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Price dynamics are evaluated to assess evidence of alleged price fixing collusion by the four largest U.S. beef packers starting in 2015. Initial variance screens find that during the period in question retail and boxed beef cutout prices increase and stabilize relative to fed cattle prices, consistent with collusive behavior, but on a much smaller scale than a benchmark case of documented collusion in fish fillet pricing. Boxed beef cutout and Kansas fed cattle prices are cointegrated. Speed of adjustment coefficients from VEC models indicate faster and more significant adjustment of boxed beef cutout prices to Kansas fed cattle prices at rates that remain consistent before and during the period of alleged collusion, while the Kansas fed cattle price adjusts slower to the boxed beef cutout price if at all but improves modestly in the period of alleged collusion Overall, the effects of the Covid-19 pandemic on price dynamics are much larger, and the results suggest collusive behavior to be minimal if any and short lived.

Keywords: beef price, cattle price, collusion, market power, mandatory price reporting, thin markets

Introduction

U.S. fed cattle producers and beef buyers filed class action antitrust lawsuits in 2019, alleging price fixing collusion by the four largest beef packers—Tyson Foods, JBS USA, Cargill, and National Beef Packing Company—as early as January 2015 (Bolotova, 2022).[1] Together these firms hold approximately 85% of beef packing market share (U.S. Department of Agriculture, Agricultural Marketing Service, 2022) in an industry increasingly vertically coordinated by forward and formulae contracts that respectively link cattle pricing to futures and ever thinning spot markets (Greene, 2019). Paradoxically, USDA mandatory price reporting (MPR) policy intended to promote pricing transparency and efficiency in a declining spot market by making price data across transaction type (spot, contract, etc.) publicly available potentially enables tacit collusion by packers even in the absence of avert collusion involving explicit agreement among them (Bolotova, 2023; Wachenheim & DeVuyst, 2001).[2] Correspondingly, Cai, Stiegert, and Koontz (2011) find evidence of oligopsonistic power and longer duration cooperative pricing regimes in beef packing margins following enactment of MPR in April 2001. Meanwhile, Lusk, Tonsor, and Schulz (2021) cast doubt on inquiries and civil suits about alleged anticompetitive behavior focusing on historically large differentials in livestock and wholesale meat prices coinciding with disruptions during the Covid-19 pandemic, noting that price spreads may not be reflective of marketing margins, as costs likely varied over the time period.

[1] JBS reached financial settlements with no admission of wrongdoing (Bolotova, 2023).
[2] Parcell and Tonsor (2017) examined confidentiality restrictions for live lamb and lamb products and offer an assessment of the reporting conundrum with mandatory livestock market reporting.

As (even regional) market concentration/power and thinning of spot markets pose concerns for pricing accuracy and efficiency, prior studies of similar issues investigate levels of price integration using vector error correction models and assess changes in time varying error correction coefficients (Franken, Parcell, Sykuta, & Fulcher, 2005; Franken, Parcell, & Tonsor, 2011). Similar price integration analyses are applied extensively to cattle spot and contract prices, finding that: larger volume markets fully adjusted to changes in other markets quicker than smaller markets (Schroeder & Goodwin, 1990); cointegration and speed of adjustment among fed cattle markets increased over time with concentration in cattle slaughtering (Goodwin, 1992; Goodwin & Schroeder, 1991); speed of adjustment among fed cattle markets is faster for processing plants in close proximity and slower for larger plants and plants with fewer cash transactions (Schroeder, 1997); price transparency and integration increased following enactment of MPR (Fausti, Qasmi, Li, & Diersen, 2010; Pendell & Schroeder, 2006); spot prices lead alternative marketing arrangements (AMAs) in rising markets and trail them in declining markets (Ward, 2008); and cash and AMAs prices are mostly cointegrated (Ward, Vestal, & Lee, 2014). As earlier studies are now a decade old, recent concerns for the potential of market power to impact pricing efficiency warrant revisiting the issues of cattle market price discovery and price integration during more recent time periods.

Building on this literature, this study examines price dynamics in the beef cattle industry for evidence of collusion by packers. An initial step entails applying market price variance screens for collusion to retail beef, choice cutout (i.e., boxed beef), and regional cattle prices available due to MPR (Abrantes-Metz, Froeb, Geweke, & Taylor, 2006). The analysis proceeds to investigate the degree of cointegration between regional weighted average live cattle cash price and choice cutout (boxed beef) price and the determinants of an associated time varying error correction coefficient measure Regressing the time varying error correction coefficient on various potential determinants of its changes (e.g., volume of cash and contract cattle sold, slaughter weights, years since last valley in cattle cycle, cattle grading percentages, exports/imports, prices of competitive animal protein products, capacity-utilization ratios, number of federally inspected plants, Covid-19 dummy, wage and energy rates, etc.) may provide valuable insights.

The paper is organized as follows. The next section presents a brief review of the relevant literature, followed by a description of the data. The empirical methods and procedures are discussed, followed by the results and conclusions sections.

Prior Literature

Studies on variance screens for market collusion

Given difficulties in detecting anticompetitive conspiracies associated with various potential forms of collusive behavior and unavailability of firm level cost data needed to infer competitive outcomes, various data screens involving the mean level and variance of prices may be enlightening. Theoretical justifications for and empirical support of the efficacy of variance screens for collusion exist, where prices are less variable under collusive than under competitive conditions. Two studies using infinitely repeated Bertrand games, find collusive equilibria entail more stable prices that are less responsive to changes in costs that are only partially passed on compared to competitive equilibrium (Athey, Bagwell, & Sanchirico, 2004; Harrington Jr & Chen, 2006). LaCasse (1995) presents a model of coordinated bidding with side payments to randomly chosen losers that effectively truncates the bidding distribution, and hence, decreases the variance of bids over time periods of collusion. Two empirical studies of bids on highway construction contracts supports the contention that collusion reduces the variance of bids (Feinstein, Block, & Nold, 1985; Lee, 1990). Similarly, Genesove and Mullin (2001) find that mean sugar refining margins are slightly higher, relative to the pre-cartel period, while its variance drops nearly 100% during the cartel period. Likewise, Bolotova, Connor, and Miller (2008) find a higher mean and lower variance of lysine prices during cartel than pre- and post-cartel periods, and similarly find a higher mean price of citric acid during a cartel period but a surprisingly higher variance, which the authors speculated may be due to the duration of the cartel or a shortage of post-collusion observations. Abrantes-Metz et al. (2006) used a documented 16% increase in the mean and 263% decrease in the standard deviation of perch fish prices during a known cartel period (Table 1) as a benchmark for detecting collusion in retail gasoline prices, with no evidence of such behavior found for the studied gas stations. The benchmark is adopted here, as detailed further in the methods and procedures section below.

