Price Connectedness in U.S. Ethanol Terminal Markets

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Abstract

This article shows, for the first time, the degree of price volatility connectedness across the major regional ethanol markets in the U.S. Connectedness measures are based on forecast error variance decompositions that inform which prices drive system dynamics. We pay special attention to volatility spillovers to and from Chicago, as it is equipped with one of the largest terminals in the U.S. and is widely regarded as the center of ethanol price discovery in the country. Ethanol prices in the Chicago terminal electronic trading platform are also suspected of being manipulated over the 2017-2019 period. We use Diebold and Yilmaz (2012 and 2014) and a rolling window approach to study the dynamics of price volatility connectedness over time. Using daily data from 2013 to the beginning of 2021, we find that Chicago is the market that generates the most innovations to other market prices. In contrast, Chicago receives the least amount of innovations from all other markets, placing Chicago at the center of price dynamics. We find that price connectedness measures are driven by market fundamentals, policy, and concentration in the Chicago terminal electronic trading platform, with the latter increasing the relevance of Chicago as a central market.

Key Words: price connectedness, forecast error variance decomposition, ethanol, spot market, market fundamentals, trading platform concentration.

JEL Categories: Q02, Q11, C3
1. Introduction

During the last fifteen years the demand for ethanol has dramatically increased, driven primarily by policy. Starting in 2006, U.S. ethanol demand surged after several states banned the use of methyl tertiary-butyl ether (MTBE) as a gasoline oxygenate additive due to its impact on groundwater pollution (Anderson and Elzinga, 2014). This led to the replacement of MTBE by ethanol and a rapid growth in ethanol demand. The Renewable Fuel Standard (RFS) was first passed in 2005 and its expansion in 2007 (Cedeno, 2016; EPA, 2017) had an even larger impact. The RFS requires that transportation fuels sold in the U.S. contain a mandatory minimum volume of renewable fuels. Domestic ethanol production increased dramatically in parallel with the policy incentives, placing the U.S. at the forefront of worldwide production. The U.S. share in global ethanol production has fluctuated between 50-60% in the last ten years, doubling Brazil’s share (Energy Information Administration - EIA, 2020a). The fuel ethanol industry in the U.S. uses corn as the dominant feedstock (EIA, 2020b), with 35-40% of national corn production being refined into ethanol (Thiesse, 2020). This has created a strong link between the biofuel industry and agriculture.

The growth of the ethanol industry has motivated research that addresses a range of questions, from the impacts of regulations on ethanol and related industries to changing price relationships between ethanol and agricultural commodities (Mallory, Irwin, and Hayes, 2012; Serra and Zilberman, 2013; Carter, Rausser, and Smith, 2017; Moschini, Lapan, and Kim, 2017; Herwartz and Saucedo, 2021). Yet to date, we know very little about a fundamental issue—how price innovations are transmitted within the burgeoning U.S. ethanol market.
When a commodity is traded in multiple markets, efficient regional arbitrage and trade ensure these markets are integrated. Understanding the extent to which regional ethanol markets reflect relevant information is important to identify the most influential markets in the pricing process and assess the degree of market integration (Koontz, Garcia, and Hudson, 1990). We study how information is spread in the domestic U.S. ethanol market through price volatility connectedness between the main spot markets. These include the regions of the Midwest (Chicago), East Coast (New York, Tampa), West Coast (Los Angeles, San Francisco, Washington), Gulf Coast and Dallas. We quantify innovation spillovers among these spot markets and how their dynamics have changed over time. This information is critical not only to ethanol-related industries such as ethanol plants, oil refiners or corn producers, but also to policy markets and society at large. Its relevance is not limited to domestic markets, but also extends to international markets such as the Brazilian ethanol market with strong connections with the U.S. domestic market.

An extensive line of research on information spillovers has examined the interconnectedness between different regional commodity markets using either cash or futures prices (e.g., Serra, Gil and Goodwin, 2006; Stephens et al., 2012; Janzen and Adjemian, 2017; Tanaka and Guo, 2020; Xiao, Fang and Ding, 2020; Vo and Le, 2021). Methods include Vector Autoregressions (VAR), error correction models (ECM), multivariate generalized autoregressive conditional heteroskedastic models (MGARCH), or forecast error variance decomposition (FEVD). We use the measures proposed by Diebold and Yilmaz (2012 and 2014) based on the FEVD, which shed light on how price innovations are transmitted across different markets. This approach relies on directed volatility spillovers that allow an assessment of connectedness within a price system, either pairwise or at a more aggregate level, including system-wide. As opposed to other methods such as the most widely used price discovery measures that are non-unique and sensitive to the
ordering of the variables in the model (Hasbrouck, 1995; Putnins, 2013), connectedness methods are unique due to invariant FEVDs.

