricity markets. In fact, real-time and day-ahead prices on the gas and coal- oriented MISO exchange appear to behave in a manner similar to what Huisman and Kilic report (2012) on the hydropower dominated Nord Pool market.

Table 1: Regression of Real-Time Price Changes (Eq. 3) and the Forward Premium (Eq. 4) on the Basis-ARHub.

Hour	β_1	t(β_1)	R^2 (β_1)	β_2	t(β_2)	R^2 (β_2)
0:00	1.03	13.26	0.52	-0.03	-0.43	0.00
1:00	1.07	17.95	0.54	-0.07	-1.21	0.01
2:00	1.07	14.27	0.53	-0.07	-0.96	0.01
3:00	1.10	13.72	0.54	-0.10	-1.20	0.01
4:00	1.19	11.23	0.58	-0.19	-1.81	0.03
5:00	1.15	5.81	0.56	-0.15	-0.78	0.02
6:00	1.12	14.24	0.54	-0.12	-1.49	0.01
7:00	1.13	12.59	0.52	-0.13	-1.46	0.01
8:00	1.06	15.75	0.53	-0.06	-0.95	0.00
9:00	1.02	21.68	0.51	-0.02	-0.47	0.00
10:00	1.00	30.34	0.52	0.00	0.08	0.00
11:00	0.97	20.34	0.52	0.03	0.67	0.00
12:00	0.91	29.95	0.47	0.09	3.01	0.01
13:00	0.95	29.37	0.48	0.05	1.69	0.00
14:00	0.90	26.84	0.45	0.10	2.93	0.01
15:00	0.89	23.86	0.44	0.11	2.84	0.01
16:00	0.79	12.74	0.39	0.21	3.30	0.04
17:00	0.83	9.53	0.42	0.17	1.92	0.03
18:00	0.88	10.14	0.47	0.12	1.32	0.01
19:00	0.96	20.49	0.50	0.04	0.83	0.00
20:00	0.91	22.11	0.48	0.09	2.17	0.01
21:00	0.96	22.34	0.54	0.04	0.97	0.00
22:00	0.98	75.78	0.50	0.02	1.45	0.00
23:00	0.95	25.42	0.51	0.05	1.43	0.00

Equation 3: $S_{t+1} - S_t = \alpha_1 + \beta_1(F_{t,t+1} - S_t) + \varepsilon_{1,t}$

Equation 4: $F_{t,+1} - S_{t+1} = \alpha_2 + \beta_2(F_{t,t+1} - S_t) + \varepsilon_{2,t}$

Each hourly time series regression consists of 1096 observations and is estimated via OLS with HAC (Newey-West)standard errors.

Table 2: Regression of Real-Time Price Changes (Eq. 3) and the Forward Premium (Eq. 4) on the Basis-ILHub.

Hour	β_1	t(β_1)	R^2 (β_1)	β_2	t(β_2)	R^2 (β_2)
0:00	1.01	12.52	0.55	-0.01	-0.09	0.00
1:00	0.99	36.06	0.54	0.01	0.51	0.00
2:00	1.02	17.56	0.57	-0.02	-0.33	0.00
3:00	1.11	8.00	0.60	-0.11	-0.81	0.02
4:00	0.98	17.02	0.54	0.02	0.31	0.00
5:00	0.98	28.68	0.52	0.02	0.72	0.00
6:00	1.05	28.85	0.55	-0.05	-1.26	0.00
7:00	1.03	27.38	0.57	-0.03	-0.69	0.00
8:00	1.16	12.83	0.55	-0.16	-1.74	0.02
9:00	1.09	14.99	0.52	-0.09	-1.24	0.01
10:00	0.96	25.57	0.50	0.04	0.99	0.00
11:00	0.94	29.72	0.51	0.06	2.04	0.00
12:00	0.93	25.42	0.49	0.07	2.03	0.00
13:00	0.91	14.13	0.47	0.09	1.40	0.01
14:00	0.91	19.93	0.47	0.09	2.00	0.01
15:00	0.88	21.70	0.44	0.12	2.95	0.01
16:00	0.86	31.76	0.43	0.14	5.34	0.02
17:00	0.90	21.99	0.46	0.10	2.34	0.01
18:00	0.92	11.75	0.48	0.08	1.05	0.01
19:00	0.93	20.19	0.48	0.07	1.57	0.01
20:00	0.88	21.50	0.49	0.12	2.87	0.02
21:00	0.94	36.43	0.53	0.06	2.33	0.00
22:00	0.95	54.88	0.49	0.05	2.88	0.00
23:00	0.95	20.88	0.53	0.05	1.15	0.00

