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RESEARCH ARTICLE

Convergence Bias in Lean Hog Futures

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Abstract
We examine the convergence of lean hog futures and cash prices, focusing on the thinning of negotiated cash markets. Using daily Livestock Mandatory Reporting data from 2001 to 2024, we confirm significant non-convergence between negotiated and futures prices over the past two decades. Regression results show that as the share of negotiated transactions declines, the absolute basis increases, emphasizing the critical role of negotiated markets in ensuring convergence. These findings highlight concerns about the reliability of negotiated prices as a benchmark for contracts and offer valuable insights for price risk management in the hog industry.

Keywords: convergence bias; cash hog markets; futures price; thin markets

AMS Subject Classifications: G13; Q13

Introduction

In recent decades, the US pork industry has undergone significant structural changes, including consolidation, vertical integration, and an increased use of contracts and market agreements (Maples, Lusk, and Peel, 2019). According to the USDA Economic Research Service, only 5% of hogs were produced under a contractual arrangement in the early 1990s. However, the share has increased to over 70% in recent years, with production contracts accounting for the majority.[1] Under production contracts, vertically integrated processors typically retain ownership of the hogs and supply most variable inputs of production. Once hogs are finished, they take delivery, slaughter, process, and market the resulting pork products. As producers increasingly rely on contracts, the share of hogs sold in negotiated cash markets has significantly decreased (Crespi and MacDonald, 2022). Negotiated sales accounted for around 60% of total sales in the early 1990s. As illustrated in Figure 1, the share fell below 20% by the early 2000s and further to 1.5% in recent years. Over the same periods, packer-owned purchases gradually increased from below 20% in the early 2000s to nearly 40% in recent years. Packer-owned prices are confidential because hogs are transferred internally from feeding to slaughter and processing operations (Butcher and Schulz, 2021). It is worth noting that the spot price (or cash price) refers to the current market price of a commodity available for immediate purchase or sale. Negotiated prices, a subset of spot prices, specifically refer to prices established through direct negotiation between buyers and sellers.

[1]Figure A1 in the Appendix presents the percentage of production under contract for major agricultural commodities in 2020. Notably, crops and dairy primarily rely on marketing contracts, where farmers retain ownership of the commodity during production. Hog producers, on the other hand, primarily rely on production contracts.

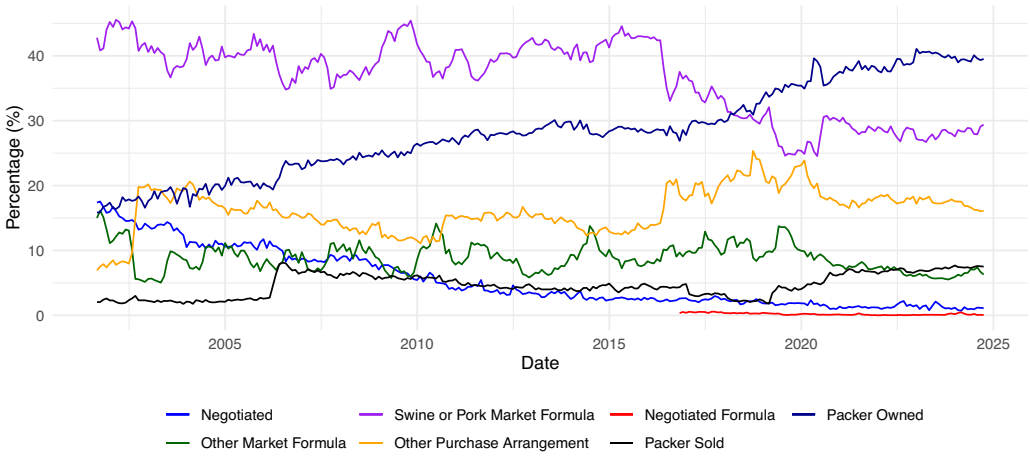

Figure 1. Percentage of volume by purchase type (*Source*: USDA AMS).

The structural changes in the industry have also affected price discovery in futures markets. In 1997, the Chicago Mercantile Exchange (CME) replaced physical delivery with cash settlement for lean hog futures, as the industry increasingly shifted from terminal and auction markets to packing plants (Frank et al., 2008). With cash settlement, the CME determines final settlement prices based on the Lean Hog Index, a two-day weighted average of hogs purchased through Negotiated, Negotiated Formula, and Swine/Pork Market Formula (SPMF) transactions. SPMF refers to the purchase of swine by a packer where the pricing mechanism is a formula price based on a market for swine, the CME Lean Hog Index, the Pork Cutout Index, or pork products. Although negotiated sales have greatly declined over the past decades, they continue to play a crucial role in price discovery since they serve as a reference point for many formula contracts. Parcell and Schulz (2024) noted that in 2022, 51.91% of producer-sold hogs (28.25% of all hogs) were priced based on an SPMF, with anecdotal evidence suggesting that half of all SPMF-priced hogs use a negotiated price as the base price mechanism. This makes the accuracy of negotiated prices crucial, as any distortion could impact a significant portion of the market.

The shift toward contracts, internal transfers, and the resulting thinness of negotiated cash markets raises concerns about price discovery in the futures market. The futures price is the expected value of the maturity price, conditional on the information available (Carter, 1999; Tomek and Peterson, 2001). In a well-functioning market, the futures price should converge predictably with the cash price near expiration, providing an unbiased forecast of market conditions. Convergence is essential to ensure futures prices reflect prevailing supply and demand. However, as more transactions occur under contracts or internal transfers, the volume of hogs sold through negotiated sales has diminished, reducing the number of participants setting negotiated prices. This raises questions about their effectiveness as a benchmark. If the cash prices used for futures settlement do not accurately reflect those received by hog farmers, inefficiencies may arise, resulting in non-convergence and weakening the futures market's role in price discovery and risk management (Adjemian et al., 2013).

With this in mind, our research question is whether futures and cash prices converge predictably near expiration and, if so, whether this convergence is related to the thinning of negotiated cash markets. We posit that a declining share of negotiated transactions may result in greater non-convergence, as cash prices derived from limited transactions may not reliably reflect market conditions. Thinness of the negotiated market refers to the reduced number of transactions conducted through direct agreements between buyers and sellers. These prices play a critical role in price discovery because they reflect actual market sentiment and trading conditions. However, with negotiated transactions now accounting for just 1.5% of total hog sales, fewer

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trades are available to establish a representative market price. This decline in trading volume reduces the reliability of negotiated prices as a benchmark. Accordingly, the share of negotiated transactions serves as a measure of cash market thinness, directly reflecting the level of market participation and the number of direct transactions. A lower share indicates reduced trading activity, making it harder for prices to accurately reflect supply and demand.

To this end, we examine the convergence of lean hog futures and cash prices over the past two decades. For our main analysis, we use the nearest expiring futures contracts, rolled to the next active contract at expiration, and cash prices from negotiated and SPMF transactions, which are used to calculate the Lean Hog Index. We apply a regression model with the absolute basis as the dependent variable and the share of negotiated volume as a key explanatory variable. The analysis focuses on three cash price series: National, Western Cornbelt, and Iowa/Minnesota negotiated prices.