We choose Chicago as the central market in our analysis and explore its degree of leadership relative to each of the other markets. We focus on Chicago because it is equipped with one of the largest terminals in the U.S. and is widely regarded as the center of ethanol price discovery in the country. We support our decision through Granger-causality tests in the framework of a multivariate VAR. The results show that Chicago Granger-causes each of the other regional markets, but virtually none of them Granger-cause Chicago. Our interest in Chicago is also motivated by its role as a reference market in pricing ethanol derivatives. There have been recent allegations that prices at the eWindow trading platform in the Chicago terminal have been subject to manipulation by one of the major ethanol producing companies in the country, Archer Daniels Midland, ADM (Voegele, 2020). Effective manipulation can move the price away from the value implied by market fundamentals at the expense of other market participants, distort price discovery, and reduce market efficiency and welfare (e.g., Pirrong, 2017). Due to data limitations, our analysis does not delve directly into the manipulation question, yet we provide evidence of how information spillovers across markets behaved during the alleged manipulation period. Manipulation of a dominant as opposed to a satellite market may have far-reaching consequences, especially if this market leadership does not decrease during manipulation. This would signal that other markets in the country are possibly adopting an inefficient price.

We quantify the informational innovation spillovers transmitted by Chicago to the other regional markers to identify whether Chicago is a dominant market. For completeness, we also consider the spillovers received by Chicago from the other markets, as well as the overall degree of information spillovers in the U.S. ethanol spot markets. We take the latter as a measure of market
integration in the context of connectedness of conditional volatility. Using a rolling window approach, we investigate how these spillovers changed over time and how they evolved during the critical period. We then assess whether spillovers can be explained by the trading role of ADM in the Chicago terminal, but also by market fundamentals and ethanol policy changes, which helps identify the reasons underlying the information spillovers and sheds light on any possible price distortion.

Based on daily data from 2013 to the beginning of 2021, we find that Chicago is the market that contributes the most to price innovations in other markets. In contrast, Chicago receives the least amount of innovations from all other markets, placing Chicago at the center of the domestic ethanol price system dynamics. We then investigate the determinants of the informational innovation flows. We find several indicators of market fundamentals and policy to exert a statistically significant impact on Chicago’s leadership. More importantly, results suggest that during the alleged manipulation period, the dominance of Chicago within the domestic market increased, and market connectedness declined. While our results do not prove or disprove manipulation, they do suggest possibly pervasive effects of Chicago’s trading platform concentration that may require further investigation.

We contribute to the literature by providing, for the first time, empirical evidence on regional information flows across U.S. ethanol spot markets. Also, this is the first study that measures the role of concentration at a spot trading platform on these flows. Finally, this is the first article to derive connectedness measures in the ethanol spot market and explain their dynamics using policy, fundamentals and market concentration.

2. The U.S. Ethanol Market
In this section, we focus on two U.S. ethanol market characteristics that are key to understand information spillovers: the relevance of the Chicago terminal and the ethanol policies.

2.1. The Chicago Ethanol Market

Large amounts of ethanol are transacted daily in spot markets commonly located in the leading oil refining, barge and pipeline centers in the U.S. As discussed, we consider eight main U.S. spot ethanol markets located in the Midwest (Chicago), East Coast (New York, Tampa), West Coast (Los Angeles, San Francisco, Washington), Gulf Coast and Dallas.