Equation 3: $S_{t+1} - S_t = \alpha_1 + \beta_1(F_{t,t+1} - S_t) + \varepsilon_{1,t}$

Equation 4: $F_{t,+1} - S_{t+1} = \alpha_2 + \beta_2(F_{t,t+1} - S_t) + \varepsilon_{2,t}$

Each hourly time series regression consists of 1096 observations and is estimated via OLS with HAC (Newey-West)standard errors.

Table 3: Regression of Real-Time Price Changes (Eq. 3) and the Forward Premium (Eq. 4) on the Basis-INHub.

Hour	β_1	t(β_1)	R^2 (β_1)	β_2	t(β_2)	R^2 (β_2)
0:00	0.93	11.50	0.50	0.07	0.92	0.01
1:00	0.99	24.21	0.53	0.01	0.24	0.00
2:00	0.88	13.52	0.50	0.12	1.77	0.02
3:00	0.75	6.11	0.43	0.25	2.03	0.08
4:00	0.88	15.19	0.47	0.12	2.07	0.02
5:00	0.91	16.25	0.48	0.09	1.61	0.01
6:00	1.03	23.58	0.53	-0.03	-0.65	0.00
7:00	1.06	51.73	0.55	-0.06	-2.97	0.00
8:00	1.19	11.06	0.54	-0.19	-1.78	0.03
9:00	1.12	12.07	0.52	-0.12	-1.26	0.01
10:00	0.96	20.35	0.48	0.04	0.83	0.00
11:00	0.93	25.54	0.50	0.07	1.97	0.01
12:00	0.96	28.80	0.51	0.04	1.26	0.00
13:00	0.93	26.56	0.50	0.07	2.00	0.01
14:00	0.95	25.02	0.51	0.05	1.42	0.00
15:00	0.92	18.75	0.49	0.08	1.63	0.01
16:00	0.92	17.79	0.48	0.08	1.64	0.01
17:00	0.91	20.08	0.48	0.09	2.00	0.01
18:00	0.90	12.12	0.47	0.10	1.40	0.01
19:00	0.89	19.42	0.46	0.11	2.33	0.01
20:00	0.85	16.42	0.46	0.15	3.00	0.03
21:00	0.93	27.62	0.51	0.07	2.23	0.01
22:00	0.95	48.73	0.49	0.05	2.47	0.00
23:00	0.95	16.92	0.53	0.05	0.82	0.00

Equation 3: $S_{t+1} - S_t = \alpha_1 + \beta_1(F_{t,t+1} - S_t) + \varepsilon_{1,t}$

Equation 4: $F_{t,+1} - S_{t+1} = \alpha 2 + \beta 2(F_{t,t+1} - S_t) + \varepsilon_{2,t}$

Each hourly time series regression consists of 1096 observations and is estimated via OLS with HAC (Newey-West)standard errors.

Table 4: Regression of Real-Time Price Changes (Eq. 3) and the Forward Premium (Eq. 4) on the Basis-LAHub.

Hour	$\beta 1$	t($\beta 1$)	R^2 ($\beta 1$)	$\beta 2$	t($\beta 2$)	R^2 ($\beta 2$)
0:00	0.53	2.03	0.28	0.47	1.82	0.23
1:00	0.33	1.69	0.19	0.67	3.44	0.50
2:00	0.52	2.61	0.24	0.48	2.37	0.21
3:00	0.83	28.95	0.50	0.17	6.00	0.04
4:00	0.49	3.41	0.26	0.51	3.54	0.28
5:00	0.78	95.12	0.54	0.22	26.33	0.08
6:00	0.58	5.00	0.38	0.42	3.61	0.24
7:00	0.78	4.89	0.39	0.22	1.36	0.05
8:00	0.43	3.16	0.32	0.57	4.24	0.46
9:00	0.44	2.80	0.29	0.56	3.62	0.40
10:00	1.01	25.24	0.54	-0.01	-0.33	0.00
11:00	1.02	37.20	0.54	-0.02	-0.58	0.00
12:00	0.99	27.75	0.49	0.01	0.39	0.00
13:00	0.99	28.68	0.49	0.01	0.17	0.00
14:00	0.95	33.80	0.46	0.05	1.81	0.00
15:00	0.86	18.55	0.44	0.14	2.97	0.02
16:00	0.94	34.38	0.48	0.06	2.11	0.00
17:00	0.78	9.97	0.38	0.22	2.80	0.05
18:00	0.89	13.24	0.46	0.11	1.58	0.01
19:00	0.74	4.15	0.41	0.26	1.43	0.08
20:00	0.95	15.76	0.48	0.05	0.76	0.00
21:00	0.92	8.91	0.46	0.08	0.81	0.01
22:00	0.85	7.01	0.44	0.15	1.26	0.02
23:00	0.80	5.04	0.45	0.20	1.28	0.05