Literature review

An extensive body of literature has examined whether futures prices are unbiased and provide accurate forecasts of cash prices in agricultural markets. However, most studies have primarily focused on the lack of convergence between futures and cash prices in grain markets (e.g., Aulerich, Fishe, and Harris, 2011; Garcia, Irwin, and Smith 2015; Goswami, Adjemian, and Karali, 2022; Irwin et al., 2008; Li and Chavas, 2023). Specifically, previous research has analyzed corn, soybean, and wheat markets, attempting to explain the lack of convergence through delivery instruments and storage rates. Garcia, Irwin, and Smith (2015) found that grain futures expired up to 35% above cash prices in most periods between 2005 and 2010. They attributed this non-convergence to instances in which the market price of physical grain storage exceeded the maximum storage rate allowed on delivery instruments. Li and Chavas (2023) examined the co-dependence between futures and spot prices in corn and soybean markets using a quantile vector autoregression-copula approach, noting that futures prices tend to stabilize as nearby contracts approach maturity.

Relatively few studies have examined convergence in livestock futures markets, particularly lean hog futures. Some related work has instead focused more broadly on basis behavior in these markets. Liu et al. (1994) analyzed the forecastability of the live cattle basis during the month preceding contract delivery, noting that pricing noise during the delivery period complicates accurate basis forecasting. Frank et al. (2008) examined basis behavior in lean hog futures following the transition to cash settlement in 1997, observing a wider and more volatile basis. However, they found no significant increase in *ex-ante* basis risk. Trujillo-Barrera, Garcia, and Mallory (2018) assessed *ex-ante* density forecasts for lean hog futures and identified short-term deviations from convergence during periods of market volatility. More recently, He, Serra, and Garcia (2021) investigated liquidity resilience in lean hog futures during price shocks, noting that although liquidity replenished after shocks, deviations from convergence became more pronounced during volatile periods. In a related study, Bina, Schroeder, and Tonsor (2022) examined how feeder cattle basis risk has changed over time, highlighting significant variation across regions and marketing periods, and identifying key factors contributing to this variability. They found that basis risk increased notably during the 2014–2015 cattle market volatility but has since returned to earlier levels.

Another branch of literature has examined the impact of Livestock Mandatory Price Reporting (LMR), which was implemented in 2001, on US hog markets.[2] Franken, Parcell, and Tonsor (2011) found that the Iowa-Southern Minnesota hog market leads terminal markets, attributing this to the thinning of hog cash markets. Mathews et al. (2015) observed that while futures markets played a key role during the LMR period, cash markets held a small yet significant role in

[2]LMR requires meat packers to report the prices they pay for livestock and the quantity of livestock purchased. This information is compiled and made publicly available by the USDA AMS.

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convergence dynamics. However, their diminished share in overall transactions raised concerns about the reliability of cash prices. Bekkerman and Tejeda (2017) noted that only few studies have examined how thinning cash markets impact futures price convergence, despite the recognition that active cash markets are essential for the effectiveness of futures markets.

Overall, previous studies provide valuable insights into the dynamics of hog markets and the role of futures markets in relation to cash prices. Some studies have examined livestock futures and LMR; however, only a few have investigated convergence bias in hog markets or empirically demonstrated its link to thinning cash markets. While market structures continue to evolve with the rise of contracts and internal transfers, negotiated cash markets remain a crucial reference for futures settlement. This highlights the need for further investigation into convergence dynamics in lean hog markets, particularly to understand the implications of reduced negotiated cash market activity.

Empirical approach

Given the assumptions of rational expectations and risk-neutral market participants, futures prices should equal expected future spot prices, with deviations arising only from unforeseen shocks. Under these conditions, the spot price at delivery should equal the futures price plus a zero-mean error term (Working, 1949). Although Working's model was developed for storable commodities, its insight – that futures prices reflect market expectations – remains broadly relevant. Futures markets for non-storable commodities such as livestock can also reflect expectations about supply and demand conditions (Leuthold, 1979; Naik and Leuthold, 1988). Given that, we estimate the following regression to test the unbiasedness hypothesis:

$$C_t = \alpha + \beta F_t + \epsilon_t, \tag{1}$$

where C_t represents the cash price at time t, F_t is the nearby futures price, and ε_t denotes the error term. If the futures price serves as an unbiased predictor of the future spot price, the regression coefficients for the intercept and the futures price should not be statistically different from zero and one, respectively (Chevallier, 2010).

We use the nearest expiring futures contract in a daily continuous time series, rolling over to the next active contract upon expiration.[3] For cash prices, we consider negotiated and SPMF prices, which are used to calculate the CME Lean Hog Index. Following common practice in the futures market literature, we apply a logarithmic transformation to the prices to stabilize variance and allow for a proportional interpretation of price changes.

To gain further insights into the bias and predictability of futures prices near expiration, we examine the alignment of futures prices with spot prices at expiration (see Figure 3). Specifically, we define the absolute difference between daily futures prices near expiration and spot prices at expiration ($|F_{t-i} - C_t|$), where F_{t-i} represents futures prices i day(s) prior to expiration for each contract month, and C_t represents cash prices at expiration.[4] In other words, we use the same cash price at expiration (C_t) and vary the futures price (F_{t-i}) for each day leading up to expiration (i days prior). This approach allows us to examine convergence dynamics by plotting the absolute difference between futures prices and cash prices against the number of days to expiration. The magnitude of this difference reflects the deviation between futures and cash prices, helping us visually assess whether futures prices converge predictably as a futures contract nears expiration. It is worth noting that predictability of the basis is critical in evaluating the effectiveness of the futures as a risk management tool. For this measure, we collected futures prices near expiration

[3]We acknowledge that rolling over to the next nearby futures contract at expiration may introduce abrupt price changes unrelated to market fundamentals, particularly on rollover days. However, we retain this rollover method, as we believe it does not materially affect the broader patterns examined in our analysis.

[4]Lean hog futures have eight contract months: February (G), April (J), May (K), June (M), July (N), August (Q), October (V), and December (Z).

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(0 to 50 days before expiration) for all contract months from February 2002 to April 2022.[5] The data were sourced from the Commodity Research Bureau (CRB Infotech CD). If futures prices do not closely align with spot prices at expiration, this may indicate potential bias or weaker predictability in the basis.

We then examine whether the thinness of cash markets has contributed to the convergence of lean hog futures and cash prices. To address this, we consider the share of negotiated volume purchased through the cash or spot market by a packer from a producer. USDA's LMR provides daily volume by purchase types: 1) Negotiated; 2) Swine/Pork Market Formula; 3) Other Market Formula; 4) Other Purchase Agreement; 5) Negotiated Formula; 6) Packer Sold; and 7) Packer Owned. We define the share of negotiated volume from the seven aforementioned purchase types. The equation is given as follows:

$$|Basis_t| = \beta_0 + \beta_1 NegShare_t + \beta_2 Volume_t + \beta_3 Corn_t + \beta_4 Volatility_t + \beta_5 VIX_t + \beta_6 Month_{i,t} + \beta_7 Year_{j,t} + \beta_8 NegShare_t \times Year_{j,t} + \epsilon_t \quad (2)$$

where $|Basis|$ is the absolute value of the basis, defined as negotiated prices minus nearby futures prices in logarithms. In this regression, we consider three negotiated prices: National, Western Cornbelt, and Iowa/Southern Minnesota. *NegShare* is the share of volume purchased via the negotiated cash market out of seven purchase types discussed above. *Volume* represents the daily trading volume for lean hog futures contracts in thousands of units. *Corn* represents futures prices (in logarithms) for corn, a primary feed for hog production. For corn futures, we use data provided by Bloomberg, referencing the same time points as those used for Lean Hog Futures in our analysis. *Volatility* measures the risk associated with lean hog futures price moves, calculated from the standard deviation of day-to-day logarithmic historical price changes over the 60 most recent trading days. *VIX* represents the CBOE Volatility Index (VIX), which measures market expectations of future volatility based on options prices of the S&P 500 index. This variable captures overall market volatility and investor sentiment. $Month_i$ and $Year_j$ are included as monthly and yearly fixed effects. Eleven binary variables for months are included from January to November to capture any potential seasonality. Likewise, twenty-three binary variables are included for quoted years, each representing a year from 2001 to 2023. December and 2024 serve as the reference points (omitted indicators) for the monthly and yearly fixed effects, respectively. Lastly, $NegShare \times Year_j$ represents the interaction term between the negotiated share and yearly fixed effects. The coefficient β_1 is of particular interest to evaluate the impact of the thinning of cash markets on the convergence.

