

## Unbiased Expectations in the MISO Energy Market

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### ABSTRACT

This study examines the relationship between spot and forward prices in the midcontinent independent system operator (MISO) wholesale electricity market. I extend existing literature by employing rolling windows and recursive regressions to test to the risk-adjusted unbiased forward rate hypothesis on the MISO exchange. Although risk premiums and downward biased forward prices do exist, I find overall support for the risk-adjusted unbiased forward rate hypothesis. This result differs from previous research on the MISO exchange and may be explained by several factors, including an increase in the number of market participants and production capacity in recent years.

**Keywords:** Electricity Derivatives, Midcontinent Independent System Operator, Unbiased Expectations Hypothesis, Forward Premiums

**JEL Classifications:** G10, G12, G14

### 1. INTRODUCTION

The deregulation of wholesale electricity markets in the United States was made possible by a series of orders issued by the federal energy regulatory commission (FERC). These orders encouraged the creation of independent system operators (ISOs) and regional transmissions organizations (RTOs), both of which are responsible for ensuring open access to transmission lines and maintaining a market for trading electricity within their geographic footprint. Approximately two-thirds of Americans rely on electricity markets managed by ISOs or RTOs (FERC, 2024).

Midcontinent Independent System Operator<sup>1</sup> (MISO), which became the first FERC-approved RTO in 2001, coordinates the flow of electricity across 15 states and Manitoba. MISO's geographic footprint is comprised of eight regional hubs: Arkansas (AR), Illinois (IL), Indiana (IN), Louisiana (LA), Michigan (MI), Minnesota (MN), Mississippi (MS), and Texas (TX). Over 635 million MWh

of power was generated within the MISO footprint in 2024, which served approximately 45 million people (MISO 2026). In addition to its transmission services, MISO oversees an active market for trading wholesale electricity. The exchange hosts 550 registered market participants who trade over US\$53 billion dollars of spot and forward power annually (MISO 2026).

This study tests the risk-adjusted unbiased forward rate hypothesis and evaluates realized risk premiums on the MISO exchange. While forward rates are often conceptualized within the cost-of-carry framework as described by Kaldor (1939), this model does not apply to wholesale electricity as it assumes the underlying commodity can be efficiently stored<sup>2</sup>. Given these storability concerns, Cootner's (1960) model—which interprets forward prices, along with any resulting premiums or discounts, as compensation for risk transference—is adopted here.

I extend existing research on MISO market prices in three critical areas. This study is the first to apply rolling and recursive

1 MISO was originally known as Midwest Independent System Operator. The not-for-profit organization changed its name to Midcontinent Independent System Operator after expanding operations to the Southern United States in 2013.

2 While progress has been made in recent years for storing electricity, there are significant physical and economic barriers that limit its effectiveness. For a more thorough discussion on the practical issues surrounding electricity storage, see Haas et al. (2022) and Glachant et al. (2023).

regressions to document the dynamic relationship between MISO forward and spot prices. Second, in a break from extant literature, I explicitly test the risk-adjusted unbiased forward rate hypothesis on the MISO exchange. Finally, I utilize a sample period that begins 5 years after the exchange expanded its operations to include portions of the southern United States. This expansion led to a substantial increase in the number of market participants, which should result in a narrowing of MISO risk premiums and increased support for the risk-adjusted unbiased forward rate hypothesis.

The rest of this paper is as follows. Section 2 provides a review of the literature. Section 3 provides an overview of the MISO exchange. Section 4 describes the data and methodology. Section 5 reports the results. Section 6 concludes.

## 2. LITERATURE REVIEW

Under the condition of risk neutrality, the unbiased forward rate hypothesis suggests that the forward rate for a given commodity is a function of the expected future spot rate at expiration. This relationship can be expressed as follows:

$$F_{t,t+1} = E_t[S_{t+1}] \quad (1)$$

Where  $F_{t,t+1}$  is the forward rate established in time  $t$  for delivery in time  $t + 1$ , and  $E_t[S_{t+1}]$  is the time  $t$  expectation of the prevailing spot rate ( $S$ ) in period  $t + 1$ . In this risk-neutral framework, the ex-ante forward premium,  $(F_{t,t+1} - E_t[S_{t+1}])$ , is equal to zero.