As of 2020, the Midwest generated 92% of the ethanol produced in the country (EIA, 2020c). We thus consider the Chicago market as representative of ethanol supply areas. The remaining markets are considered representative of the largest ethanol demand markets, with San Francisco and Los Angeles representing top ports of entry for ethanol imports, and the Gulf, New York and Washington being top export hubs (RFA 2017, 2020). During the period studied, the U.S. exported on average 7.7% of its ethanol production, fluctuating from 4.6% in 2013 to 10.4% in 2018 (RFA, 2020). Global ethanol demand has been growing as several countries mandate a specific percentage of ethanol to be blended with gasoline. In general, upward-trending corn yields and relatively low corn prices have competitively positioned the U.S. in the worldwide ethanol market (USDA-FAS, 2019). On average, the U.S. represents half of the global ethanol trade, with Canada and Brazil being the top export destinations (RFA, 2020). Canada imports ethanol mainly through the Great Lakes as well as Seattle and Portland. Brazil imports through Gulf, which accounts on average for 74% of the total U.S. ethanol exports. The rest of the world (India, the European Union and South Korea) imports from any of these hubs as well as from the New York port (which accounts for 2-3% of exports) due to its closer proximity to Europe (RFA, 2018; 2019; 2020).
While being a net ethanol exporter, the U.S. imports ethanol almost exclusively from Brazil which represents 90-99% of overall U.S. imports (RFA, 2020). From 2013 to 2015, ethanol entered the country primarily through the West Coast (Los Angeles, San Francisco) but also through the East Coast (New York) in order to be able to satisfy increasing RFS blending targets during these years (RFA, 2015). Since then, California has dominated ethanol imports (with San Francisco representing 65% and Los Angeles 23% of total ethanol imports) despite the geographical disadvantage of shipping Brazilian ethanol to the West Coast relative to other U.S. ports of entry (RFA, 2019). The underlying reason is the California Low Carbon Fuel Standard (LCFS) and the lower carbon intensity of Brazilian ethanol relative to U.S. ethanol (EIA, 2013), making imports necessary to comply with environmental regulation. California is not only the first ethanol importer, but also the largest consumer of ethanol as it consumes one-ninth of the nation’s fuel ethanol supply due to its large population that uses ethanol through the transportation, commercial and industrial sectors (EIA, 2013).

Particularly relevant among the markets studied is the Chicago terminal, a multimodal facility that handles shipments by barge, rail or truck and is one of the largest storage facilities in the country, serving a wide range of ethanol purchasers such as middlemen, blenders and end users. Especially relevant to the Chicago terminal is its unique role in pricing in the U.S. ethanol derivative markets. The daily settlement price of the Chicago ethanol (Platts) futures contract, the most popular ethanol derivative in the U.S. in terms of trading volume, is based on the Chicago price assessments produced by Platts. The Platts Ethanol Price Assessment (PEPA) heavily relies on transaction prices registered at the Chicago Platts eWindow marketplace during the 30-minute trading window from 1:00 pm to 1:30 pm CT, which precedes the futures market close, known as the Market-on-Close ("MOC") window.
Platts eWindow is an electronic marketplace where bids, offers and transactions are published in real-time throughout the day until the market closes. This formal environment provides an opportunity for participants who seek to have their transparent bids/offers and trades used to form the final price assessment published by Platts. Based on the assumption that price discovery is a function of time, Platts considers that the data published in the MOC eWindow directly preceding the market close is of the highest quality for price assessment purposes. Transactions made outside the MOC eWindow are not considered in the price assessment. Apart from the MOC eWindow prices, the PEPA is also a function of information collected through a survey of market activity throughout the day and other data sources, including public news feeds and information provided by entities participating in the relevant markets (S&P Global Platts, 2017, 2021).

The PEPA system has recently been embroiled in controversy. AOT Holding AG and Green Plains Trade Group, both ethanol producers, recently sued one of their largest competitors, Acher Daniels Midland (ADM), for allegedly manipulating the PEPA (Class Action Complaint, 2019, 2020). According to the plaintiffs, starting in November 2017, ADM forced Chicago terminal ethanol prices artificially lower through a two-step manipulation scheme based on selling at artificially low prices in the terminal, with compensating losses through large short positions in the ethanol (Platts) futures contract (Renshaw and Hirtzer, 2020; Voegele, 2020).

We use nonpublic data from the Platts eWindow which contain, for every day, all ethanol transaction quantities occurring between 1:00 and 1:30 pm, their respective prices and the firms acting as counterparties. We use these data to compute the ADM market share as a seller for the sample period (from January 2, 2013 to February 4, 2021). While from 2013 to late 2017 ADM average seller share was 6%, large sales during the alleged manipulation period increased the average share to 70%, with relatively frequent peaks of 90% and 100% (Figure 1a). Afterward
ADM essentially stopped sales of ethanol through eWindow. Interestingly, from 2013 to the end of 2017, ADM was a net buyer of ethanol in Chicago but after that stopped buying through the eWindow (Figure 1b).