Studies on market price integration

Studies of market price integration are commonly applied to investigate the potential effects of market power associated with concentration (i.e., mergers and acquisitions) and thin markets (declining spot transactions with growing contract use) for crops and livestock in general (e.g., Franken et al., 2005; Franken et al., 2011). Here, given the focus of this paper on a particular period of alleged market power abuse possibly facilitated by MPR and thinning cash markets associated with growing use of AMAs, emphasis is placed on more recent studies of cattle markets not already described in the introduction. As already noted, MPR appears to have increased price transparency and integration (Fausti et al., 2010; Pendell & Schroeder, 2006), and cash and AMAs prices are mostly cointegrated (Lee, Ward, & Brorsen, 2010), with cash prices leading AMAs in rising markets and trailing them in declining markets (Ward, 2008).

Mathews, Brorsen, Hahn, Arnade, and Dohlman (2015) estimate error correction models for cash fed cattle prices and live cattle futures prices for three periods: 1990-2001 (pre-MPR), 2002-08 (post-MPR), and 2008-14 (post-MPR with higher price volatility). Resulting speed of adjustment coefficients (or long-run adjustment parameters) are used to compute Schwarz and Szakmary (1994) price discovery weights to infer relative contributions by cash and futures prices. Results indicate better convergence of cash and futures prices at futures contract maturity following enactment of MPR and that the cash market began to play a small role in price discovery that previously occurred solely in the futures market, with little differences apparent in the more and less volatile post-MPR periods.

Rahman and Palash (2018) revisit the issue of market price integration for five U.S. regional fed cattle markets for the post-MPR period of May 2001-March 2015. Consistent with prior work (e.g., Pendell & Schroeder, 2006), the study finds all price series to be integrated of order one, I(1), with evidence of cointegration indicating a long run spatial equilibrium price relationship among each market. Granger causality tests indicated causal effects for each market considered for steers except the Iowa-Minnesota market, while only the Texas-Oklahoma market for heifers influence other heifer markets, perhaps reflecting market shares of heifers relative to steers. The study, however, did not proceed with an error correction model that could inform upon the responsiveness of markets to changes in prices at each location.

Ramsey, Goodwin, Hahn, and Holt (2021) analyze the effects of the COVID-19 pandemic on f beef, pork, and poultry industry price dynamics by applying autoregressive and VEC models to weekly farm, wholesale, and retail prices. All three markets are well integrated with price exhibiting large but transitory shocks in April and May of 2020, and returning to expected levels at a pace consistent with speeds of transmission prior to the pandemic.

Erol and Saghaian (2022) investigate the impact of the COVID-19 pandemic on beef industry price dynamics using monthly farm, wholesale, and retail prices from the USDA for 1970 through 2021. Results indicate cointegration and asymmetric price transmission with absolute values of speed of adjustment coefficients from VEC models being much higher (0.26) for wholesale prices than retail prices (0.021) or farm prices (0.074). As such, historical decomposition graphs demonstrated that the COVID-19 pandemic led to consumers paying higher prices and farmers receiving lower prices. Pozo, Bachmeier, and Schroeder (2021) similarly find beef industry price transmission asymmetries using farm, wholesale, and retail prices from the Bureau of Labor Statistics, which are remedied when using scanner data on retail transactions that are more reflective of actual consumer purchases.

Data

The analysis utilizes weekly data on the boxed beef cutout price ($/cwt) and regional fed cattle prices for Kansas, Texas, Nebraska, and Iowa-Minnesota for November, 2002 through December, 2023, from the Livestock Marketing Information Center and originating from reports published by Livestock Market News of the Agricultural Marketing Service. By region, USDA publishes price data as cattle of all quality grade sold live, cattle of all quality grade sold dressed, and many sub-categories of all sold categories by percentage quality grade ranges. For the present study, only all quality grade cattle prices were used because the sub-categories by percentage quality grade contained too many no transactions during weeks over the entire time period. Recall, the objective of the research is to examine market price behavior over a long-time frame.

Prices used for the analysis are graphed over the study period in Figure 1 with summary statistics reported in Table 2. Fed cattle prices across locations track each other fairly closely and as such exhibit similar means around $114/cwt on a live basis and $181/cwt dressed. Maximum cattle prices tend to vary slightly more across locations, as minimums are more similar, with the exception of lower minimums in Nebraska on either a live or dressed basis. As such, absolute cattle price variation is similar across markets, with slightly higher standard deviations on a dressed basis. In comparison, the boxed beef cutout and retail beef prices, priced at higher levels, exhibit greater absolute cattle price variability. Remaining variables in Table 2 are national level statistics used later to explain variation in time varying speed of adjustment coefficients. For instance, formula and forward contract share of cattle marketed exhibits notable variation, and when fewer cattle are marketed through cash transactions, cash prices may be slower to respond to innovations in related price series. Similarly, since most cattle grade choice, price discovery typically happens for this quality grade with established premiums and deductions for higher and lower grades, and thus, cash prices may also respond slower when fewer cattle grade choice.

Consistent with the close correspondence of fed cattle prices across markets apparent in Figure 1, correlations across markets exceed 0.97 (Table 3). The correlation between retail beef prices and the boxed beef cutout is 0.94 and correlations between each of these series and the fed cattle prices generally exceed 0.80.