Equation 3: $S_{t+1} - S_t = \alpha_1 + \beta_1(F_{t,t+1} - S_t) + \varepsilon_{1,t}$

Equation 4: $F_{t,+1} - S_{t+1} = \alpha 2 + \beta 2(F_{t,t+1} - S_t) + \varepsilon_{2,t}$

Each hourly time series regression consists of 1096 observations and is estimated via OLS with HAC (Newey-West)standard errors.

Table 5: Regression of Real-Time Price Changes (Eq. 3) and the Forward Premium (Eq. 4) on the Basis-MIHub.

Hour	β_1	$t(\beta_1)$	R^2 (β_1)	β_2	$t(\beta_2)$	R^2 (β_2)
0:00	0.80	4.47	0.40	0.20	1.13	0.04
1:00	1.03	49.00	0.52	-0.03	-1.35	0.00
2:00	1.01	37.00	0.52	-0.01	-0.20	0.00
3:00	0.96	18.20	0.49	0.04	0.76	0.00
4:00	1.03	38.73	0.52	-0.03	-1.07	0.00
5:00	0.97	27.79	0.51	0.03	0.72	0.00
6:00	1.02	18.19	0.52	-0.02	-0.28	0.00
7:00	1.09	53.24	0.56	-0.09	-4.34	0.01
8:00	1.05	22.05	0.53	-0.05	-1.08	0.00
9:00	0.99	14.00	0.49	0.01	0.15	0.00
10:00	0.94	17.33	0.48	0.06	1.07	0.00
11:00	1.03	65.50	0.54	-0.03	-1.81	0.00
12:00	1.04	32.11	0.56	-0.04	-1.13	0.00
13:00	0.94	20.20	0.51	0.06	1.34	0.00
14:00	0.99	13.90	0.55	0.01	0.13	0.00
15:00	0.99	17.89	0.54	0.01	0.21	0.00
16:00	1.00	16.40	0.54	0.00	0.06	0.00
17:00	1.02	17.53	0.55	-0.02	-0.36	0.00
18:00	0.94	16.77	0.49	0.06	1.10	0.00
19:00	0.97	37.86	0.50	0.03	0.99	0.00
20:00	0.97	25.75	0.52	0.03	0.88	0.00
21:00	0.99	45.93	0.52	0.01	0.67	0.00
22:00	0.98	59.58	0.50	0.02	1.23	0.00
23:00	0.98	32.16	0.50	0.02	0.59	0.00

Equation 3: $S_{t+1} - S_t = \alpha_1 + \beta_1(F_{t,t+1} - S_t) + \varepsilon_{1,t}$

Equation 4: $F_{t,+1} - S_{t+1} = \alpha_2 + \beta_2(F_{t,t+1} - S_t) + \varepsilon_{2,t}$

Each hourly time series regression consists of 1096 observations and is estimated via OLS with HAC (Newey-West)standard errors.

Table 6: Regression of Real-Time Price Changes (Eq. 3) and the Forward Premium (Eq. 4) on the Basis-MNHub.