As trade is at the core of market connectedness, our analysis of regional volatility spillovers in the U.S. ethanol market relies on the MOC eWindow information. This allows us to assess to what extent ADM has driven the price signal during our sample period and how this changed during the alleged manipulation period. This does not allow us to prove or refute price manipulation, but it provides insights into significant changes that occurred during the period.

2.2. Ethanol Policies

During the last fifteen years the ethanol industry has significantly increased, driven mainly by policy changes. The 2005 RFS and its expansion in 2007 to RFS2 (Cedeno, 2016; EPA, 2017) stimulated demand and investment in ethanol plants by requiring that transportation fuels sold in the U.S. contain a specific minimum amount of renewable fuel. While biofuel blending mandates have become larger over time, the existing fleet of vehicles places a technical constraint on the amount of ethanol that can be safely blended into gasoline without damaging vehicle engines. This constraint is known as the blend wall and represents 10% of the motor fuel for a large proportion of the automobile fleet. The blend wall results in a kinked demand curve with infinite price elasticity before the blend wall is hit and zero price elasticity afterwards (Irwin and Good, 2015). From 2007 to 2010, the implied concentration of ethanol in gasoline (Radich and Hill, 2011) was significantly under 10% but reached values very close to 10% by mid-2011 as domestic ethanol production grew. Starting in 2013, the implied blend rate hit 10% and remained at this level through mid-2015, when the blend wall was breached (see Figure 2a). By driving ethanol demand and given the particular characteristics of this demand, U.S. ethanol policy may have a substantial
impact on price volatility spillovers. We capture the influence of policy through the costs of compliance described below.

To ensure compliance of the oil industry (refiners and importers) with the RFS blending mandates, the Renewable Identification Number (RIN) system was created. RINs are generated with each gallon of biofuel produced. When the biofuel is blended with petroleum fuel, the RIN is separated and the refiner can retire it with the Environmental Protection Agency (EPA) as proof of compliance, or trade it in a secondary market. The two most relevant RINs in terms of market value are the D6 and D4 RINs. D6 RINS can be exclusively used to prove compliance with conventional biofuel requirements. The vast majority of the conventional mandate has been met by corn ethanol, so D6 RINs are generally referred to as ethanol RINs. D4 RINs can be used to demonstrate compliance with both the biomass-based diesel and the conventional biofuel requirements. This nested RINs structure results in D4 prices providing a cap on D6 prices (Irwin, McCormack and Stock, 2020). Both prices are highly volatile and reflect the expected cost of compliance with the regulations. These are intrinsically related to the costs of producing the biofuels, but also expectations about the implementation of future RFS mandates.

The relative price of D6 (corn ethanol) over D4 (biodiesel) RINs, the \( \frac{D_6}{D_4} \) RIN price ratio (“RIN price ratio” henceforth), has been identified as a key forward-looking indicator of policy-driven increased demand for ethanol. This ratio should be bounded between 0 and 1. Whether the RIN price ratio is near the lower or upper bound depends on several factors. First, biodiesel is generally much more expensive than the petroleum diesel it replaces as a result of the RFS mandates. This means that biodiesel RIN prices are generally very expensive, typically in the range of $0.50 to $1.50 per gallon (Irwin, McCormack and Stock, 2020). Second, once ethanol plants were built, ethanol became a cost competitive component in the E10 gasoline blend (Irwin, 2018). This means
that when the RFS conventional mandate is below the E10 blend wall ethanol RIN prices are very cheap, often less than $0.10 per gallon. Third, when the RFS conventional mandate is above the E10 blend wall, this necessitates either the expansion of ethanol consumption in the form of higher ethanol gasoline blends, such as E15 and E85, or the use of higher nested D4 biodiesel RINs to fill in the gap above the E10 blend wall. To date, obligated parties have used D4 biodiesel RINs most heavily to fill the gap because biodiesel minimizes the cost of compliance, which in turn has profound implications for D6 ethanol RIN prices. Essentially, when the conventional RFS mandate is below the E10 blend wall the price of ethanol RINs is close to zero. However, when the RFS mandate is above the E10 blend wall, D4 RINs become the marginal gallon for filling the conventional mandate. As a result, the price of ethanol RINs rises dramatically to the level of the much more expensive D4 biodiesel RINs. This can create wild swings in the price of ethanol RINs as market expectations change regarding the likelihood of the conventional mandate being above or below the E10 blend wall (see Irwin and Good, 2015 and Taheripour et al., 2020 for further detail).