Empirical results

Our analysis focuses on daily lean hog futures and cash prices from August 1, 2001, to September 6, 2024. As noted, final futures prices are cash-settled based on the CME Lean Hog Index, which is a two-day weighted average of prices and volumes from Negotiated, Negotiated Formula, and Swine/Pork Market Formula (SPMF) transactions. We collected Negotiated and SPMF prices from the USDA Agricultural Marketing Service (AMS) Datamart, which provides historical mandatory reporting data since 2001. We also collected CME Lean Hog futures, their trading volume, corn futures, the Lean Hog Index, the volatility measure of lean hog futures, and the VIX from the Bloomberg Terminal.[6] The CME hog futures contracts began in 1966, listed as live contracts, with a 30,000-pound unit and

[5]As CRB discontinued providing data, we only have data up to April 2022. Throughout this paper, aside from this measure, we use daily nearby futures data collected from the Bloomberg Terminal for the period from 2001 to 2024.

[6]Summary statistics of the variables of interest used for analysis can be found in the Appendix of Table A1.

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Figure 2. Futures, negotiated, and basis (Aug. 1, 2001–Sep. 6, 2024).

deliverable grade of USDA No.1, 2, and 3 barrows and gilts. In 1997, the contract was updated to a lean basis, with a 40,000-pound unit, which corresponds to the quantity of meat produced from around 200 hogs.

Figure 2 presents the time series plot for nearby futures, negotiated prices, and their basis. In the early periods, the basis fluctuated relatively close to zero. However, it has experienced substantial variation over the past decade, with nearby futures often greatly exceeding negotiated prices. It is worth noting that the implementation of Livestock Mandatory Reporting (LMR) for wholesale pork in 2013 may have contributed to the observed increase in basis variation. This coincided with a growing interest in using the cutout value for pricing, which likely influenced both the negotiated cash market and futures market dynamics. Another notable point is the substantial basis observed in 2020. This may partly result from the impact of COVID-19, which created a substantial price gap between negotiated and other prices. During the pandemic, negotiated prices were the most affected compared to prices derived from the futures market or those determined by formula (Meyer and Goodwin, 2021). Moreover, many pork processing plants temporarily closed or reduced operations, leading to an oversupply of hogs at the farm level and a shortage of pork at the retail level. Interestingly, even after the COVID period, we still observe concerning basis levels, as they exhibit higher fluctuations compared to historical levels.

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Table 1. Convergence of futures and cash prices: $C_t = \alpha + \beta F_t$

	α		β			
	Estimate	Std. Err.	Estimate	Std. Err.	*R*2	*F*-stat.
Negotiated	−0.3822**	0.1854	1.0803***	0.0422	0.8492	504.00***
SPMF	0.1228	0.0887	0.9715***	0.0205	0.9206	29.59***
Index	0.0864	0.0885	0.9791***	0.0205	0.8968	15.87***

Notes: *Negotiated* refers to negotiated prices, *SPMF* represents the Swine or Pork Market Formula, and *Index* refers to the CME Lean Hog Index. The F-tests are performed to test the joint hypothesis that $\alpha = 0$ and $\beta = 1$. All standard errors are adjusted using the Newey-West method to account for heteroscedasticity and autocorrelation.
** and *** indicate statistical significance at the 5% and 1% levels, respectively.

Table 1 presents the regression results of Equation (1), which examines the convergence of nearby futures and cash prices.[7] The analysis considers three cash price series: the CME Lean Hog Index, negotiated, and SPMF prices. Prior to the analysis, we conducted the Augmented Dickey-Fuller unit root tests for the price series in Equation (1), confirming that all the logarithmic price series are stationary at levels.[8] To assess whether futures prices serve as unbiased predictors of future spot prices, we test the joint null hypothesis that $\alpha = 0$ and $\beta = 1$. As presented in Table 1, the F-statistics indicate significant deviations from the theoretical values across all series. The most significant bias is observed in negotiated prices, with regression estimates for the intercept and slope of −0.38 and 1.08, respectively.

This bias may reflect the negotiated market functioning as a residual market for lower-quality hogs, potentially contributing to biased estimates. It could also indicate structural issues within the negotiated cash market. Franken and Parcell (2012) observed a decline in hog quality in cash markets as transactional volumes decreased, suggesting that reduced negotiated transactions diminish the representativeness of cash prices. They emphasize the need to maintain sufficient cash market activity for accurate price discovery, as many contracts reference these prices. Butcher and Schulz (2021) found that the declining volume of negotiated trades has increased price variability, reducing their effectiveness for price discovery. Furthermore, SPMF prices have increasingly incorporated pork cutout values – estimated to account for approximately 50% in 2022 (Meyer and Schulz, 2024) – which have shown a weakening correlation with negotiated prices.

It is also worth noting that SPMF and Index prices exhibit smaller bias estimates compared to negotiated cash prices. This is reasonable, given that lean hog futures are cash-settled and designed to converge with the CME Lean Hog Index. As noted, the Index is a weighted average of values transacted through Negotiated, Negotiated Formula, and SPMF prices. With SPMF currently accounting for over 90% of the Index, it closely aligns with SPMF prices, which likely explains their smaller bias estimates.[9]

Figure 3 graphically presents the alignment of expiring futures (up to 50 days prior to expiration) with negotiated and SPMF prices at expiration. As noted above, futures at expiration are expected to serve as unbiased predictors of future spot prices. Therefore, futures and cash prices are not expected to differ significantly as expiration approaches. We confirm results consistent with the regression findings. Specifically, futures prices align closely with SPMF prices across all contract months. Even 40 days before expiration, all contracts exhibit values within a

[7]Residual diagnostics were conducted to assess heteroscedasticity and autocorrelation (see Table A2 in the Appendix). Identified issues were addressed by adjusting the standard errors using the Newey-West method, with the corrected values reported in Table 1.

[8]See Table A3 in the Appendix for unit root tests on futures, negotiated, SPMF, and Index.

[9]See the article, "The Mystery of the CME Lean Hog Index" https://www.nationalhogfarmer.com/farm-policy-news/the-mystery-of-the-cme-lean-hog-index, for a related discussion.