Hour	β_1	t(β_1)	R^2 (β_1)	β_2	t(β_2)	R^2 (β_2)
0:00	0.89	6.62	0.51	0.11	0.80	0.01
1:00	0.94	15.10	0.54	0.06	1.03	0.01
2:00	0.83	0.97	0.56	0.17	2.03	0.05
3:00	0.86	8.32	0.56	0.14	1.40	0.04
4:00	0.88	6.31	0.56	0.12	0.83	0.02
5:00	0.89	9.59	0.50	0.11	1.20	0.02
6:00	1.01	14.28	0.54	-0.01	-0.14	0.00
7:00	0.99	13.80	0.57	0.01	0.13	0.00
8:00	1.16	13.93	0.57	-0.16	-1.94	0.02
9:00	1.11	17.91	0.54	-0.11	-1.72	0.01
10:00	1.09	13.71	0.55	-0.09	-1.14	0.01
11:00	1.02	28.07	0.58	-0.02	-0.47	0.00
12:00	0.91	22.31	0.53	0.09	2.09	0.00
13:00	0.91	17.56	0.48	0.09	1.69	0.01
14:00	0.88	23.23	0.49	0.12	3.14	0.02
15:00	0.87	12.88	0.46	0.13	1.99	0.02
16:00	0.85	37.22	0.44	0.15	6.43	0.02
17:00	0.85	18.05	0.44	0.15	3.10	0.02
18:00	0.90	9.69	0.48	0.10	1.08	0.01
19:00	0.94	18.86	0.50	0.06	1.22	0.00
20:00	0.85	16.38	0.52	0.15	2.79	0.03
21:00	0.93	27.57	0.54	0.07	2.19	0.01
22:00	0.97	55.22	0.51	0.03	1.94	0.00
23:00	0.98	26.51	0.55	0.02	0.57	0.00

Equation 3: $S_{t+1} - S_t = \alpha_1 + \beta_1(F_{t,t+1} - S_t) + \varepsilon_{1,t}$

Equation 4: $F_{t,+1} - S_{t+1} = \alpha 2 + \beta 2(F_{t,t+1} - S_t) + \varepsilon_{2,t}$

Each hourly time series regression consists of 1096 observations and is estimated via OLS with HAC (Newey-West)standard errors.

Table 7: Regression of Real-Time Price Changes (Eq. 3) and the Forward Premium (Eq. 4) on the Basis-MSHub.

Hour	$\beta 1$	t($\beta 1$)	R^2 ($\beta 1$)	$\beta 2$	t($\beta 2$)	R^2 ($\beta 2$)
0:00	0.70	2.84	0.34	0.30	1.24	0.09
1:00	0.65	2.79	0.32	0.35	1.50	0.12
2:00	1.06	7.38	0.35	-0.06	-0.40	0.00
3:00	1.61	3.93	0.56	-0.61	-1.48	0.16
4:00	0.15	0.32	0.01	0.85	1.80	0.20
5:00	2.24	3.90	0.70	-1.24	-2.16	0.41
6:00	0.57	1.60	0.11	0.43	1.21	0.07
7:00	0.63	2.07	0.21	0.37	1.22	0.08
8:00	0.56	1.77	0.17	0.44	1.38	0.11
9:00	0.28	0.75	0.05	0.72	1.93	0.27
10:00	1.39	3.61	0.48	-0.39	-1.01	0.07
11:00	1.15	7.50	0.52	-0.15	-1.00	0.02
12:00	0.93	15.90	0.45	0.07	1.19	0.00
13:00	1.00	28.74	0.48	0.00	0.03	0.00
14:00	0.95	17.54	0.46	0.05	0.96	0.00
15:00	0.92	22.08	0.45	0.08	2.02	0.01
16:00	0.86	12.42	0.42	0.14	2.10	0.02
17:00	0.72	7.65	0.34	0.28	3.03	0.07
18:00	0.85	10.59	0.44	0.15	1.93	0.03
19:00	0.88	16.44	0.46	0.12	2.24	0.02
20:00	0.88	23.39	0.47	0.12	3.16	0.02
21:00	0.76	7.36	0.47	0.24	2.29	0.08
22:00	0.95	29.65	0.48	0.05	1.42	0.00
23:00	0.94	11.91	0.49	0.06	0.82	0.00

Equation 3: $S_{t+1} - S_t = \alpha_1 + \beta_1(F_{t,t+1} - S_t) + \varepsilon_{1,t}$

Equation 4: $F_{t,+1} - S_{t+1} = \alpha 2 + \beta 2(F_{t,t+1} - S_t) + \varepsilon_{2,t}$

Each hourly time series regression consists of 1096 observations and is estimated via OLS with HAC (Newey-West)standard errors.