Empirical Methods and Procedures

Variance screens for market collusion

As an initial step, a variance screen for evidence of collusion is performed by comparing the mean, standard deviation, and coefficient of variation for the period of alleged collusion, a prior period, and the period affected by COVID-19. We begin by specifying the mean for each data series denoted by μ as

$$\mu = \frac{\sum_{i=1}^{n} x_i}{n}, \tag{1}$$

where x_i represents each individual price value in the dataset and n is the number of observations in the dataset. The standard deviation for a data series denoted by σ is specified as

$$\sigma = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \mu)^2}{n}}, \tag{2}$$

where variables are specified as in the mean equation. To look at relative variation in the data, the coefficient of variation denoted by CV is then be specified as

$$CV = \left(\frac{\sigma}{\mu}\right) \times 100, \tag{3}$$

where variables are derived in equations (1) and (2). The three values can be used together to compare market actions during different regimes over time. Mean and standard deviation measures provide an absolute assessment of price and coefficient of variation provides a relative comparison to account for changing average price levels between regimes. Following the *ex-post* findings by Abrantes-Metz et al. (2006), Bolotova et al. (2008), Feinstein et al. (1985), Lee (1990), and Genesove and Mullin (2001), the following conditions are expected if market collusion occurs,

Mean of sale price (i.e., output price received by collusive sector) increases and increases by more than the mean input cost (i.e., procurement price paid by collusive sector) increases:

$$\mu_{collusion,sales\ price} > \mu_{competition,sales\ price}\text{, and} \tag{4}$$

$$\frac{\mu_{collusion,sales\ price} - \mu_{competition,sales\ price}}{\mu_{competition,sales\ price}} > \frac{\mu_{collusion\ input\ cost} - \mu_{competition,input\ cost}}{\mu_{competition,input\ cost}}.$$

Variation of sales price decreases and decreases by more than that of input costs:

$$\sigma_{collusion,sales\ price} < \sigma_{competition,sales\ price} \text{ , and} \tag{5}$$

$$\frac{\sigma_{collusion,sales\ price} - \sigma_{competition,sales\ price)}}{\sigma_{competition,sales\ price}} < \frac{\sigma_{collusion,input\ cost} - \sigma_{competition,input\ cost}}{\sigma_{competition,input\ cost}}.$$

CV of sale price decreases and decreases by more than the input cost CV decreases:

$$CV_{collusion,sales\ price} < CV_{competition,sales\ price} \text{ , and} \tag{6}$$

$$\frac{CV_{collusion,sales\ price} - CV_{competition,sales\ price}}{CV_{competition,sales\ price}} < \frac{CV_{collusion\ input\ cost} - CV_{competition,input\ cost}}{CV_{competition,input\ cost}}.$$

The interpretation of equations 4 through 6 is straightforward. During collusion, the observed mean average sale price will increase relative to average input cost and the variation in sales price will decline relative to input cost variation. There is the question of the magnitude of the size of the change needed to signal market behavior other than normal market deviations. A first step is to be able to identify the period of perceived collusion. This places importance on identifying the "competitive" period so that the period is representative of a competitive market. That is, the results of a market variance screen are sensitive to both the number of observations chosen and choice of time period included in the "competitive" or "collusion" time periods. As noted in the literature review, we adopt the benchmarks employed by Abrantes-Metz et al. (2006) for magnitudes of changes in means, standard deviations, and coefficients of variation between competition and collusion periods (Table 1).

Market price integration analysis

Conceptually, if Augmented Dickey-Fuller (ADF) tests are unable to reject the null hypothesis of nonstationarity for each of the data series in levels, but can using first differenced data, then long run equilibrium relationships may be estimated.[3] The well-known test for cointegration between two price series attributed to Engle and Granger (1987) is estimated by ordinary least squares (OLS) as:

$$P_t = \alpha_0 + \alpha_1 Z_t + e_t, \tag{7}$$

where P_t and Z_t are individual nonstationary price series observed over $t = 1, 2, \ldots, T$ time periods (here weeks), α_0 and α_1 are intercept and slope coefficients, and e_t is is the error term. If an ADF

[3] Cointegration requires that each of the time series be integrated of the same order (Gujarati & Porter, 2009). For instance, time series are integrated of order 1, denoted I(1), if differencing nonstationary time series once yields stationary or I(0) time series. While research suggests nominal commodity spot prices often do not possess unit roots (i.e., prices are stationary) and findings of nonstationarity are sensitive to specification of the data generating process (Wang & Tomek, 2007), these procedures work relatively well in practice.

test for stationarity of e_t indicates the presence of a unit root (i.e., et is nonstationary), then the two price series are not cointegrated.

Multivariate tests of cointegration commonly employ the Johansen (1988) method, which utilizes trace and maximum eigenvalue tests to investigate the number of cointegration vectors (Enders, 2012). Both test statistics follow a nonstandard distribution, and critical values are listed in Osterwald-Lenum (1992). If there are n prices with r cointegrating vectors, then $n - r$ stochastic trends exist. Equivalently, if all price series exhibit the same stochastic trend, there must be $n - 1$ cointegrating vectors meaning that all prices are pairwise cointegrated; but if more than one common trend exists, the price series are not fully integrated. Correspondingly, the null hypothesis for both tests is that there are no more than r cointegrating vectors. The alternative hypothesis for the trace test statistic is that there exist more than r cointegration vectors. The alternative hypothesis for the maximum eigenvalue test statistic is that there are exactly $r + 1$ cointegration vectors.

To further analyze price relationships, Vector Error Correction (VEC) models are estimated to investigate whether the responsiveness (i.e., speed of adjustment) among price series changes over time. Highly integrated markets quickly return to long-run equilibrium following price shocks (Enders, 2012).[4] The VEC model is specified as:

$$\Delta P_t = \beta_0 + \beta_1 \hat{e}_{t-1} + \sum_{k=1}^{K} \beta_{1k}(k)\Delta P_{t-k} + \sum_{k=1}^{K} \beta_{2k}(k)\Delta Z_{t-k} + u_t, \tag{8}$$

where Δ indicates the change (i.e., first difference) in price series P and Z, $\hat{e}_{t-1}$ is the estimated error term from equation (1), k is the lag length; u_t is a n × 1 vector of normally distributed random errors, and β are estimated coefficients, such that β_1 measures the speed of adjustment or the one period lagged errors' effect on a relative price change. A speed of adjustment coefficient (β_1) close to negative one indicates quick adjustment to deviations from equilibrium, whereas a value near zero indicates slow adjustment. Any changes in speed of adjustment brought about by collusion would be indicated by a speed of adjustment coefficient becoming noticeably closer to zero, indicating a tendency for a slower return to equilibrium differences for the two price series.