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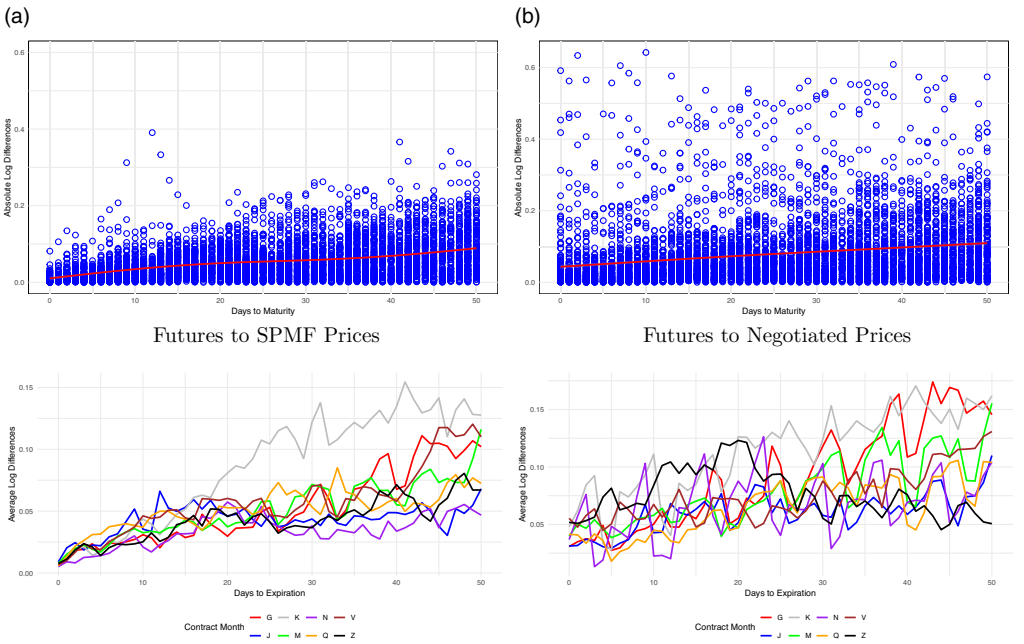

Note: Lean hog futures are traded in the following contract months: February (G), April (J), May (K), June (M), July (N), August (Q), October (V), and December (Z).

Figure 3. Convergence of futures to SPMF and to negotiated prices (Feb. 2002–Apr. 2022).

10% difference, except for the May contract. This deviation is reasonable, given that the May hog futures contract was newly introduced in 2001 and remains thinly traded compared to other contract months (Carter and Mohapatra, 2008). Notably, we observe larger differences with negotiated prices near expiration. Futures prices often expire up to 5% above negotiated prices in many contract months. More interestingly, these differences frequently exceed 10%, even 20 days prior to expiration, raising concerns about bias and weaker predictability in the basis associated with negotiated prices.

Table 2 presents the regression results of Equation (2).[10] Notably, we find a negative and statistically significant coefficient for the negotiated share (*NegShare*) in the regression using national prices, indicating that a higher share of negotiated transactions is associated with a smaller absolute basis.[11] This may indicate that greater negotiated market activity is associated with improved convergence between futures and cash prices. Conversely, a decline in the share of negotiated volume may increase the absolute basis, potentially contributing to non-convergence. While similarly negative estimates are observed for the IA/MN and Western Cornbelt series, these coefficients are not statistically significant. Nonetheless, the consistency in sign across regions is noteworthy and aligns with expectations, given that IA/MN is a subset of the Western Cornbelt, which in turn is a subset of the National market.

The estimates for trading volume are statistically significant and positive yet close to zero, indicating that the influence of trading activity in lean hog futures on convergence is somewhat limited over the periods considered. Corn prices show a negative relationship with the absolute

[10]The estimates for yearly fixed effects and interactions of negotiated share and yearly fixed effects are not presented in Table 2 but can be found in Table A4 of the Appendix.

[11]We consider regressions with interaction terms between negotiated share and monthly fixed effects, models without interaction terms, and models using the basis as a dependent variable, where generally consistent results are confirmed (see Tables A5, A6, and A7 in the Appendix).

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Table 2. Regression results

	National		IA/MN		Western	
	Estimate	Std. Err.	Estimate	Std. Err.	Estimate	Std. Err.
Intercept	0.2803*	0.1489	0.4155***	0.1513	0.4099***	0.1529
NegShare	−7.8350**	3.8760	−5.0527	3.1625	−4.6427	3.0933
Volume	0.0012***	0.0004	0.0008**	0.0004	0.0007**	0.0004
Corn	−0.0211	0.0208	−0.0442**	0.0219	−0.0433*	0.0222
Volatility	0.0028***	0.0005	0.0024***	0.0006	0.0024***	0.0006
VIX	−0.0008	0.0005	−0.0012**	0.0006	−0.0013**	0.0006
Jan	0.0022	0.0132	−0.0162	0.0129	−0.0166	0.0127
Feb	−0.0332**	0.0151	−0.0442***	0.0136	−0.0454***	0.0138
Mar	−0.0436***	0.0150	−0.0490***	0.0151	−0.0497***	0.0151
Apr	−0.0338**	0.0155	−0.0453***	0.0157	−0.0455***	0.0158
May	−0.0552***	0.0158	−0.0646***	0.0156	−0.0660***	0.0156
Jun	−0.0615***	0.0155	−0.0743***	0.0157	−0.0761***	0.0158
Jul	−0.0520***	0.0150	−0.0717***	0.0145	−0.0726***	0.0145
Aug	−0.0318**	0.0148	−0.0555***	0.0155	−0.0572***	0.0156
Sep	−0.0788***	0.0151	−0.0938***	0.0148	−0.0956***	0.0148
Oct	−0.0815***	0.0149	−0.0927***	0.0150	−0.0895***	0.0151
Nov	−0.0462***	0.0134	−0.0393***	0.0136	−0.0401***	0.0134
Adjusted R^2	0.4984		0.4855		0.4859	
N	5,777		5,777		5,777	

Notes: The model includes yearly fixed effects and interaction terms between the negotiated share and yearly fixed effects. These are not presented here but are available in Table A4 of the Appendix. December and 2024 serve as the reference points (omitted indicators) for the monthly and yearly fixed effects. *Corn* represents futures corn prices in logarithmic form. *Volatility* is a measure of the risk associated with price movements of lean hog futures. All standard errors are adjusted using the Newey-West method to account for heteroscedasticity and autocorrelation.

*, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

basis, suggesting that as corn prices rise–a key input in hog production–the gap between futures and cash prices narrows. Conversely, positive and statistically significant estimates for lean hog futures volatility are observed, suggesting that higher hog futures volatility leads to greater divergence between futures and cash prices. This finding aligns with conventional wisdom that, with greater uncertainty in futures prices, a wider basis is expected. On the other hand, the estimates for the VIX are close to zero, suggesting that overall market volatility has a limited impact on price discovery in lean hog markets. This implies that broader market conditions, as measured by the VIX, do not significantly affect the convergence process in the lean hog market. Therefore, hog markets are more influenced by their own dynamics than by broader market fluctuations.

Conclusion

The US pork industry has undergone substantial structural changes over recent decades, with an increasing reliance on contracts or internal transfers over negotiated cash market transactions. This study examines whether these changes, particularly the thinning of cash markets, have

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contributed to a convergence bias in the hog futures market. In other words, we explore whether a reduction in the share of negotiated transactions impacts the effectiveness of the futures market – specifically its role in price discovery and risk management. To answer this question, we first examine the convergence of futures and cash prices over the past two decades. We use negotiated and SPMF prices, which are used to calculate the Lean Hog Index. We then consider regression models with the share of negotiated volume as a key variable.

The results confirm a clear non-convergence between negotiated and futures prices over the past two decades. Interestingly, we find that a declining share of negotiated sales contributes to greater non-convergence. Regression results show that the absolute basis increases as the share of negotiated transactions decreases. This implies that negotiated sales play an important role in the efficiency of futures markets and thus in price discovery and price risk management. We also confirm that market volatility, as measured by lean hog futures volatility, increases non-convergence, while broader market conditions, captured by the VIX, have a limited impact.