Table 8: Regression of Real-Time Price Changes (Eq. 3) and the Forward Premium (Eq. 4) on the Basis-TX Hub.

Hour	β_1	t(β_1)	R^2 (β_1)	β_2	t(β_2)	R^2 (β_2)
0:00	0.86	6.49	0.46	0.14	1.10	0.02
1:00	0.82	8.60	0.44	0.18	1.88	0.04
2:00	1.00	8.97	0.49	0.00	-0.01	0.00
3:00	1.21	4.46	0.56	-0.21	-0.78	0.04
4:00	0.90	6.44	0.29	0.10	0.70	0.00
5:00	1.43	3.61	0.61	-0.43	-1.08	0.12
6:00	1.23	6.26	0.59	-0.23	-1.19	0.05
7:00	1.06	29.19	0.46	-0.06	-1.62	0.00
8:00	0.94	8.06	0.42	0.06	0.50	0.00
9:00	0.91	7.60	0.41	0.09	0.79	0.01
10:00	0.79	3.57	0.40	0.21	0.97	0.05
11:00	1.22	10.47	0.49	-0.22	-1.91	0.03
12:00	1.13	52.18	0.50	-0.13	-5.98	0.01
13:00	1.06	30.47	0.53	-0.06	-1.59	0.00
14:00	1.21	11.24	0.49	-0.21	-1.92	0.03
15:00	1.25	20.14	0.51	-0.25	-4.09	0.04
16:00	1.25	11.25	0.49	-0.25	-2.26	0.04
17:00	1.15	43.02	0.51	-0.15	-5.74	0.02
18:00	1.08	40.19	0.50	-0.08	-3.01	0.01
19:00	1.03	56.50	0.50	-0.03	-1.75	0.00
20:00	1.04	137.39	0.50	-0.04	-4.80	0.00
21:00	1.03	568.17	0.50	-0.03	-17.85	0.00
22:00	1.03	575.90	0.50	-0.03	-15.11	0.00
23:00	0.88	7.43	0.48	0.12	1.03	0.02

Equation 3: $S_{t+1} - S_t = \alpha_1 + \beta_1(F_{t,t+1} - S_t) + \varepsilon_{1,t}$

Equation 4: $F_{t,+1} - S_{t+1} = \alpha_2 + \beta_2(F_{t,t+1} - S_t) + \varepsilon_{2,t}$

Each hourly time series regression consists of 1096 observations and is estimated via OLS with HAC (Newey-West)standard errors.

As noted in Fama and French (1987), the relative variances between the basis, risk premium, and spot price changes can play a role in the statistical significance of β_1 and β_2. In situations where basis variation is low compared to the variances of real-time price changes or the realized forward premium, Equations 3 and 4 may lackstatistical power. Following Fama (1984) and Huisman and Kilic (2012), estimates of the difference between β_1 andβ_2 are calculated as follows:

$$\beta_1 - \beta_2 = \frac{var(S_{t+1}-S_t)-var(F_{t,t+1}-S_{t+1})}{var(F_{t,t+1}-S_t)} \tag{5}$$

Since Equations 3 and 4 have the same independent variable, the standard errors for the basis coefficients areidentical. Therefore, t-statistic for the difference between the coefficients can be calculated as[1]:

$$t = \frac{\beta_1 - \beta_2}{2(SE_{\beta_1})}. \tag{6}$$

Table 9 shows the results of Equations 5 and 6. Of the 192 total estimates, 174 (90.63%) are statistically significant. 17 of the 18 insignificant β_1-β_2 estimates occurred on the newer, southern hubs. The difference between β_1 and β_2 is positive for 186 of the 192 total estimates, with the only exceptions being statistically insignificant. In other words, the variances of real-time price movements on the MISO exchange tend to be significantly larger than the variances of the realized forward premiums. This is in contrast with the findings of Huisman and Kilic (2012), who report no significant differences between spot price and forward premium variances on the predominantly fossil-fuel powered Amsterdam Power Exchange.