The realized (ex-post) forward premium is the sum of the ex-ante forward premium and the forecast error,  $(E_t[S_{t+1}] - S_{t+1})$ :

$$FP_{ex-post} = FP_{ex-ante} + Forecast\ Error \quad (2)$$

If the forecast error is random with a mean of zero, the realized forward premium is equivalent to the ex-ante forward premium. Consistent with prior research, the ex-post forward premium serves as a proxy for the ex-ante forward premium in this study.

The cost-of-carry model as expressed by Kaldor (1939) is a no-arbitrage condition which rests on the assumption that investors can create a synthetic forward contract by purchasing the underlying asset and selling it on the desired forward contract expiration date. The cost-of-carry model can be formally expressed as:

$$F_{t,t+1} = S_t + S I_{t,t+1} + X_{t,t+1} - C_{t,t+1} \quad (3)$$

Where  $S_t$  is the period  $t$  spot price,  $I_{t,t+1}$  represents the prevailing interest rate from period  $t$  to  $t + 1$ ,  $X_{t,t+1}$  is the storage cost of holding the commodity from time  $t$  to  $t + 1$  and  $C_{t,t+1}$  is the convenience yield from period  $t$  to  $t + 1$ . As previously mentioned, the difficulties of storing wholesale electricity necessitate a different approach for examining the relationship between MISO forward and spot prices.

Cootner (1960) popularized the notion that forward prices are a function of expected future spot prices and compensation for risk transference. In this framework, forward premiums and discounts

occur whenever there is an imbalance between the supply and demand for forward contracts amongst hedgers or differences in risk aversion between long and short hedgers. Cootner's (1960) approach suggests that forward discounts occur when market hedgers are net short or if short hedgers are more risk averse than long hedgers. These forward discounts act as an incentive for speculators to buy forward contracts. Similarly, forward premiums exist to entice speculators to sell forward contracts in markets dominated by net long hedgers or markets where long hedgers are more risk averse than short hedgers.

Equation 1 can be modified to account for risk aversion as follows:

$$F_{t,t+1} = E_t[S_{t+1}] + RP \quad (4)$$

$RP$  is the constant risk premium associated with risk transference. The risk-adjusted, ex-post version of the unbiased forward rate hypothesis can be expressed as:

$$F_{t,t+1} = S_{t+1} + RP \quad (5)$$

The risk-adjusted unbiased forward rate hypothesis suggests the ex-post forward premium,  $F_{t,t+1} - S_{t+1}$ , is equivalent to the compensation earned due to risk transference:

$$F_{t,t+1} - S_{t+1} = RP \quad (6)$$

Forward premiums and discounts in deregulated U.S. wholesale electricity markets have been analyzed by several authors, with varying results. Hadsell and Shawky (2007) find significant premiums and discounts in the New York ISO (NYISO) energy market. Longstaff and Wang (2004) find similar results on the Pennsylvania, New Jersey, Maryland (PJM) Interconnection. However, in a later study of the PJM market, Haugom and Ullrich (2012) find significant forward premiums but no evidence of forward discounts.

Several authors have previously examined the relationship between MISO forward and spot prices. Bowden et al. (2009), Birge et al. (2018), and Zarnikau et al. (2020) all report statistically significant forward premiums, but no evidence of forward discounts on the MISO exchange.

However, the results reported in the MISO studies mentioned above may not be indicative of the current forward-spot relationship on the exchange. MISO underwent a major expansion in 2013 to include portions of Arkansas, Louisiana, Mississippi, and Texas. MISO grew from approximately 350 market participants immediately prior to its expansion to 550 today (Midcontinent ISO 2026). Bowden et al. (2009) and Birge et al. (2018) both use samples that predate MISO's 2013 expansion to the Southern United States. The findings reported by Zarnikau et al. (2020) may have been affected by their 2013-2017 sample period. A learning curve in developing load and/or generation schedules within the larger MISO footprint may have led to persistent forward premiums within their sampling period. To account for any potential learning curves in the price discovery process, I utilize a sample that begins in 2018—5 years after the expansion.