With this background, the demand implications of the RIN price ratio can be understood. Specifically, price ratios near zero indicate the market is expecting the conventional RFS mandate to be below the E10 blend wall and the policy pressure on ethanol demand to be lessened. The situation is reversed when the RIN price ratio is nearer to one, with expected policy pressure on ethanol demand to increase. This allows us to interpret the RIN price ratio as a forward-looking indicator of policy-induced pressure on domestic ethanol demand in the U.S. It also allows us to capture expected changes in the ethanol demand elasticity when the blend wall is reached. When the RIN price ratio is close to zero, the expected demand elasticity should be large. When the RIN price ratio is close to one, expected demand elasticity should be small. Daily observed values of
the RIN price ratio are presented in Figure 2b for our sample period and reveal that policy support was especially strong up to the end of 2015-16, with the remaining of the sample showing noticeably lower ratio values and larger fluctuations. The lower values and fluctuations reflect the intense political battle that erupted over setting the conventional RFS mandate above or below the E10 blend wall (e.g., Babcock, 2020). Our research considers the RIN price ratio as a possible driver of price volatility spillovers through the channel of ethanol demand.

3. Methods

In this section we describe the methods used to derive the connectedness measures among the daily ethanol prices observed across the U.S. from January 2, 2013 to February 4, 2021 and shed light on its determinants.

We assess the degree of connectedness among ethanol spot prices at different U.S. terminals based on the Diebold and Yilmaz (2012 and 2014) approach. Their method is based on the use of a VAR model representing an $N$-dimensional covariance-stationary data-generating process. Since innovations to the VAR drive the price system, they can be used to interpret the VAR model. These innovations are approximated through $H$-step forecast errors. Forecast error variance decompositions (FEVD) allow parsing each price forecast error variance into parts that are attributable to own shocks as well as shocks to other prices. This is important because it explains how relevant a shock to a particular price is in explaining the variance of the prices in the model, and how this relevance changes over time. Diebold and Yilmaz (2012 and 2014) use pairwise variance decompositions as a measure of pairwise directional connectedness. Total directional connectedness from other markets to market ‘$i$’ and from market ‘$i$’ to others are derived based on the sum of pertinent pairwise directional connectedness measures. A grand-total connectedness measure is finally calculated based on the sum of all possible pairwise measures.
To shed light on how connectedness changes over time, we take a rolling estimation window approach which makes our method more robust to structural breaks. We chose a fixed window size of 480 days to ensure that at least one of the rolling window subsamples in the analysis captures in its entirety the two-year period during which ADM actively sold in the Chicago terminal according to Platts MOC eWindow data (Figure 1a), starting late 2017 up to late 2019. The number of increments between successive rolling windows is one day such that the first rolling window contains observations from day 1 to day 480, the second rolling window encompasses observations from day 2 to 481 and so on. As a result, from our sample of 2,112 observations, we can build 1,632 subsamples of 480 observations for each pair of prices. For each window, we assess the time series properties of the data and derive the connectedness measures for those rolling windows with an $N$-dimensional covariance stationary data generating process.

Let $p_{it}, i = 1, \ldots, N$ represent the ethanol price in market $i$ (Chicago, New York, Tampa, Dallas, Gulf, Los Angeles, San Francisco or Washington) on day $t$. The $N$-dimensional VAR($L$) can be expressed as:

$$P_t = \sum_{l=1}^{L} \Phi_l P_{t-l} + \epsilon_t$$  

(1)

Where $L$ is the order of the VAR model, $P_t$ is the $N \times 1$ vector of prices, $\Phi$ are $N \times N$ coefficient matrices, and $\epsilon_t \sim (0, \Sigma)$ is i.i.d. with covariance matrix $\Sigma$. We work with prices in levels, as opposed to using price returns, since the eigenvalues of the VAR companion matrix are all inside the unit circle.\(^{1}\) The MA representation of the VAR($L$) is

\(^{1}\) We also checked for the presence of stochastic trends in our series using Dickey-Fuller tests and rejected the null hypothesis of a unit root for all price series. In the rolling window analysis, we check this condition for each subsample and set connectedness measures to missing values if the VAR model is not stationary. Less than 1.8\% of the subsamples are affected by this problem.
\[ P_t = \sum_{i=0}^{\infty} \psi_t \varepsilon_{t-i} \]  

with \( \psi_0 \) being the \( N \times N \) identity matrix and \( \psi_t = \sum_{i=1}^{L} \Phi_t \psi_{t-i} \).