As noted in Fama (1984), Equation 5 provides a means to compare basis variance to the variances of real- time price changes and the forward premium. The average value of ($\beta_1 - \beta_2$) on the southern hubs is .86 across all hours of the day, while the average difference on the older, northern hubs is .93. This means the difference between the variance of real-time price changes and the variance of the forward premium is, on average, 93% and 86% of the variance in the basis itself for the northern and southern hubs, respectively. The differences in beta coefficients on the MISO exchange are similar in size to the differences that Huisman and Kilic (2012) report on Nord Pool, a market in which the authors find no evidence of forward premiums. In summary, the variance of real- time price movements on the MISO exchange is high relative to both the variances of the forward premium and thebasis, which opposes the perfect indirect storability theory suggested by Huisman and Kilic (2012). This can affect the statistical power of Equations 3 and 4 and may explain the lack of evidence of time-varying forward premiums on the MISO and Nord Pool markets.

Other explanations for the discrepancy in results here as compared to those in Huisman and Kilic (2012) trace back to the differences in methodology. As previously mentioned, Huisman and Kilic (2012) use average day-ahead prices (and average gas spot prices as a robustness check) as a proxy for spot prices when calculating the forward premium and basis. The use of day-ahead prices to proxy spot market prices will lead to unreliable estimates of both the forward premium and basis if the day-ahead price, on average, does not equal the spot priceat expiration. Choosing this approach is somewhat puzzling since significant forward premiums have been found invarious wholesale electricity markets. The time-varying forward premium described in Huisman and Kilic (2012) may also be due to intra-day patterns that have been obscured by averaging the daily forward and spot price proxies.

Table 9: Estimates of $\beta_1 - \beta_2$.

[1] For a complete explanation, see Fama (1984)

Hour	AR	IL	IN	LA	MI	MN	MS	TX
0:00	1.07*	1.01*	0.85*	0.05	0.60	0.78*	0.39	0.71*
1:00	1.14*	0.97*	0.98*	-0.34	1.06*	0.87*	0.30	0.64*
2:00	1.14*	1.04*	0.77*	0.05	1.01*	0.65*	1.12*	1.00*
3:00	1.19*	1.23*	0.50*	0.66*	0.92*	0.71*	2.22*	1.42*
4:00	1.38*	0.96*	0.76*	-0.02	1.06*	0.77*	-0.70	0.80*
5:00	1.31*	0.95*	0.82*	0.57*	0.95*	0.78*	3.48*	1.85*
6:00	1.23*	1.09*	1.06*	0.16	1.03*	1.02*	0.14	1.47*
7:00	1.26*	1.05*	1.12*	0.57	1.18*	0.98*	0.26	1.12*
8:00	1.13*	1.31*	1.38*	-0.15	1.10*	1.32*	0.12	0.88*
9:00	1.04*	1.18*	1.23*	-0.13	0.98*	1.21*	-0.44	0.81*
10:00	0.99*	0.93*	0.92*	1.03*	0.88*	1.18*	1.77*	0.57
11:00	0.94*	0.87*	0.86*	1.03*	1.06*	1.03*	1.31*	1.45*
12:00	0.82*	0.85*	0.92*	0.97*	1.07*	0.83*	0.86*	1.26*
13:00	0.89*	0.82*	0.86*	0.99*	0.88*	0.82*	1.00*	1.11*
14:00	0.80*	0.82*	0.89*	0.90*	0.98*	0.76*	0.90*	1.41*
15:00	0.79*	0.76*	0.84*	0.72*	0.98*	0.73*	0.83*	1.51*
16:00	0.59*	0.71*	0.83*	0.88*	0.99*	0.71*	0.71*	1.50*
17:00	0.66*	0.81*	0.82*	0.56*	1.04*	0.71*	0.43*	1.31*
18:00	0.77*	0.84*	0.79*	0.79*	0.88*	0.80*	0.69*	1.16*
19:00	0.92*	0.86*	0.79*	0.49	0.95*	0.88*	0.76*	1.06*
20:00	0.82*	0.76*	0.69*	0.91*	0.93*	0.71*	0.76*	1.07*
21:00	0.92*	0.88*	0.85*	0.83*	0.97*	0.85*	0.53*	1.06*
22:00	0.96*	0.90*	0.90*	0.70*	0.96*	0.93*	0.91*	1.05*
23:00	0.89*	0.90*	0.91*	0.59*	0.96*	0.96*	0.87*	0.76*

*Significant at the 5% level.