Results

Variance screens for market collusion

Table 4 compares findings for the variance screen analysis of the cattle industry with those reported by Abrantes-Metz et al. (2006) for a known case of collusion in perch fish and fillet prices as a baseline (Table 1). The sign or direction of changes across the periods of competition and alleged collusion are consistent with the allegations, but the magnitudes of these effects are relatively small in comparison to the aforementioned benchmarks. Specifically, collusive

[4] The word "quickly" will be dependent on the markets examined. A researcher studying intra-day deviations in financial markets using tick data may conclude a deviation from long-run equilibrium returning to equilibrium within minutes to be quick. A researcher studying a market represented by a perishable product where biological processes require multiple years to respond to market signals may conclude a deviation from long-run equilibrium returning to equilibrium within months to be quick.

behavior would increase and stabilize (i.e., increase mean and decrease variability of) retail and boxed beef cutout prices, relative to fed cattle prices. While mean retail and boxed beef cutout prices are respectively 3.9% and 7.7% higher in the period of alleged collusion (Table 4), these increases are less than half of the benchmark 16.2% increase in retail fish fillet prices (Table 1). With respect to variability, the CV of the boxed beef cutout is quite like that of fed cattle prices during the competitive period but decreases relative to that of fed cattle in the period of alleged collusion (Table 4). For boxed beef price, the CV declines 23.2% between the competitive and alleged collusion time periods. For fed cattle live prices, the CV is observed to increase between 1.8% and 6.2% during the alleged collusion period. For fed cattle dress prices, the CV is observed to increase around 12%. While the sale and input cost CVs diverge between the competition and alleged collusion periods, the order of magnitude of these changes is small in comparison to the 332% increase in the CV of retail fish fillet prices relative to a 41.8% increase in the CV of perch fish cost (Table 1). At the market level the variance screen findings here alone are insufficient to validate the alleged collusion in the beef cattle market.

In addition to comparing the alleged period of collusion to a more competitive period, the latter is also compared with the period of the Covid-19 pandemic. Relative to alleged collusive behavior, Covid-19 has much larger effects on price levels and (with the exception of retail prices) on variability. For instance, mean retail and boxed beef cutout prices increase by 20.0% and 29.7%, respectively, reflecting consumer demand outpacing supply of beef in the period, perhaps being exacerbated by impacts of government stimulus programs. That is, relative to the competitive period, during the Covid-19 pandemic, retail beef prices are higher on average but slightly more variable and boxed beef cutout prices are higher are notably more variable, while fed cattle prices are lower on average and consistently so (i.e., lower variability), partly reflecting decreased demand for slaughter cattle when packers had to shut down due to sick workers.

Figure 2 presents a graphical representation of a 24 week moving average of coefficient of variation for boxed beef cutout and fed cattle prices that illustrates similar effects. A moving average of 24 weeks was chosen as it may roughly correspond to the movement of cattle from start to finish through feedlots over about six months with approximately four weeks per month. Consistent with the above discussed results, the coefficient of variation for the boxed beef cutout price is noticeably lower than those of fed cattle prices for parts of 2016 and 2017, during the period of alleged collusion, and is wildly higher during the Covid-19 pandemic.

Market price integration analysis

Prior to market integration analysis, Augmented Dickey-Fuller tests of nonstationarity were performed, with the appropriate lag structure determined by minimizing the Akaike Information Criteria. Given the close correspondence among fed cattle spot market prices already discussed in the data section, results are presented for Kansas fed cattle prices and boxed beef prices, as representative examples, in the interest of space (Table 5). As the null hypothesis of nonstationarity could not be rejected at the 1% significance level, the price series are deemed nonstationary, which is corrected by first differencing the data, leading to rejection of the null hypothesis. Johansen (1988) unrestricted cointegration rank test trace statistics reject the null hypothesis of no cointegrating vector at the 1% level, and thus, the series are deemed cointegrated. Hence, long run price relationships exist and may be estimated with a VEC model.

Results for VEC models of price relationships for the boxed beef cutout and Kansas fed cattle are presented in Table 6 for the full sample with the inclusion of a binary dummy to account for the Covid-19 pandemic, and monthly retail beef prices as an exogenous variable to account for changes in beef demand (i.e., same value repeated for all four weeks within the month), as well as subsamples corresponding to the competitive period and alleged collusive period prior to the Covid-19 pandemic. Omitting retail beef prices yields qualitatively similar results in terms of size and significance of speed of adjustment coefficients. In each case, the retail beef price is included account for larger price movements in the general beef value complex. Comparing the speed of adjustment coefficient (β_1) across samples is of primary interest. Recall that the speed of adjustment coefficient should be negative, indicating reversion away from past errors toward long run relationships, and values closer to negative one indicate faster adjustment. The values indicate faster adjustment for boxed beef cutout prices than for Kansas fed cattle prices and are relatively similar for the full sample and competitive period. The speed of adjustment remains similar for the boxed beef cutout at -0.12 for the period of alleged collusion, while the speed of adjustment for the Kansas fed cattle price increases to -0.06 compared to a value of -0.01 that is statistically significant at only the 10% level for the full sample and a value of 0.01 that is insignificantly different from zero statistically at any conventional level for the competitive period. Recall Erol and Saghaian (2022) also find small speed of adjustment coefficients between farm (0.074), wholesale (0.26), and retail prices (0.021) in their study of beef industry price dynamics.

Figure 3 graphs time varying speed of adjustment coefficients alongside its standard deviation and an approximate t-statistic computed by dividing the absolute value of the former by the later in order to offer some inference of statistical significance. The time varying aspect is achieved by initially running the VEC from November 2002 through January 2003, and the reiterating with each successive observation. Panel A illustrates the responsiveness of Kansas fed cattle price to boxed beef cutout price, and Panel B shows the reverse. In each case, the initial estimates are quite large but converge to consistently smaller values somewhere around 2013. Consistent with the results in Table 5, the Kansas fed cattle price adjusts much slower to the boxed beef cutout price (i.e., it's speed of adjustment coefficient is much smaller) if at all, compared to the boxed beef cutout price's adjustment to Kansas fed cattle price. The approximate t-statistic is also larger for the boxed beef cutout price than for the Kansas fed cattle price, indicating that the boxed beef cutout price exhibits significant responses to fed cattle prices, whereas fed cattle more often do not respond statistically significantly to innovations in the boxed beef cutout price. In this respect, further breakdown in the statistical significance of responses for each to the other are apparent during the Covid-19 pandemic.