The variance decompositions are based on the Koop, Pesaran and Potter (1996) and Pesaran and Shin (1998) generalized VAR framework which does not rely on shock orthogonalization. Instead, it produces order-invariant FEVD and accounts for correlated shocks across the VAR equations using the historical error distribution.

Let the \( H \)-step-ahead FEVD \( \theta_{ij}(H) \), \( i, j = 1, \ldots, N \) measure the contribution of innovations to variable ‘\( j \)’ on the \( H \)-step-ahead forecast error variance of variable ‘\( i \)’. \( \theta_{ij}(H) \) can be expressed as:

\[ \theta_{ij}(H) = \frac{\sigma_{jj}^{-1} \sum_{n=0}^{H-1} (e'_i \psi_n \varepsilon_j)^2}{\sum_{n=0}^{H-1} (e'_i \psi_n \varepsilon_j e_i)^2} \]  

(3)

where \( \sigma_{jj} \) is the standard deviation of the error term for the \( j \)th equation, with \( e_i \) being a selection vector whose \( i \)th element equals 1 and the rest equal zero. Since innovations are not orthogonalized, the sum of the contributions to variable \( i \)’s forecast error variance derived from shocks to each variable in the system, does not necessarily equal unity, i.e., \( \sum_{j=1}^{N} \theta_{ij}(H) \neq 1 \).

Diebold and Yilmaz (2012, 2014) normalize the different \( \theta_{ij}(H) \) measures using \( \sum_{j=1}^{N} \theta_{ij}(H) \), i.e.,

\[ \bar{\theta}_{ij}(H) = \frac{\theta_{ij}(H)}{\sum_{j=1}^{N} \theta_{ij}(H)} \]  

(4)

which results in \( \sum_{j=1}^{N} \bar{\theta}_{ij}(H) = 1 \). Notice that, by construction, \( \sum_{i,j=1}^{N} \bar{\theta}_{ij}(H) = N \). Connectedness measures are defined based on \( \bar{\theta}_{ij}(H) \).

Below we discuss the directional spillovers and total spillovers measures that we use to capture the degree of price connectedness among the U.S. ethanol terminals. Equation (5) shows the directional spillovers received by market ‘\( i \)’ from the rest of the markets ‘\( j \)’. We define ‘\( i \)’ as the Chicago terminal, which is central to our analysis for the reasons discussed above.
Similarly, the directional volatility spillovers transmitted by market ‘i’ to all other markets ‘j’ can be computed as

$$S_{ij}(H) = \frac{\sum_{j \neq i}^{N} \tilde{\theta}_{ij}(H)}{\sum_{j \neq i}^{N} \tilde{\theta}_{ij}(H)} \times 100 = \frac{\sum_{j \neq i}^{N} \tilde{\theta}_{ij}(H)}{N} \times 100$$  (5)

Finally, total spillovers across all markets are calculated as:

$$S(H) = \frac{\sum_{i,j=1}^{N} \tilde{\theta}_{ij}(H)}{N \times 100}$$  (7)

In a second step, we assess the drivers of the magnitude of the spillover measures $S_{ij}(H), S_{ji}(H)$ and $S(H)$ based on regression analysis:

$$y_w = x'_w \delta + e_l \text{ with } e_l \sim N(0, \sigma^2)$$  (8)

where $y_w$ is a measure of connectedness ($S_{ij}(H), S_{ji}(H), \text{or } S(H)$) derived from the rolling window $w$. The set of explanatory variables is $x'_w$, with $\delta$ measuring the linear dependence between $x'_w$ and $y_w$.

4. Data and results

This section presents the research results in three subsections, the first being devoted to the data, the second to connectedness measures and the third to their determinants.