It is important to mention the distinction between risk premiums and the risk-adjusted unbiased forward rate hypothesis. Consider the following equation:

$$S_{t+1} = \alpha + \beta F_{t,t+1} + \varepsilon_{t+1} \quad (7)$$

Where  $\alpha$  represents a constant risk premium, while  $S_{t+1}$  and  $F_{t,t+1}$  once again represent the spot price in period  $t + 1$  and the forward price established in period  $t$  for delivery in period  $t + 1$ , respectively. As noted in Barnhart and Szakmary (1991), Equation 7 can be used to test the risk-adjusted unbiased forward rate hypothesis and to assess whether constant risk premiums or discounts exist. The risk-adjusted unbiased forward rate hypothesis holds if the error term ( $\varepsilon_{t+1}$ ) and slope coefficient ( $\beta$ ) in Equation 7 are equal to zero and one, respectively. The risk-adjusted unbiased forward rate hypothesis does not require the risk premium to equal zero. Relatedly, if  $\beta$  is significantly different than one, a forward premium or discount is present which may ( $\alpha \neq 0$ ) or may not ( $\alpha = 0$ ) be explained by a constant risk premium. While Zarnikau et al. (2020) tested the unbiased forward rate hypothesis on the MISO exchange, they performed a much stricter joint hypothesis test that assumed risk neutrality i.e.,  $\alpha = 0$  and  $\beta = 1$ .

### 3. MISO EXCHANGE

Since location plays a crucial role in determining the equilibrium value of electricity, MISO manages a distinct forward and spot market for each of its 8 regional hubs. Consistent with other North American electricity exchanges, forward contracts account for most of the energy traded in the MISO market (Potomac Economics, 2024). The forward market, referred to as the day-ahead (DA) market, allows traders to place demand bids and supply offers for wholesale electricity for a specific hour during the operating (delivery) day. Day-ahead bids and offers may be placed up to 1 week in advance, but they must be submitted by 10:30 Eastern prevailing time (EPT) 1 day prior to the operating day. MISO releases equilibrium day-ahead prices for each hour of the day on all 8 hubs by 13:30 EPT on the day prior to delivery.

MISO's spot market is known as the real-time (RT) market. The real-time market primarily functions as a mechanism to account for imbalances between scheduled DA production and consumption during a specific operating hour and the actual energy supplied and demanded during that hour. For example, a market participant who contracts to sell 500 megawatt hours (MWh) in the day-ahead market for delivery at 16:00 the following day but delivers only 450 MWh due to capacity constraints will be charged the prevailing real-time price at 16:00 on the delivery day for the 50 MWh shortfall. MISO requires that RT bids and offers by submitted by 30 min prior to the operating hour (Midcontinent ISO 2025). Real-time prices for each operating hour are calculated at 5-min intervals, and the aggregated hourly real-time price series for each hub is released 1 day after the operating day (Midcontinent ISO 2025).

Equilibrium day-ahead and real-time prices are referred to as locational marginal prices (LMPs) and are quoted in terms of

dollars per megawatt hour (\$/MWh). LMPs reflect the cost of supplying one megawatt hour of energy within a given node and are a function of generation and congestion costs, as well as transmission losses. As is customary in deregulated electricity markets, MISO relies on Security Constrained Unit Commitment (SCUC) and Security Constrained Economic Dispatch (SCED) algorithms to determine nodal day-ahead and real-time LMPs (Midcontinent ISO 2025). These algorithms are co-optimized and designed to ensure that power is generated at the lowest possible cost, subject to reliability standards and the physical capabilities of the footprint. MISO aggregates nodal LMPs and posts hourly, hub-level day-ahead and real-time LMPs for each hub.

### 4. DATA AND METHODOLOGY

This study utilizes hub level day-ahead and real-time prices from January 01, 2018 until December 31, 2024 obtained from MISO's website (<https://www.misoenergy.org/>). In total, the sample includes 2557 day-ahead prices and 2557 real-time prices for each hour of the day on each of the 8 MISO hubs. This sample begins 5 years after MISO's major expansion to the southern United States and should account changes in the price formation process associated with that event.

The goal of this study is to measure the relationship between spot and forward prices on the MISO exchange. The following equation is used to test the risk-adjusted unbiased forward rate hypothesis for each hub in three distinct subperiods: daily (24 h), peak hours (06:00-22:00), and off-peak hours (00:00-05:59, 22:01-23:59). Time windows for each subperiod are in terms of EPT.

$$RT_{i,j,t+1} = \alpha_{i,j,t+1} + \beta DA_{i,j,t,t+1} + \varepsilon_{i,j,t+1} \quad (8)$$

$RT_{i,j,t+1}$  represents the real-time price in hub during subperiod  $j$  of day  $t + 1$ .  $\alpha_{i,j,t+1}$  is the risk premium on hub in subperiod  $j$  observed on day  $t + 1$ .  $DA_{i,j,t,t+1}$  is the day-ahead price for hub  $i$  during subperiod  $j$  established in period  $t$  for delivery in day  $t + 1$  The risk-adjusted unbiased forward rate hypothesis suggests that  $\beta$  is equal to one and the error term is white noise. Risk premiums exist if  $\alpha$  is significantly different than zero. Equation 8 is estimated via OLS with Newey-West standard errors to obtain static parameter estimates for each hub and subperiod.