Table 7 shows results of seemingly unrelated regressions of the time varying speed of adjustment coefficients for the cutout boxed beef and Kansas fed cattle prices, respectively, on selected explanatory variables for the period of 2013 forward where the speed of adjustments seem to be more precise (Figure 3). The models explain 81% and 66% of the variance in these two dependent variables, respectively, based on R^2. Signs of coefficients are mostly as expected. Volume of cattle marketed significantly increases speed of adjustment for the Kansas fed cattle price, consistent with expectations of better performance when markets aren't thin, but significantly decreases that of the cutout. Perhaps the volume of cattle marketed does not as accurately reflect that of beef marketed or perhaps a lag should be used. Correspondingly, as more cattle are traded through forward and formula contracts, as opposed to cash transactions, the speed of adjustment for Kansas cash fed cattle declines. Similarly, as price discovery occurs for choice grade cattle with established premiums and discounts for higher and lower grades, increases in the shares of cattle that grade prime and choice, respectively, statistically significantly decrease and increase the speed of adjustment coefficient for Kansas fed cattle. Coefficients for all variables other than perhaps the grade and contract share variables are small in magnitude and of little economic significance, however. For instance, although the cartel dummy variable statistically significantly increases the speed of adjustment for cutout boxed beef prices and decreases that of Kansas fed cattle prices, as would be expected under collusive behavior, the effects are small. Interestingly, the Covid-19 dummy has the expected statistically significant negative effect on the speed of adjustment for the cutout boxed beef price, but an unexpectedly statistically positive effect on the speed of adjustment for Kansas fed cattle prices. In both cases, these effects are also small, consistent with prior findings that the effects of Covid-19 on the beef market were transitory (Lusk, Tonsor, and Schulz, 2021).

Conclusions

This paper evaluates price dynamics to assess evidence of alleged price fixing collusion by the four largest U.S. beef packers starting in 2015. An initial variance screen finds that during the period in question retail and boxed beef cutout prices increase and stabilize relative to fed cattle prices, consistent with collusive behavior, but on a much smaller scale than a benchmark case of documented collusion in fish fillet pricing. In comparison, the Covid-19 pandemic had much larger effects, as illustrated by graphing moving average time varying coefficients of variation.

In light of these findings, price dynamics are further investigated for the boxed beef cutout and Kansas fed cattle, which are found to be cointegrated, permitting estimation of long-run relationships with VEC models. Resulting speed of adjustment coefficients are presented for the full sample and subsamples of competitive and alleged collusive time periods, as well as graphically representation of time varying speed of adjustment coefficients generated by continuously updating model estimations with additional observations. These values indicate faster and more significant adjustment of boxed beef cutout prices to Kansas fed cattle prices at rates that remain consistent across sample periods, while the Kansas fed cattle price adjusts slower to the boxed beef cutout price if at all in the competitive period and actually improves modestly in the period of alleged collusion relative to the full sample. Both price series respond less significantly to innovations in the other during the Covid-19 pandemic. Regressions of time varying speed of adjustment coefficients on selected explanatory variables indicate, as expected, that Kansas fed cattle prices respond faster with greater volumes of cattle sold and smaller shares thereof contracted and suggest respective increases and decreases for cutout and fed cattle prices' speeds of adjustment, consistent with collusion but economically small, during the alleged cartel period. Overall, the results suggest collusive behavior to be minimal if any and short lived.

The primary limitation of the study is not a limitation that can be easily overcome. Access to firm-level transactions over the full time period would allow for a firm-level variance screen to determine if certain firms engaged in anti-competitive behavior. Given the concentration of beef packing firms, i.e., 85% CR4 in 2010 (Crespi, Saitone, & Sexton, 2012), any subset of packers engaged in anti-competitive pricing activities would carry over in the aggregation. One argument could be regional anti-competitive behavior. Our variance screen was conducted for multiple regions and for both live and dressed animals with similar findings across geographies and marketing types. We did not examine more granular lots of cattle transactions broken down by quality grade. The inconsistency of "printed" transactions made results unreliable for computing moving average variance screens or measures of time-varying market integration.

Extensions of our study are to other industries where there exits concerns over anti-competitive pricing behavior. Using MPR, the creation of a real-time dashboard of variance screen is possible.

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Table 1. Benchmark Statistics for Variance Screen for Collusion.

	Competition (A)	Collusion (B)	Competition – Collusion (% change) (A – B)
Fillet Retail Price			
Mean	2.97	3.544	-16.2%
S.D.	0.283	0.078	263%
C.V.	0.095	0.022	332%
Perch Fish Cost			
Mean	0.771	0.722	6.8%
S.D.	0.173	0.114	51.8%
C.V.	0.224	0.158	41.8%

Source: Abtrantes-Metz et al. (2006).

Table 2. Descriptive Statistics, November, 2002 through December, 2023.

Price ($/cwt)	Mean	S.D.	Maximum	Minimum
Retail Beef	539.11	125.48	830.80	334.00
Boxed Beef Cutout	197.48	51.65	459.04	120.97
KS Live	113.70	26.02	185.64	71.61
TX Live	113.74	25.93	184.98	71.86
NE Live	114.09	26.73	190.30	71.19
IA-MN Live	114.98	25.99	189.94	77.29
NE Dressed	181.14	42.14	299.61	112.20
IA-MN Dressed	181.78	41.34	298.65	119.63
Volume (1,000 head)	350.03	47.45	538.84	159.66
Live Weight	1317.08	49.78	1411.00	1192.00
Formula Share (%)	0.54	0.14	0.88	0.14
Forward Share (%)	0.08	0.04	0.28	0.01
Prime Share (%)	0.05	0.03	0.13	0.02
Choice Share (%)	0.64	0.08	0.75	0.49
Select Share (%)	0.26	0.09	0.41	0.11
Beef Exports (1,000 metric tons)	12.46	4.84	0.00	41.83

Note: N=1101.

Table 3. Correlations.

	Boxed beef cutout ($/cwt)	*Retail Beef ($/cwt)*	*KS LIVE FOB ($/cwt)*	*NE LIVE FOB ($/cwt)*	*NE Dressed ($/cwt)*	*TX Live FOB ($/cwt)*	*IA-MN Live FOB ($/cwt)*	*IA-MN Dressed ($/cwt)*
Boxed beef cutout ($/cwt)	1.000							
Retail Beef ($/cwt)	0.941	1.000						
Boxed beef cutout ($/cwt)	0.833	0.816	1.000					
NE LIVE FOB ($/cwt)	0.837	0.821	0.998	1.000				
NE Dressed ($/cwt)	0.838	0.822	0.997	0.999	1.000			
TX Live FOB ($/cwt)	0.832	0.815	1.000	0.998	0.996	1.000		
IA-MN Live FOB ($/cwt)	0.818	0.791	0.970	0.975	0.975	0.970	1.000	
IA-MN Dressed ($/cwt)	0.835	0.812	0.991	0.994	0.995	0.990	0.986	1.000

Table 4. Variance Screen Investigations of Collusion.