4.1. Data

To quantify the innovation spillovers among the major U.S. ethanol markets and shed light on how their dynamics have changed over time, we use daily spot prices expressed in $/gallon for regional U.S. ethanol markets observed from January 2, 2013 to February 4, 2021. All prices are taken from the Oil Price Information Service (OPIS), except for the Chicago PEPA price described earlier which is obtained from S&P Global Platts. OPIS reports a daily range of high and low prices for
each terminal based on completed transactions. When there is no confirmed trade on a particular
day, OPIS uses a “highest bid/lowest offer” methodology based on the open deals posted that day
but not traded by the end of the day to assess the daily prices. For our analysis, we use the daily
midpoint as the average of the high and low price reported by OPIS.

4.2. Connectedness measures

As explained, we choose Chicago as the central market. We derive the directional spillovers
received by Chicago from the rest of the markets ($S_{ij}(H)$), those that Chicago transmits to all other
markets ($S_{ji}(H)$) and $S(H)$ the grand-total measure of spillovers, which provides a summary of
the overall degree of connectedness across the different domestic markets. Selection of Chicago
as the center is supported by Granger-causality tests in the framework of a multivariate VAR that
show that while Chicago Granger-causes each of the other regional markets, none of them
Granger-cause Chicago, except the Gulf price.2 Summary statistics for the eight ethanol price
series can be found in Table 1. While in the empirical analysis we use log prices to induce
normality and reduce heteroskedasticity (Bierlen, Wailes, and Cramer, 1998), prices in Table 1 are
in $/gallon to facilitate interpretation. Not surprisingly, prices in ethanol-producing regions are
lower than prices in consumption areas, with prices in Chicago averaging $1.64 per gallon and
being the least volatile of the group. Prices in top net ethanol consumption regions such as
California (Los Angeles and San Francisco), where the main import ports of entry are located, and
Florida (Tampa) are the highest in the country ($1.85 per gallon). Major export markets such as
the Gulf and New York have average ($1.73-$1.75 per gallon) prices in the range between the
highs for California and Florida and the lows in the Midwest.

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2 The Gulf price is only statistically significant if lags are chosen according to the SBC information criteria, but not
if AIC criteria is followed. To save space, Granger-causality tests are not presented but are available upon request.
Visual inspection of the price series (see Figure 3) suggests a strong co-movement over the whole sample period. In terms of ethanol price levels, the sample encompasses two different subperiods: 2013 and 2014 with relatively high average ethanol price levels on the order of $2.28 per gallon in Chicago, and the remaining sample period with reduced price levels of around $1.43 per gallon. The drop in prices was facilitated by historically large corn production in 2014-2018, leading to a sharp decline in corn prices and thus ethanol production costs. This resulted in increased ethanol consumption in many regions of the country (USDA-FAS, 2015). On average, prices in Chicago fluctuated around $1.43 per gallon for the remainder of the sample, except during the Covid-19 pandemic, which significantly reduced the demand and price for crude oil and gasoline and spilled over to ethanol (Irwin and Hubbs, 2020). This is reflected in the drastic drop in ethanol prices by March 2020. Prices rebound to previous levels afterward.

Table 2 presents the spillovers transmitted by Chicago to others, received by Chicago from others and total spillovers across all markets ($S_{ij}(H)$, $S_{ji}(H)$ and $S(H)$, with $i$ representing Chicago) for the whole sample for $H=10$. A 10-day forecast horizon is long enough to ensure that the price system fully absorbs informational shocks. This is investigated through impulse-response analysis of the underlying VAR model, which shows that usually less than 5 days are required for the price returns to be statistically significant. Figure 4 presents the evolution of the three connectedness measures in Table 2 over time. The vertical axis measures the magnitude of connectedness and the horizontal axis measures time. Given the rolling window nature of the analysis, the horizontal axis is labeled in intervals of two years since every dot represents a
spillover index produced based on price data collected during 480 days. Figure 5 shows that the spillover results are not sensitive to the VAR lag structure or to the choice of the forecast.\textsuperscript{4}