Following Haugom and Ulrich (2012), I use both rolling and recursive regressions as robustness checks. Rolling regressions are performed to assess the stability of the  $\alpha$  and  $\beta$  coefficients shown in Equation 8. A 365-day window is utilized to create rolling regression parameter estimates for each subperiod. Recursive regressions are useful to determine whether the  $\alpha$  and  $\beta$  coefficients tend to converge to their hypothesized values of 0 and 1, respectively over time. Recursive regressions are performed by estimating Equation 8 for the first 365 days of the sample and extending the sample period by 1 day for each regression. This process is performed for each hub and subperiod.

## 5. RESULTS

Table 1 shows summary statistics for the day-ahead and real-time prices within the MISO system<sup>3</sup>. Day-ahead prices tend to be higher, less volatile, and contain fewer outliers than their real-time counterparts for the peak hours and daily subperiods. During off-peak hours however, forward prices exhibit more variation and outliers as compared to real-time prices.

Panel C of Table 1 displays forward premiums, defined as  $(DA_{i,j,t,t+1} - RT_{i,j,t,t+1})$ , for each subperiod. Given the non-normality of the day-ahead and real-time price series across all three subperiods, a one-sample sign test was used to assess whether median forward premiums differed from zero. While median forward premiums for all three subperiods are positive and statistically significant, premiums during off-peak hours are substantially smaller than those observed in the peak hours and daily subperiods.

Table 2 shows the risk-adjusted unbiased forward rate hypothesis estimation results for each hub and the overall MISO system. Panel A provides regression results from Equation 8 as applied to system-level day-ahead and real-time prices. As shown in Panel A, risk premiums are mostly insignificant and there is overall support for the risk-adjusted unbiased forward rate hypothesis across the MISO footprint. Panel A also reveals that significant risk premiums and biased forward prices are mostly confined to off-peak hours on aggregate.

Panels B-G expose interesting hub-level differences within the footprint. Surprisingly, significant risk premiums and biased forward prices occur more frequently in the older, northern hubs (IL, IN, MI, MN). 50% of the risk premiums and 67% of the beta coefficients

<sup>3</sup> System-wide summary statistics are provided shown here. Hub-level summary statistics are similar and available upon request.

**Table 1: Summary statistics**

| Panel                    | Daily  | Peak hours | Off-peak hours |
|--------------------------|--------|------------|----------------|
| Panel A: Day-ahead       |        |            |                |
| Mean                     | 33.57  | 37.34      | 26.03          |
| Median                   | 27.94  | 30.98      | 21.73          |
| Standard deviation       | 18.63  | 21.26      | 14.33          |
| Skewness                 | 4.73   | 4.62       | 4.81           |
| Kurtosis                 | 48.95  | 46.74      | 49.96          |
| Panel B: Real-time       |        |            |                |
| Mean                     | 33.03  | 36.85      | 25.40          |
| Median                   | 27.03  | 29.70      | 21.44          |
| Standard deviation       | 22.26  | 28.29      | 13.51          |
| Skewness                 | 10.49  | 13.22      | 3.90           |
| Kurtosis                 | 227.95 | 334.09     | 42.25          |
| Panel C: Forward premium |        |            |                |
| Mean                     | 0.54   | 0.49       | 0.63           |
| Median                   | 1.34*  | 1.77*      | 0.65*          |
| Standard deviation       | 14.30  | 20.06      | 5.95           |
| Skewness                 | -20.05 | -23.39     | 6.44           |
| Kurtosis                 | 759.81 | 879.23     | 139.55         |