While differences in the statistical power of Equations 3 and 4 may explain the lack of time-varying forward premiums on the MISO and Nord Pool markets, this conclusion is less than satisfying since it's devoid ofeconomic theory. Is there an economic explanation for the similarities between the Nord Pool and MISO markets? One strong possibility is based on the structure of the futures/forward contracts in each market.

Huisman and Kilic (2012) note that forward contracts on Nord Pool are financially settled, whereas futures contracts on the Amsterdam Power Exchange are physically settled. MISO's day-ahead contracts can be settled either physically or financially. The exclusive use of physically settled contracts on the Amsterdam Power Exchange restricts the market to those who can either receive or deliver wholesale electricity. Financially settled forward contracts offered by MISO and Nord Pool provide greater liquidity and efficiency by increasing the numberof possible market participants and opening the door for purely speculative trading, which should minimize persistent violations of the unbiased forward rate hypothesis. In fact, Huisman and Kilic (2012) note Nord Pool is more liquid than the Amsterdam Power Exchange as measured by the average bid-ask spread in both markets.

The existence of forward premiums on the Amsterdam Power Exchange may simply be due to limitations onmarket participation as compared to Nord Pool or MISO.

5. CONCLUSION

This research applies Huisman and Kilic's (2012) indirect storability theory to the Midcontinent Independent System Operator electricity market. While the basis contains information regarding future real-time price movements, it reveals no evidence of consistent time-varying forward premiums as predicted by Huisman and Kilic (2012). Several possible explanations for the difference between the results here and those Huisman andKilic (2012) report for another fossil-fuel power market, the Amsterdam Power Exchange, are explored. An inspection of the differences in the variance of real-time prices, the forward premium, and the basis reveals that low statistical power is a possible cause for the lack of support for time-varying forward premiums on the MISO exchange. However, methodological differences in the approach used here and the one employed by Huisman and Kilic (2012) make it difficult to point toward statistical power as the main factor for the existence of forward premiums on the Amsterdam exchange and the absence of them on MISO. More importantly, focusing on a possible lack of statistical power ignores any economic explanation that could explain the similarities between Nord Pool and MISO. The existence of forward premiums on the Amsterdam market may not be due to perfect indirect storability, but rather a homogeneous, inefficient market brought on by a lack of financially settled forward contracts. Both MISO and Nord Pool offer financially settled forward contracts, which provide an economic rationale for the lack of persistent time varying forward premiums in these markets. In summary, the results here call into question the theory of indirect perfect storability as it pertains to wholesale electricity markets.

REFERENCES

1. Fama, E. (1984) 'Forward and spot exchange rates,' *Journal of Monetary Economics* 14:3:319-38.

2. Fama, E. and K. French (1987) 'Commodity futures prices: some evidence on forecast power, premiums and the theory of storage,' *Journal of Business* 60:1:55-73.

3. Handika, R. & Trück S. (2013) 'Risk premiums in interconnected Australian electricity futures markets,' *Working Paper* 1-33.

4. Huisman, R. & Kilic, M. (2012) 'Electricity futures prices: indirect storability, expectations, andrisk premiums,' *Energy Economics* 34:4: 892-98.

5. Kaldor, N. (1939) 'Speculation and economic stability,' *Review of Economic Studies* 7:1:1-27.

6. Keynes, J., (1930) '*Treatise on Money*,' (London: Macmillan).

7. Longstaff, F. & Wang, A. (2004) 'Electricity forward prices: a high-frequency empirical analysis,' *Journal of Finance* 59:4:1877-1900.

8. Lucia, J. & Torro, H. (2008) 'Short-term electricity futures prices: evidence on the time-varyingrisk premium,' *Working Paper* 1-35.

9. Midcontinent ISO. (2021a) Midcontinent ISO business practice manual 002: energy and operating reserves markets. Retrieved March 2021, from https://www.misoenergy.org/about/

10. Midcontinent ISO. (2021b) Midcontinent ISO fact sheet. Retrieved March 2021, from https://www.misoenergy.org/about/media-center/corporate-fact-sheet/

11. Redl, C. & Bunn, D. (2013) 'Determinants of the premium in forward contracts,' *Journal ofRegulatory Economics* 43:1:90-111.

12. Viehmann, J. (2011) 'Risk premiums in the German day-ahead electricity market,' *EnergyPolicy*, 39:1:386-94.