Prices ($/cwt)	Competition (A)	Collusion (B)	COVID-19 (C)	Competition – Collusion (% change) (A – B)	Competition – COVID (% change) (A – C)
Retail (monthly)					
Mean	363.93	378.28	436.72	-3.9%	-20.0%
S.D.	26.10	9.35	34.78	64.2%	-33.2%
C.V.	0.07	0.02	0.08	65.5%	-11.0%
Boxed Beef (weekly)					
Mean	201.45	217.03	261.33	-7.7%	-29.7%
S.D.	24.14	19.97	49.42	17.3%	-104.7%
C.V.	0.12	0.09	0.19	23.2%	-57.8%
KS Fed Cattle (weekly)					
Mean	129.12	126.80	118.85	1.8%	8.0%
S.D.	16.27	16.61	12.99	-2.1%	20.2%
C.V.	0.13	0.13	0.11	-4.0%	13.3%
NE Live Fed Cattle (weekly)					
Mean	129.79	126.73	119.47	2.4%	8.0%
S.D.	16.22	16.81	13.72	-3.7%	15.4%
C.V.	0.12	0.13	0.11	-6.2%	8.1%
TX Live Fed Cattle (weekly)					
Mean	129.16	126.82	118.82	1.8%	8.0%
S.D.	16.17	16.58	13.04	-2.5%	19.3%
C.V.	0.13	0.13	0.11	-4.4%	12.3%
IA-MN Live Fed Cattle (weekly)					
Mean	130.09	125.91	119.97	3.2%	7.8%
S.D.	17.16	16.90	14.20	1.5%	17.2%
C.V.	0.13	0.13	0.12	-1.8%	10.3%
NE Dressed Fed Cattle (weekly)					
Mean	205.94	200.70	189.71	2.5%	7.9%
S.D.	24.69	26.89	22.11	-8.9%	10.4%
C.V.	0.12	0.13	0.12	-11.8%	2.8%
IA-MN Dressed Fed Cattle (weekly)					
Mean	205.64	200.45	189.72	2.5%	7.7%
S.D.	24.54	26.89	21.85	-9.6%	10.9%
C.V.	0.12	0.13	0.12	-12.4%	3.5%

Notes: S.D. is standard deviation, and C.V. is coefficient of variation = standard deviation/mean. Competition period is 1/1/2011 - 12/31/2014, alleged collusion period is 1/1/2015 - 12/31/2018, and Covid-19 pandemic lasted 1/25/2020 - 5/22/2022.

Table 5. Summary of Tests for Non-Stationarity, Cointegration, and Lag Length

Test	Test Statistic	Critical Value (1% value)
Augmented Dickey – Fuller test for stationarity	t-statistic	
KS weekly live cattle price (levels)	- 2.414	-3.4361
KS weekly live cattle price (first-differenced)	-25.869	
Boxed beef weekly price (levels)	-1.314	
Boxed beef weekly price (first-differenced)	-20.017	
Johansen cointegration test for a single cointegrating relationship	Trace	
No cointegrating relationship	31.108	15.495
At most 1 cointegrating relationship	1.462	3.841
Model selection criteria for lag	AIC	
(1,1)	4.621	
(2,2)	4.581	
(3,3)	4.537	
(4,4)	4.539	

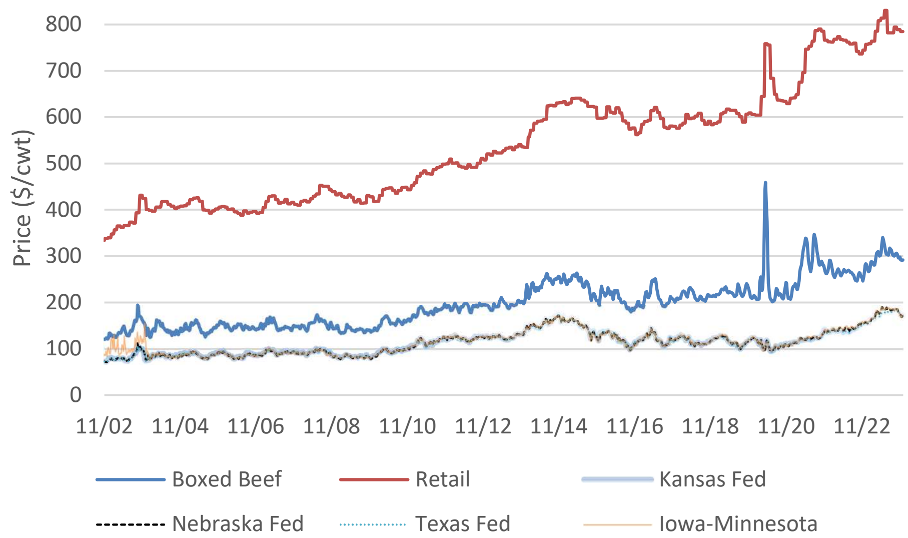
Table 6. Vector Error Correction Models.