This table provides summary statistics DA prices, RT prices, and the realized forward premiums on the MISO footprint from January 01, 2018- December 31, 2024. Peak hours are defined as 06:00-22:00 EST whereas off-peak hours are 00:00-05:59 and 22:01-23:59 EST. The forward premium is defined as  $FP_{i,j,t,t+1} = DA_{i,j,t,t+1} - RT_{i,j,t,t+1}$ .  $DA_{i,j,t,t+1}$  is the day-ahead price for electricity established in day  $t$  to be delivered in period  $i$  in subperiod  $j$  on day  $t + 1$ .  $RT_{i,j,t,t+1}$  is real-time price for electricity in hub during subperiod  $j$  on day  $t + 1$ . Given the non-normality of the data, a one-sample sign test is used to evaluate whether the median forward premiums are significantly different than zero.\*Represents significance at the 5% level.

observed in the northern hubs are significantly different than zero and one, respectively. By comparison, 16% of alpha coefficients and 16% of beta coefficients in the southern hubs are statistically significant. In total, the four northern hubs account for 75% of the significant hub-level risk premiums and 80% of the significant hub-level biased forward prices. Prices in MISO's southern region tend to behave more in line with the risk-adjusted, unbiased forward rate hypothesis and may explain why previous research that included sample years prior to MISO's expansion found more evidence of biased day-ahead prices.

Figures 1 and 2 show system-level<sup>4</sup> rolling windows and recursive regression coefficients for each subperiod, respectively. While rolling windows beta coefficients were generally indistinguishable from unity for each subperiod, significantly biased forward prices occurred more frequently during off-peak hours. Similarly, rolling windows risk premiums are typically near their hypothesized value

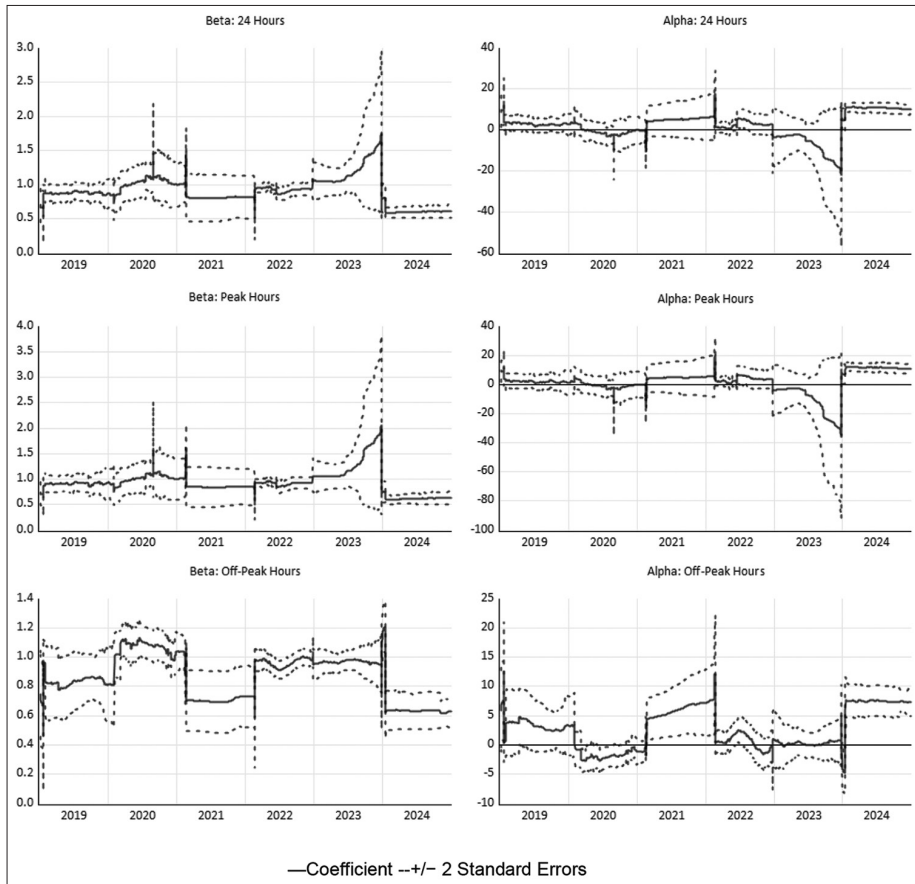
<sup>4</sup> System-level rolling windows and recursive regressions results are shown here to save space. Similar analysis was performed for each hub and is available upon request.