Our empirical analyses make several important contributions. Specifically, the findings raise concerns about the use of negotiated prices as a benchmark, given the observed non-convergence between futures and negotiated prices, as well as the impact of thinning cash markets on convergence. Although the Lean Hog Index is primarily based on SPMF prices, many contracts still rely on negotiated prices as a reference. Moreover, SPMF prices are increasingly based on pork values, which have been shown to diverge from negotiated prices. As cash markets continue to diminish – currently representing only 1.5% of total transactions – quoted cash prices may poorly reflect actual prices, contributing to inefficiencies in futures markets. To our knowledge, this is the first study to examine the convergence and thinning of cash hog markets using USDA LMR price and volume data across regions and purchase types. Our findings provide valuable insights for the industry regarding agricultural price risk management.

Moreover, our results have important implications for policy. Policymakers have become increasingly concerned that negotiated prices do not provide a reliable benchmark for assessing value in the lean hog market. Without reliable negotiated hog prices, many market transactions may lack efficiency and may not adequately value the underlying asset. Policy efforts have been made to improve the transparency of transactions in hog markets, including mandatory livestock price reporting and submission of contracts to a USDA contract library. We highlight the importance of negotiated transactions and demonstrate that futures and cash prices are less likely to converge when the share of negotiated transactions is small. This, in turn, may make hedging less effective. Our results may suggest that additional policy actions to improve transparency and the reliability of negotiated prices may be warranted.

This study can be extended in several ways. One potential avenue is to explore convergence bias in other meat markets, such as feeder cattle futures, which are also cash-settled and face thinning negotiated cash markets, albeit to a lesser extent than lean hog markets. Therefore, one may further investigate this through comparative analysis across different meat markets. Additionally, while our analysis relies on basis plotting near contract expiration and regression analyses of cash price series and key variables, adopting alternative methodologies, such as nonlinear modeling approaches, could offer deeper insights into convergence issues and the implications of thinning negotiated markets.

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Appendix

See Appendix Fig. A1 and Tables A1, A2, A3, A4, A5, A6 and A7.

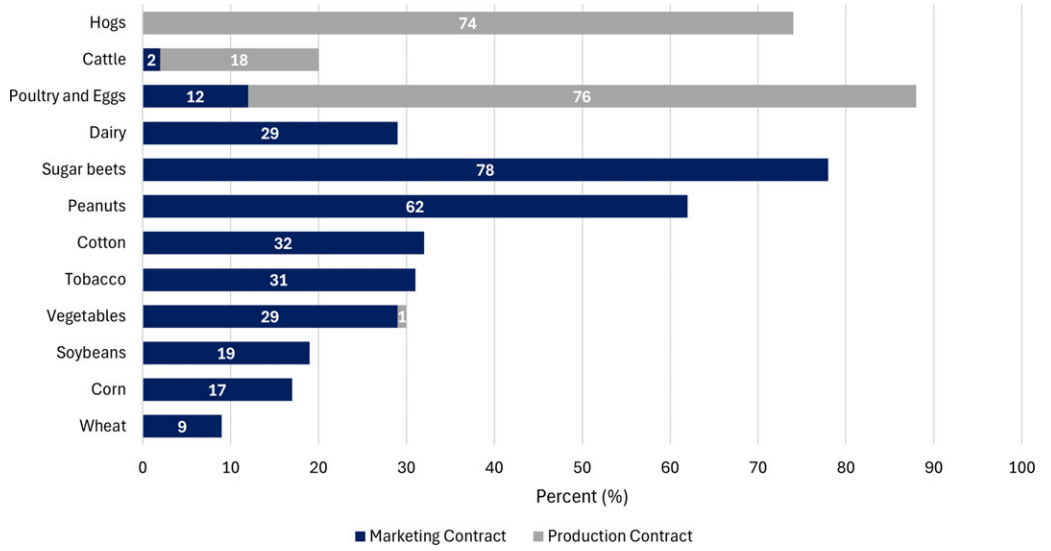

Figure A1. Percentage of production under contract for selected commodities in 2020 (*Source*: USDA ERS and NASS, Agricultural Resource Management Survey).

Table A1. Summary statistics

	Level				Log level			
Variable	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max
National	71.232	19.144	27.330	134.070	4.230	0.268	3.308	4.898
IA/MN	70.114	19.237	25.660	134.870	4.213	0.273	3.245	4.904
Western	69.957	19.169	25.720	135.170	4.211	0.273	3.247	4.907
Futures	73.399	16.974	30.050	133.875	4.270	0.229	3.403	4.897
SPMF	73.540	17.307	32.370	134.200	4.271	0.232	3.477	4.899
Index	73.331	17.522	30.250	134.170	4.267	0.237	3.409	4.899
Corn	419.108	158.677	186.250	831.250	5.967	0.379	5.227	6.723
Volume	9.751	8.141	0.086	50.629				
Volatility	36.519	13.454	13.451	93.898				
VIX	19.650	8.701	9.140	82.690				

Notes: Level prices are in original units. Each series contains 5,777 observations.

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Table A2. Breusch–Pagan and Breusch–Godfrey test results

	Breusch–Pagan test		Breusch–Godfrey test	
	Statistic	*P*-value	Statistic	*P*-value
		Equation (1)		
Negotiated	150.19	1.58E-34	5272.37	0.0000
SPMF	188.48	6.84E-43	5027.59	0.0000
Index	188.41	7.06E-43	5152.04	0.0000
		Equation (2)		
National	1413.07	1.68E-254	4646.84	0.0000
IA/MN	1557.71	1.22E-284	4609.42	0.0000
Western	1451.22	1.94E-262	4579.44	0.0000

Notes: The Breusch–Pagan and Breusch–Godfrey tests assess heteroscedasticity and autocorrelation, respectively.

Table A3. Unit root test results

	ADF test	
Variable	Statistic	*P*-value
Futures	−4.6793	0.01
Negotiated	−5.0011	0.01
SPMF	−5.1121	0.01
Index	−5.1391	0.01

Note: All prices are expressed in logarithmic terms.

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Table A4. Regression with negotiated share × yearly fixed effects