Sample	Full Sample (12/23/2002-12/25/2023)		Competitive Period (12/27/2010-12/29/2014)		Alleged Collusive Period (12/29/2014- 12/31/2018)	
Cointegrating Equation:						
Boxed Beef Cutout_L1						
KS_Live_FOB_L1	-0.67		-1.39		-0.74	
	(0.10)		(0.31)		(0.21)	
	[-6.46313]		[-4.50153]		[-3.50254]	
Constant	-121.91		-21.95		-123.74	
Error Correction Model:	D_Boxed_Beef_Cutout	D_KS_LIVE	D_ Boxed Beef Cutout	D_KS_LIVE	D_ Boxed Beef Cutout	D_KS_LIVE
Speed of adjustment (β_1)	-0.12	-0.01	-0.13	0.01	-0.12	-0.06
	(0.01)	(0.01)	(0.03)	(0.03)	(0.03)	(0.03)
	[-10.5066]	[-1.92638]	[-3.80273]	[0.45014]	[-4.17473]	[-2.40786]
D_Boxed_Beef_Cutout_L1	0.83	0.02	0.69	0.05	0.63	-0.02
	(0.03)	(0.01)	(0.07)	(0.07)	(0.07)	(0.07)
	[27.9497]	[1.40917]	[9.74940]	[0.74897]	[8.70444]	[-0.31916]
D_Boxed_Beef_Cutout_L2	-0.26	0.02	-0.37	-0.03	-0.27	0.09
	(0.04)	(0.02)	(0.08)	(0.07)	(0.08)	(0.08)
	[-6.98415]	[0.95955]	[-4.56907]	[-0.43293]	[-3.31016]	[1.15432]
D_Boxed_Beef_Cutout_L3	0.07	0.03	-0.02	-0.06	0.09	0.03
	(0.03)	(0.01)	(0.06)	(0.06)	(0.06)	(0.06)
	[2.30734]	[1.77810]	[-0.33202]	[-1.04107]	[1.50241]	[0.51245]
D_KS_LIVE_L1	0.31	0.23	0.43	0.16	0.55	0.22
	(0.06)	(0.03)	(0.09)	(0.08)	(0.08)	(0.08)
	[4.74979]	[7.30032]	[4.83995]	[1.93575]	[6.80770]	[2.90279]
D_KS_LIVE_L2	-0.41	-0.23	-0.24	-0.27	-0.08	-0.28
	(0.06)	(0.03)	(0.09)	(0.08)	(0.09)	(0.08)
	[-6.41904]	[-7.32297]	[-2.73224]	[-3.35811]	[-0.95882]	[-3.41438]
D_KS_LIVE_L3	-0.11	-0.04	0.11	0.03	0.01	-0.17
	(0.07)	(0.03)	(0.09)	(0.09)	(0.09)	(0.08)
	[-1.64364]	[-1.24818]	[1.21144]	[0.37652]	[0.09083]	[-2.01820]
RETAIL_PRICE	0.03	2.76E-03	2.37E-03	4.95E-04	0.03	-0.01
	(3.28×10^{-3})	(1.608×10^{-3})	(3.938×10^{-3})	(3.638×10^{-3})	(0.01)	(0.01)
	[9.18343]	[1.72319]	[0.60181]	[0.13626]	[2.50933]	[-0.93638]
COVID	2.97	0.25	–	–	–	–
	(0.59)	(0.29)				
	[5.04862]	[0.88173]				
Constant	-16.54	-1.43	-1.04	0.08	-20.36	6.96
	(1.80)	(0.87)	(2.08)	(1.92)	(8.12)	(7.67)
	[-9.21122]	[-1.63632]	[-0.50113]	[0.04128]	[-2.50948]	[0.90653]
R-squared	0.54	0.10	0.59	0.09	0.61	0.21
Adj. R-squared	0.54	0.09	0.57	0.06	0.60	0.18
N	1097		210		210	

Table 7. Seemingly Unrelated Regressions of Speed of Adjustments, 2013 Onward.

	$\lvert\beta_{\text{Cutout to KS}}\rvert$	$\lvert\beta_{\text{KS to Cutout}}\rvert$
Covid-19 (=1 if 1/25/2020–5/22/2022, 0 o.w.)	-0.0019***	0.0024**
	(0.0005)	(0.0011)
Cartel (=1 if >1/1/2015, 0 o.w.)	0.0044***	-0.0068***
	(0.0008)	(0.0017)
Volume (1,000 head)	-2.2100×10^{-5}***	3.7300×10^{-5}***
	(4.9700×10^{-6})	(1.0100×10^{-5})
Live Weight (lb)	1.4600×10^{-5}*	4.7000×10^{-5}***
	(8.7300×10^{-6})	(1.7800×10^{-5})
Formula Share (%)	-0.0153***	-0.0176***
	(0.0033)	(0.0068)
Forward Share (%)	-0.0641***	-0.0754***
	(0.0053)	(0.0108)
Prime Share (%)	-0.0730***	-0.0846**
	(0.0163)	(0.0332)
Choice Share (%)	-0.0498***	0.0914***
	(0.0113)	(0.0230)
Beef Exports (1,000 metric tons)	-2.1200×10^{-5}	0.0002*
	(6.2400×10^{-5})	(0.0001)
Time Trend	3.7600×10^{-5}***	7.1800×10^{-5}***
	(2.4600×10^{-6})	(5.0200×10^{-6})
Constant	0.1098***	0.0551*
	(0.0139)	(0.0284)
R^2	0.8063	0.6555

Notes: N = 573. ***,**,* denote statistical significance at 1%, 5%, and 10%. Standard errors in parentheses.