**Table 2: Unbiased expectations hypothesis**

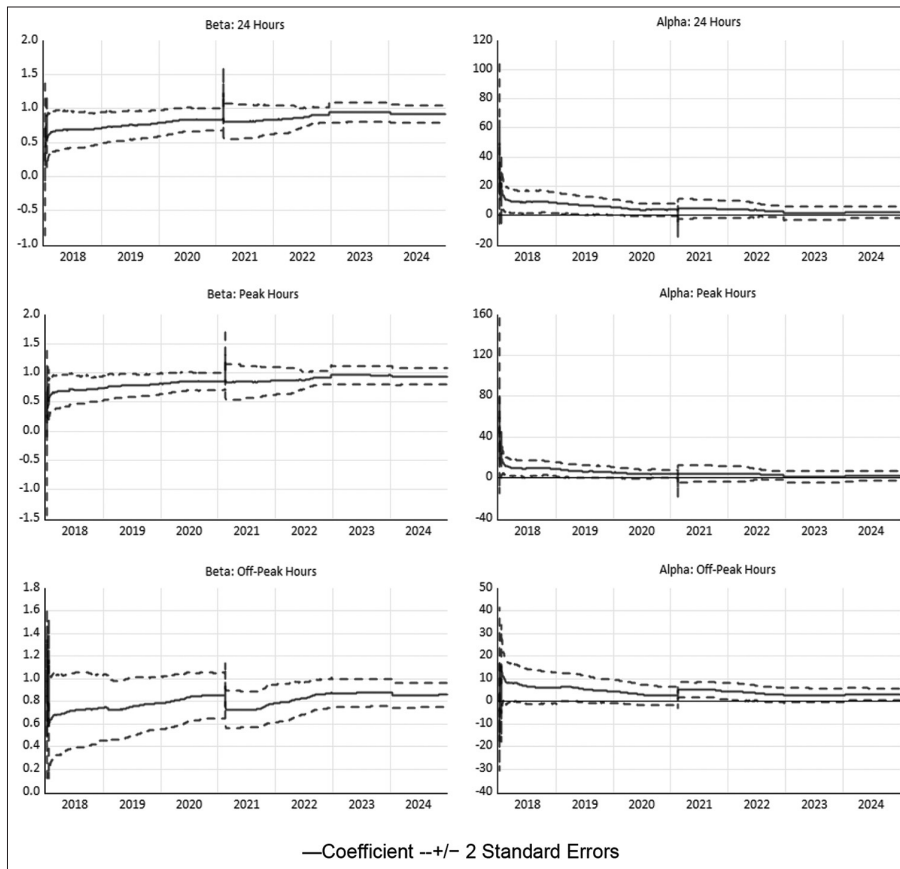
| Panel          | $\alpha$ | $\beta$ | R <sup>2</sup> |
|----------------|----------|---------|----------------|
| Panel A: MISO  |          |         |                |
| Daily          | 2.170    | 0.919   | 0.592          |
| Peak hours     | 1.747    | 0.940   | 0.499          |
| Off-peak hours | 3.055*   | 0.858*  | 0.829          |
| Panel B: AR    |          |         |                |
| Daily          | 1.934    | 0.928   | 0.473          |
| Peak hours     | 1.458    | 0.953   | 0.400          |
| Off-peak hours | 3.347    | 0.840   | 0.713          |
| Panel C: IL    |          |         |                |
| Daily          | 3.619    | 0.864*  | 0.623          |
| Peak hours     | 3.560    | 0.879   | 0.543          |
| Off-peak hours | 3.605*   | 0.825*  | 0.697          |
| Panel D: IN    |          |         |                |
| Daily          | 3.490    | 0.892   | 0.553          |
| Peak hours     | 4.571    | 0.871   | 0.481          |
| Off-peak hours | 0.655    | 0.973   | 0.657          |
| Panel E: LA    |          |         |                |
| Daily          | 2.838    | 0.893   | 0.501          |
| Peak hours     | 1.508    | 0.941   | 0.409          |
| Off-peak hours | 5.850*   | 0.740*  | 0.756          |
| Panel F: MI    |          |         |                |
| Daily          | 3.562*   | 0.884*  | 0.621          |
| Peak hours     | 3.922*   | 0.884*  | 0.525          |
| Off-peak hours | 2.695    | 0.890*  | 0.716          |
| Panel G: MN    |          |         |                |
| Daily          | 5.601*   | 0.797*  | 0.559          |
| Peak hours     | 6.414*   | 0.797*  | 0.492          |
| Off-peak hours | 3.354*   | 0.826*  | 0.634          |
| Panel H: MS    |          |         |                |
| Daily          | 2.094    | 0.913   | 0.530          |
| Peak hours     | 0.489    | 0.967   | 0.450          |
| Off-peak hours | 6.295*   | 0.721*  | 0.655          |
| Panel G: TX    |          |         |                |
| Daily          | 2.461    | 0.928   | 0.294          |
| Peak hours     | 3.942    | 0.906   | 0.194          |
| Off-peak hours | 0.477    | 0.953   | 0.757          |