	National		IA/MN		Western	
	Estimate	Std. Err.	Estimate	Std. Err.	Estimate	Std. Err.
Intercept	0.2803*	0.1489	0.4155***	0.1513	0.4099***	0.1529
NegShare	−7.8350**	3.8760	−5.0527	3.1625	−4.6427	3.0933
Volume	0.0012***	0.0004	0.0008**	0.0004	0.0007**	0.0004
Corn	−0.0211	0.0208	−0.0442**	0.0219	−0.0433*	0.0222
Volatility	0.0028***	0.0005	0.0024***	0.0006	0.0024***	0.0006
VIX	−0.0008	0.0005	−0.0012**	0.0006	−0.0013**	0.0006
Jan	0.0022	0.0132	−0.0162	0.0129	−0.0166	0.0127
Feb	−0.0332***	0.0151	−0.0442**	0.0136	−0.0454***	0.0138
Mar	−0.0436***	0.0150	−0.0490***	0.0151	−0.0497***	0.0151
Apr	−0.0338**	0.0155	−0.0453***	0.0157	−0.0455***	0.0158
May	−0.0552***	0.0158	−0.0646***	0.0156	−0.0660***	0.0156
Jun	−0.0615***	0.0155	−0.0743***	0.0157	−0.0761***	0.0158
Jul	−0.0520***	0.0150	−0.0717***	0.0145	−0.0726***	0.0145
Aug	−0.0318**	0.0148	−0.0555***	0.0155	−0.0572***	0.0156
Sep	−0.0788***	0.0151	−0.0938***	0.0148	−0.0956***	0.0148
Oct	−0.0815***	0.0149	−0.0927***	0.0150	−0.0895***	0.0151
Nov	−0.0462***	0.0134	−0.0393***	0.0136	−0.0401***	0.0134
Year 2001	−0.2516***	0.0947	−0.1411*	0.0826	−0.1295	0.0838
Year 2002	−0.1048	0.1031	−0.0406	0.0881	−0.0453	0.0882
Year 2003	−0.1841**	0.0912	−0.1464	0.0936	−0.1441	0.0947
Year 2004	−0.1595**	0.0786	−0.0883	0.0661	−0.0867	0.0659
Year 2005	−0.1484*	0.0784	−0.1317**	0.0653	−0.1295**	0.0642
Year 2006	−0.1333*	0.0801	−0.1021	0.0650	−0.0983	0.0636
Year 2007	−0.1476*	0.0862	−0.1011	0.0681	−0.0902	0.0664
Year 2008	−0.0921	0.0836	−0.0192	0.0753	−0.0192	0.0735
Year 2009	−0.1727**	0.0806	−0.1304*	0.0670	−0.1362**	0.0657
Year 2010	−0.0875	0.0820	−0.0321	0.0656	−0.0288	0.0639
Year 2011	−0.1573**	0.0781	−0.0753	0.0630	−0.0714	0.0615
Year 2012	−0.1409*	0.0783	−0.0708	0.0630	−0.0673	0.0615
Year 2013	−0.1295	0.0842	−0.0556	0.0697	−0.0453	0.0682
Year 2014	−0.1820**	0.0843	−0.1315*	0.0705	−0.1292*	0.0694
Year 2015	−0.1611**	0.0800	−0.0965	0.0639	−0.0955	0.0625
Year 2016	−0.0783	0.0818	−0.0398	0.0640	−0.0365	0.0627
Year 2017	−0.1243	0.0814	−0.1184	0.0756	−0.1159	0.0743
Year 2018	−0.1779*	0.0912	−0.0900	0.0949	−0.0857	0.0939
Year 2019	−0.1800**	0.0893	−0.1165	0.0828	−0.1085	0.0831

(*Continued*)

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Table A4. (*Continued*)

	National		IA/MN		Western	
	Estimate	Std. Err.	Estimate	Std. Err.	Estimate	Std. Err.
Year 2020	−0.0587	0.0922	0.0049	0.0884	0.0071	0.0868
Year 2021	−0.0599	0.0928	0.0005	0.0732	0.0021	0.0715
Year 2022	−0.1613*	0.0874	−0.1204*	0.0643	−0.1198*	0.0628
Year 2023	−0.1428**	0.0707	−0.0884*	0.0519	−0.0830*	0.0496
NegShare x Year 2001	8.4638**	3.9155	5.1670	3.2076	4.7104	3.1431
NegShare x Year 2002	7.4107*	3.8861	4.5252	3.1649	4.1553	3.0970
NegShare x Year 2003	8.0309**	3.9288	5.3394*	3.2387	4.9350	3.1740
NegShare x Year 2004	7.7541**	3.8785	4.5736	3.1672	4.1684	3.1000
NegShare x Year 2005	7.7355**	3.8719	4.9996	3.1567	4.5943	3.0862
NegShare x Year 2006	7.5190*	3.8845	4.7119	3.1628	4.2942	3.0928
NegShare x Year 2007	7.9237**	3.8983	5.0830	3.1732	4.5984	3.1045
NegShare x Year 2008	7.3108*	3.8926	4.2860	3.2020	3.8936	3.1338
NegShare x Year 2009	7.9292**	3.9264	5.3336*	3.2264	5.0034	3.1598
NegShare x Year 2010	6.8586*	3.9172	3.9967	3.1869	3.5645	3.1167
NegShare x Year 2011	8.4765**	3.9055	5.0852	3.1874	4.6585	3.1194
NegShare x Year 2012	7.8763**	3.8928	4.6376	3.1791	4.1954	3.1092
NegShare x Year 2013	7.7536*	3.9869	4.2208	3.2852	3.6116	3.2187
NegShare x Year 2014	8.6587**	3.9833	5.2296	3.2792	4.8375	3.2165
NegShare x Year 2015	8.0502**	3.9722	4.1280	3.2302	3.7782	3.1626
NegShare x Year 2016	5.3815	3.9954	2.7441	3.2225	2.4024	3.1650
NegShare x Year 2017	6.7913*	3.9227	5.2003	3.4289	4.7762	3.3630
NegShare x Year 2018	9.1786**	4.3670	5.0130	4.4229	4.5346	4.3738
NegShare x Year 2019	12.4954***	4.1555	9.0292**	3.5276	8.8865**	3.4550
NegShare x Year 2020	11.0022**	5.0439	7.2508	4.8297	6.8681	4.7371
NegShare x Year 2021	6.2588	4.9438	2.4954	3.8464	2.0451	3.7431
NegShare x Year 2022	11.2606**	4.8175	8.9484**	3.8615	8.5071**	3.8197
NegShare x Year 2023	6.9557*	3.8413	4.1760	3.0283	3.6123	2.9288
Adjusted R^2	0.4984		0.4855		0.4859	
N	5,777		5,777		5,777	

Notes: December and 2024 serve as the reference points. All standard errors are adjusted using the Newey-West method to account for heteroscedasticity and autocorrelation.

*, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

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Table A5. Regression with negotiated share × monthly fixed effects

	National		IA/MN		Western	
	Estimate	Std. Err.	Estimate	Std. Err.	Estimate	Std. Err.
Intercept	0.2187*	0.1303	0.3612***	0.1383	0.3590**	0.1394
NegShare	−0.3579	0.2317	−0.4834**	0.2334	−0.5067**	0.2336
Volume	0.0013***	0.0003	0.0008**	0.0003	0.0008**	0.0003
Corn	−0.0220	0.0210	−0.0418*	0.0223	−0.0405*	0.0225
Volatility	0.0029***	0.0006	0.0025***	0.0006	0.0025***	0.0006
VIX	−0.0007	0.0004	−0.0010*	0.0005	−0.0011**	0.0005
Jan	0.0154	0.0249	−0.0100	0.0241	−0.0113	0.0236
Feb	−0.0400	0.0287	−0.0588**	0.0255	−0.0616**	0.0259
Mar	−0.0798***	0.0288	−0.0873***	0.0281	−0.0889***	0.0280
Apr	−0.0639**	0.0297	−0.0797***	0.0293	−0.0820***	0.0294
May	−0.0656**	0.0303	−0.0673**	0.0299	−0.0710**	0.0299
Jun	−0.0724**	0.0294	−0.0770**	0.0301	−0.0803***	0.0306
Jul	−0.0734**	0.0293	−0.0867***	0.0284	−0.0889***	0.0286
Aug	−0.0664**	0.0284	−0.0751**	0.0299	−0.0785***	0.0303
Sep	−0.1143***	0.0263	−0.1182***	0.0264	−0.1203***	0.0264
Oct	−0.1082***	0.0256	−0.1125***	0.0260	−0.1058***	0.0267
Nov	−0.0776***	0.0234	−0.0600**	0.0255	−0.0618**	0.0249
Year 2001	−0.0805*	0.0453	−0.0428	0.0402	−0.0403	0.0396
Year 2002	−0.0886*	0.0465	−0.0409	0.0423	−0.0437	0.0417
Year 2003	−0.0790*	0.0436	−0.0328	0.0392	−0.0337	0.0386
Year 2004	−0.0884**	0.0430	−0.0686*	0.0375	−0.0704*	0.0370
Year 2005	−0.0782*	0.0432	−0.0635*	0.0379	−0.0645*	0.0374
Year 2006	−0.0823*	0.0422	−0.0646*	0.0360	−0.0656*	0.0353
Year 2007	−0.0592	0.0409	−0.0316	0.0338	−0.0312	0.0329
Year 2008	−0.0581	0.0417	−0.0223	0.0345	−0.0254	0.0336
Year 2009	−0.0892**	0.0415	−0.0532	0.0337	−0.0583*	0.0329
Year 2010	−0.0577	0.0414	−0.0284	0.0338	−0.0310	0.0330
Year 2011	−0.0507	0.0415	−0.0191	0.0345	−0.0208	0.0337
Year 2012	−0.0587	0.0417	−0.0307	0.0344	−0.0331	0.0335
Year 2013	−0.0507	0.0422	−0.0267	0.0354	−0.0273	0.0348
Year 2014	−0.0806*	0.0426	−0.0733**	0.0358	−0.0749**	0.0353
Year 2015	−0.0772*	0.0405	−0.0672**	0.0328	−0.0692**	0.0319
Year 2016	−0.0587	0.0427	−0.0422	0.0355	−0.0417	0.0347
Year 2017	−0.0712*	0.0426	−0.0608*	0.0356	−0.0629*	0.0348
Year 2018	−0.0726*	0.0430	−0.0403	0.0361	−0.0420	0.0352