Sources: Livestock Marketing Information Center

Figure 1. Monthly Retail Beef Prices and Weekly Boxed Beef and Fed Cattle Prices

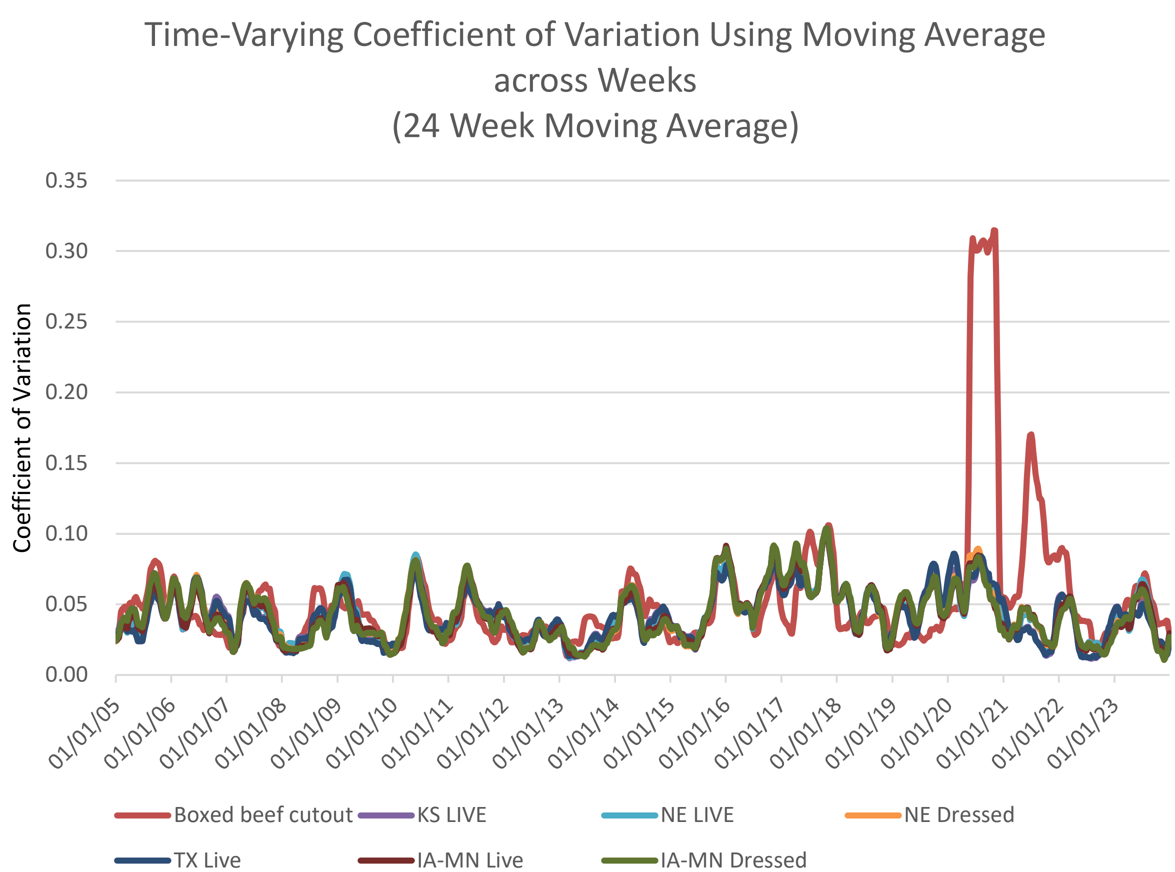
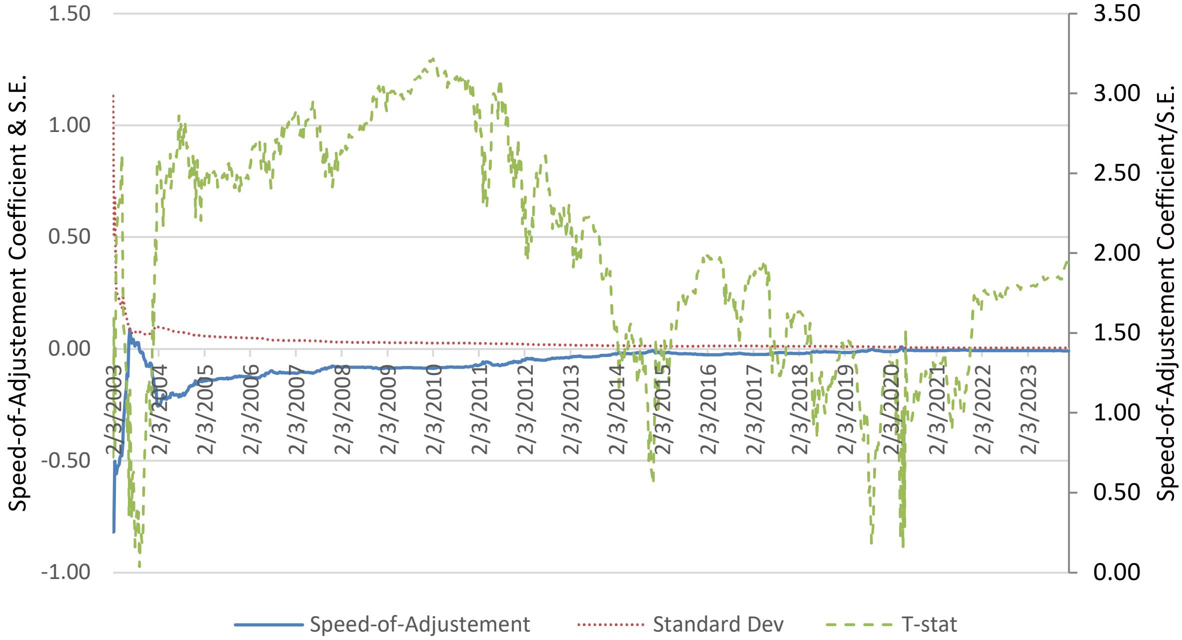


Figure 2. Time Varying Coefficient of Variation using a 24-Week Moving Average

Panel A
(Kansas Fed Cattle Price Adjustment to Boxed Beef Cutout Price)



Panel B
(Boxed Beef Cutout Price Adjustment to Kansas Fed Cattle Price)

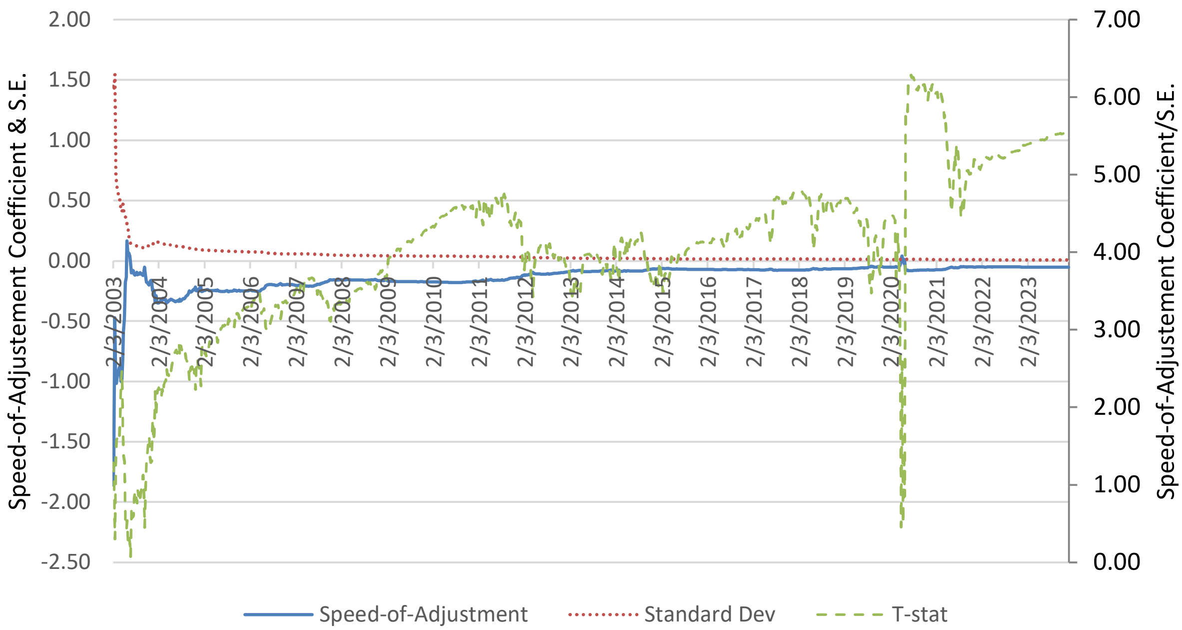


Figure 3. Time Varying Speed of Adjustment