This table presents OLS regression results for the following equation applied to 3 periods (daily, peak hours, and off-peak hours):  $RT_{i,j,t+1} = \alpha_{i,j,t+1} + \beta DA_{i,j,t,t+1} + \epsilon_{i,j,t+1}$ .  $RT_{i,j,t+1}$  is hub  $i$  real-time price for electricity observed in subperiod  $j$  of day  $t + 1$ .  $DA_{i,j,t,t+1}$  represents the hub  $i$  day-ahead price for subperiod  $j$ , established on day  $t$  for delivery on day  $t + 1$ . Regressions were performed with HAC (Newey-West) standard errors. Null hypothesis:  $\alpha = 0, \beta = 1$ . \*Indicates significance at the 5% level

**Figure 1:** Unbiased expectations rolling regression coefficients



**Figure 2:** Unbiased expectations recursive regression coefficients



of zero for all three subperiods, with off-peak hours exhibiting more instances of significant risk premiums as compared to the other subperiods.

The recursive regressions displayed in Figure 2 reveal that beta coefficients for all three subperiods begin well below the hypothesized value of one. However, as more observations are added with each recursive iteration, the confidence bands tighten and beta coefficients gradually increase. By the end of the sample, beta coefficients for the daily and peak-hours subperiods are indistinguishable from 1, while forward prices during off-peak hours are biased downward. A very similar story can be seen with the risk premiums observed in each subperiod. Initially, risk premiums are much higher than zero for each subperiod but fall rapidly after the first several recursive regressions. Significant risk premiums are isolated to off-peak hours by the end of the sample period.

This figure shows the coefficients and confidence intervals from the following rolling regression applied to three periods (24 h, peak hours, off-peak hours):

$RT_{i,t+1} = \alpha_{i,t} + \beta DA_{i,t,t+1} + \varepsilon_{i,t+1}$ .  $RT_{i,t+1}$  is period  $i$  system-level real-time price for electricity observed on day  $t + 1$ .  $DA_{i,t,t+1}$  represents the period system-level day-ahead price established in on day  $t$  for delivery on day  $t + 1$ . Rolling regressions were performed with a 365-day window which moved forward by 1 day throughout the sample. All regressions utilize HAC (Newey-West) standard errors. This figure shows the coefficients and confidence intervals from the following recursive regression applied to three periods (24 h, peak hours, off-peak hours):  $RT_{i,t+1} = \alpha + \beta DA_{i,t,t+1} + \varepsilon_{i,t+1}$ .  $RT_{i,t+1}$  is system-level subperiod real-time price for electricity observed on day  $t + 1$ .  $DA_{i,t,t+1}$  represents the system-level subperiod  $i$  day-ahead price established in on day  $t$  for delivery on day  $t + 1$ . Recursive regressions were performed by estimating the above equation for the first 365 days of the sample and extending the sample period by 1 day for each regression. All regressions utilize HAC (Newey-West) standard errors.

## 6. CONCLUSION

This study applies the risk-adjusted unbiased expectations hypothesis to the MISO wholesale electricity exchange. Contrary to prior research on the MISO exchange, we find support for the risk-adjusted unbiased expectations hypothesis on the MISO market. While risk premiums and downward biased forward prices do exist, I find they are primarily confined to off-peak hours and somewhat surprisingly, the older, northern portion of the footprint. Collectively, these results suggest that MISO is a maturing market. The number of market participants has grown substantially, and

risk premiums have narrowed in the years since the Zarnikau et al. (2020) study. Although the unbiased expectations hypothesis is supported on the MISO exchange, concerns remain regarding overall market efficiency, particularly as it relates to the ability for participants to exert market power. Future research on the prevalence of market power exertion on the MISO exchange should be explored.

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