(*Continued*)

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Table A5. (*Continued*)

	National		IA/MN		Western	
	Estimate	Std. Err.	Estimate	Std. Err.	Estimate	Std. Err.
Year 2019	−0.0197	0.0520	0.0052	0.0506	0.0135	0.0524
Year 2020	0.0630	0.0547	0.0843*	0.0486	0.0820*	0.0486
Year 2021	−0.0008	0.0440	0.0178	0.0371	0.0140	0.0361
Year 2022	−0.0332	0.0450	−0.0151	0.0387	−0.0200	0.0377
Year 2023	−0.0773**	0.0359	−0.0515*	0.0263	−0.0528**	0.0253
NegShare x Jan	−0.2563	0.2489	−0.1320	0.2465	−0.1135	0.2429
NegShare x Feb	0.1305	0.2924	0.2648	0.2713	0.2969	0.2734
NegShare x Mar	0.6693**	0.3026	0.7009**	0.3088	0.7217**	0.3077
NegShare x Apr	0.5496*	0.2966	0.6245**	0.3039	0.6628**	0.3033
NegShare x May	0.1518	0.3255	0.0136	0.3316	0.0574	0.3290
NegShare x Jun	0.1790	0.3126	0.0324	0.3325	0.0584	0.3360
NegShare x Jul	0.4058	0.2963	0.2926	0.3028	0.3181	0.3026
NegShare x Aug	0.6355**	0.2810	0.3708	0.3012	0.3995	0.3010
NegShare x Sep	0.6039**	0.2565	0.4148	0.2636	0.4210	0.2615
NegShare x Oct	0.4546*	0.2549	0.3310	0.2735	0.2703	0.2777
NegShare x Nov	0.5443**	0.2315	0.3483	0.2477	0.3693	0.2424
Adjusted R^2	0.5065		0.4919		0.4923	
N	5,777		5,777		5,777	

Notes: December and 2024 serve as the reference points. All standard errors are adjusted using the Newey-West method to account for heteroscedasticity and autocorrelation.

*, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

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Table A6. Regression without interaction term

	National		IA/MN		Western	
	Estimate	Std. Err.	Estimate	Std. Err.	Estimate	Std. Err.
Intercept	0.1699	0.1312	0.3469**	0.1352	0.3453**	0.1368
NegShare	−0.0428	0.1279	−0.1952	0.1311	−0.1932	0.1345
Volume	0.0013***	0.0004	0.0008**	0.0004	0.0008**	0.0004
Corn	−0.0163	0.0210	−0.0414*	0.0217	−0.0404*	0.0219
Volatility	0.0028***	0.0006	0.0024***	0.0006	0.0024***	0.0006
VIX	−0.0006	0.0005	−0.0010*	0.0006	−0.0011*	0.0006
Jan	0.0020	0.0134	−0.0173	0.0130	−0.0178	0.0127
Feb	−0.0330**	0.0150	−0.0448***	0.0134	−0.0460***	0.0135
Mar	−0.0435***	0.0158	−0.0495***	0.0157	−0.0501***	0.0157
Apr	−0.0338**	0.0157	−0.0460***	0.0159	−0.0462***	0.0160
May	−0.0563***	0.0160	−0.0658***	0.0157	−0.0672***	0.0157
Jun	−0.0618***	0.0153	−0.0747***	0.0153	−0.0767***	0.0155
Jul	−0.0512***	0.0154	−0.0711***	0.0149	−0.0721***	0.0150
Aug	−0.0304**	0.0154	−0.0544***	0.0158	−0.0563***	0.0160
Sep	−0.0793***	0.0150	−0.0943***	0.0147	−0.0963***	0.0147
Oct	−0.0817***	0.0150	−0.0931***	0.0152	−0.0900***	0.0152
Nov	−0.0473***	0.0135	−0.0406***	0.0138	−0.0414***	0.0136
Year 2001	−0.0617	0.0483	−0.0421	0.0407	−0.0425	0.0406
Year 2002	−0.0826*	0.0489	−0.0416	0.0431	−0.0449	0.0427
Year 2003	−0.0732	0.0467	−0.0337	0.0400	−0.0350	0.0397
Year 2004	−0.0836*	0.0465	−0.0696*	0.0383	−0.0717*	0.0379
Year 2005	−0.0731	0.0465	−0.0654*	0.0386	−0.0669*	0.0383
Year 2006	−0.0791*	0.0457	−0.0659*	0.0368	−0.0671*	0.0362
Year 2007	−0.0585	0.0443	−0.0334	0.0346	−0.0331	0.0337
Year 2008	−0.0595	0.0446	−0.0231	0.0351	−0.0258	0.0342
Year 2009	−0.0885**	0.0443	−0.0529	0.0343	−0.0576*	0.0336
Year 2010	−0.0592	0.0442	−0.0294	0.0342	−0.0314	0.0333
Year 2011	−0.0548	0.0443	−0.0204	0.0344	−0.0214	0.0334
Year 2012	−0.0632	0.0447	−0.0324	0.0344	−0.0341	0.0333
Year 2013	−0.0543	0.0451	−0.0285	0.0354	−0.0287	0.0346
Year 2014	−0.0808*	0.0458	−0.0730**	0.0363	−0.0743**	0.0357
Year 2015	−0.0769*	0.0437	−0.0671**	0.0335	−0.0686**	0.0326
Year 2016	−0.0587	0.0460	−0.0425	0.0360	−0.0416	0.0351
Year 2017	−0.0703	0.0457	−0.0608*	0.0362	−0.0627*	0.0354
Year 2018	−0.0709	0.0457	−0.0387	0.0361	−0.0400	0.0352
Year 2019	−0.0180	0.0554	0.0067	0.0518	0.0155	0.0538

(*Continued*)

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Table A6. (*Continued*)

	National		IA/MN		Western	
	Estimate	Std. Err.	Estimate	Std. Err.	Estimate	Std. Err.
Year 2020	0.0649	0.0567	0.0869*	0.0491	0.0852*	0.0488
Year 2021	−0.0040	0.0475	0.0175	0.0377	0.0145	0.0369
Year 2022	−0.0369	0.0474	−0.0149	0.0388	−0.0190	0.0376
Year 2023	−0.0786**	0.0389	−0.0506*	0.0263	−0.0513**	0.0252
Adjusted R^2	0.4859		0.4760		0.4765	
N	5,777		5,777		5,777	

Notes: December and 2024 serve as the reference points. All standard errors are adjusted using the Newey-West method to account for heteroscedasticity and autocorrelation.

*, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

Table A7. Regression with basis

	National		IA/MN		Western	
	Estimate	Std. Err.	Estimate	Std. Err.	Estimate	Std. Err.
Intercept	0.7147***	0.1776	0.7001***	0.1863	0.6822***	0.1874
NegShare	−8.5002**	3.8410	−4.9512	3.1378	−4.6071	3.0585
Volume	−0.0006	0.0006	−0.0003	0.0005	−0.0003	0.0005
Corn	−0.0771***	0.0271	−0.0823***	0.0283	−0.0797***	0.0285
Volatility	0.0014**	0.0007	0.0016**	0.0007	0.0017**	0.0007
VIX	−0.0016***	0.0006	−0.0017***	0.0006	−0.0017***	0.0006
Jan	0.0079	0.0151	−0.0145	0.0148	−0.0152	0.0146
Feb	−0.0421**	0.0173	−0.0497***	0.0151	−0.0506***	0.0152
Mar	−0.0401***	0.0153	−0.0492***	0.0153	−0.0498***	0.0153
Apr	−0.0487***	0.0180	−0.0548***	0.0165	−0.0545***	0.0165
May	−0.0692***	0.0174	−0.0794***	0.0168	−0.0796***	0.0167
Jun	−0.0902***	0.0170	−0.1008***	0.0170	−0.1012***	0.0171
Jul	−0.0866***	0.0175	−0.0931***	0.0158	−0.0931***	0.0158
Aug	−0.1501***	0.0169	−0.1346***	0.0175	−0.1349***	0.0174
Sep	−0.1027***	0.0175	−0.1104***	0.0169	−0.1105***	0.0167
Oct	−0.1088***	0.0165	−0.1076***	0.0167	−0.1064***	0.0169
Nov	−0.0420***	0.0149	−0.0359**	0.0145	−0.0368***	0.0142
Year 2001	−0.1126	0.0953	−0.0503	0.0940	−0.0324	0.0914
Year 2002	−0.1138	0.0958	−0.0900	0.0971	−0.0918	0.0952
Year 2003	−0.2167**	0.1104	−0.1695	0.1139	−0.1693	0.1139
Year 2004	−0.1466*	0.0840	−0.0892	0.0761	−0.0829	0.0750
Year 2005	−0.2226***	0.0806	−0.1665**	0.0678	−0.1615**	0.0667

(*Continued*)

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Table A7. (*Continued*)

	National		IA/MN		Western	
	Estimate	Std. Err.	Estimate	Std. Err.	Estimate	Std. Err.
Year 2006	−0.1858**	0.0812	−0.1334**	0.0668	−0.1244*	0.0658
Year 2007	−0.1615*	0.0835	−0.1014	0.0665	−0.0927	0.0651
Year 2008	−0.0826	0.0859	−0.0005	0.0746	−0.0025	0.0730
Year 2009	−0.1689**	0.0859	−0.1183	0.0745	−0.1207	0.0736
Year 2010	−0.0623	0.0839	−0.0225	0.0670	−0.0190	0.0657
Year 2011	−0.1184	0.0811	−0.0541	0.0661	−0.0519	0.0646
Year 2012	−0.0851	0.0809	−0.0257	0.0666	−0.0248	0.0651
Year 2013	−0.1305	0.0906	−0.0601	0.0745	−0.0518	0.0728
Year 2014	−0.1946**	0.0861	−0.1215*	0.0731	−0.1200*	0.0720
Year 2015	−0.1741**	0.0828	−0.0989	0.0652	−0.0967	0.0640
Year 2016	−0.1176	0.0806	−0.0525	0.0638	−0.0493	0.0627
Year 2017	−0.2073**	0.0905	−0.1571*	0.0803	−0.1536*	0.0793
Year 2018	−0.1194	0.0997	−0.0549	0.0934	−0.0535	0.0925
Year 2019	−0.1624*	0.0945	−0.1024	0.0850	−0.0971	0.0857
Year 2020	−0.0079	0.1036	0.0317	0.0998	0.0329	0.0979
Year 2021	−0.0244	0.0923	0.0226	0.0772	0.0239	0.0752
Year 2022	−0.0527	0.0964	−0.0677	0.0729	−0.0623	0.0714
Year 2023	−0.1197	0.0749	−0.0737*	0.0540	−0.0673*	0.0516
NegShare x Year 2001	7.7302**	3.8781	4.2047	3.1970	3.7883	3.1183
NegShare x Year 2002	7.6715**	3.8368	4.4899	3.1443	4.1650	3.0648
NegShare x Year 2003	8.6108**	3.9131	5.2549	3.2435	4.9380	3.1671
NegShare x Year 2004	7.4292*	3.8472	3.9087	3.1467	3.5471	3.0675
NegShare x Year 2005	8.2776**	3.8333	4.7398	3.1274	4.4049	3.0473
NegShare x Year 2006	7.9841**	3.8572	4.5172	3.1434	4.1417	3.0641
NegShare x Year 2007	8.4273**	3.8646	4.8655	3.1545	4.4834	3.0762
NegShare x Year 2008	7.8273**	3.8443	3.9960	3.1656	3.6744	3.0880
NegShare x Year 2009	8.6563**	3.9109	5.1464	3.2276	4.8040	3.1526
NegShare x Year 2010	6.3854	3.8943	3.5334	3.1737	3.1684	3.0941
NegShare x Year 2011	7.9513**	3.8649	4.7116	3.1720	4.3761	3.0937
NegShare x Year 2012	6.7071*	3.8406	3.3203	3.1567	3.0104	3.0772
NegShare x Year 2013	7.6411*	3.9953	4.1558	3.3097	3.7057	3.2334
NegShare x Year 2014	8.7852**	3.9539	4.5721	3.2715	4.2987	3.1994
NegShare x Year 2015	7.6347*	4.0000	3.6185	3.1857	3.3183	3.1089
NegShare x Year 2016	6.8275*	3.8779	2.8842	3.1480	2.4488	3.0690
NegShare x Year 2017	9.2411**	4.0687	6.1129*	3.5056	5.7227*	3.4349
NegShare x Year 2018	6.7395	4.5884	3.6003	4.2872	3.3025	4.2432

(*Continued*)

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Table A7. (*Continued*)

	National		IA/MN		Western	
	Estimate	Std. Err.	Estimate	Std. Err.	Estimate	Std. Err.
NegShare x Year 2019	12.6806***	4.2722	8.6501**	3.5684	8.6946**	3.5045
NegShare x Year 2020	10.1601*	5.5016	6.9605	5.3219	6.5887	5.2147
NegShare x Year 2021	2.5979	4.1023	−1.3628	3.4716	−1.6853	3.3715
NegShare x Year 2022	0.0963	4.7045	−0.4228	3.6639	−0.9203	3.5604
NegShare x Year 2023	6.5262*	3.9353	2.6619	3.1104	2.1537	2.9813
Adjusted R^2	0.4842		0.4903		0.4890	
N	5,777		5,777		5,777	

Notes: December and 2024 serve as the reference points. All standard errors are adjusted using the Newey-West method to account for heteroscedasticity and autocorrelation.

*, **, and *** indicate statistical significance at the 10%, 5%, and 1% levels, respectively.

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