We now focus on interpretation of Table 2 results. Overall connectedness is 81.7%, which suggests that almost 82% of total forecast error variance in the price system comes from volatility spillovers. This contrasts with the 12.6% obtained by Diebold and Yilmaz (2012) when measuring spillovers between U.S. stock, bond, foreign exchange and commodity markets, but is much closer to the 78.3% reported in Diebold and Yilmaz (2014) for a sample of financial stocks. Notice that Chicago is the market that absorbs the smallest amount of directional spillovers from the rest of the markets (74.9%), and the one that transmits the largest spillovers to them (104.0%) (see table A1). This results in a positive net spillover \( S_{ij}(H) - S_{ji}(H) \) for Chicago of +29.1% (table 2). Pairwise, Chicago has positive net spillovers against each market. The net spillovers are relatively small with the Gulf of Mexico, Dallas, and New York terminals (between 1.83% and 3.65%), representing export markets. In contrast, the net spillovers of Chicago with the West Coast markets (LA, SF and WAS) are the largest (between 5.26% and 5.96%). This is consistent with the West coast importing ethanol for the California market, which is less connected to the rest of the country due to its regulatory framework (LCFS). As a result, price changes in the latter markets may be less useful to Chicago.

Turning to Figure 4, here we mainly focus on the discussion of spillovers transmitted by Chicago to the rest of the markets. We devote more attention to other spillover measures in the following subsection when assessing the drivers of connectedness. The relatively low spillovers (around 100%) during the 2014-2015 period coincided with the decrease in ethanol prices.

\textsuperscript{4} Regression estimates when forecast horizons are 5 and 15 are qualitative the same. Results are available from the authors upon request.
following historically large corn crops. Figure 3 shows that ethanol prices in 2014 declined from a historical peak above $4.00 per gallon to less than $1.50 per gallon. Relatively low spillovers to other markets are indicative of Chicago being slower at incorporating new information during sharp price declines. This is consistent with evidence that market power can lead to asymmetric price transmission patterns (Borenstein et al., 1997; Serra and Goodwin, 2003; Tapata, 2009). Notice that during this period, price innovations from other markets became more influential on Chicago (they increased from 70% to more than 75%). Hence, terminals demanding ethanol were somewhat faster at incorporating ethanol price declines. Low spillovers from Chicago to other markets at the beginning of the sample also coincide with relatively large transportation costs (represented by gasoline prices presented in Figure 6), which may have reduced market arbitrage activities across the U.S. geography.

Once ethanol and gasoline prices stabilize at a lower level, Chicago gains dominance resulting in relevant increases in the spillovers to other markets (on the order of +10 to +20%). The low spillovers during the first half of 2015 and subsequent recovery in the second half also resembles the RINS ratio pattern in 2015. During the first half of 2015, the RIN ratio dropped from 1.0 to 0.4 and recovered back to 1.0 in the second half of the year (see Figure 2b). Policy support for ethanol is likely to increase connectedness from producing areas to the rest of the country.

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5 We collected price data from 2010 for Chicago, Dallas and New York to investigate whether the low spillovers transmitted by Chicago to other markets in Figure 6 are indeed related to the large price declines resulting from the historically large corn crop in 2013-2014. We found Chicago’s spillovers to other markets before the price decline to be much larger, which seems to confirm our hypothesis. The lack of eWindows Platts data does not allow us to conduct our analysis for this extended period.
From 2017 to the end of our sample, the RIN ratio experiences large volatility. Within 2017 the ratio drops from highs above 0.8 to lows close to 0.4 and recovers back to initial levels in the second half of the year. From 2018 to the end of our sample, the RIN ratio has a clear ‘U’ shape. It experiences a sharp decline in 2018 from approximately 0.8 to 0.2, stays at relatively low levels between 0.2 and 0.4 in 2019, and recovers back to 0.8 or higher in the latter part of the sample. This pattern is imprinted, to some extent, in the Chicago spillovers to other markets. However, spillover declines both in 2017 and 2018 are relatively mild compared to the RIN ratio declines. This may be related to the role of ADM in the Chicago terminal during this period, characterized by relatively large market shares, first as a buyer and second as a seller. ADM held a relatively large buying market share in the eWindow (31% on average) from October 2016 to October 2017 (see Figure 1b). From the end of 2017 to the end of 2019 ADM increased its role as a seller in the Platts eWindow and concerns about manipulation grew. During this period, ADM drastically changed its trading pattern in the eWindow; the company ceased to be a buyer and became a large seller, with an average seller market share of about 70%, with relatively frequent peaks of 90% and 100% (see Figure 1a). By causing price volatility and diffusing it across the U.S. geography, concentration in the Chicago eWindow could have prevented spillovers from Chicago to other markets from falling as much as the RIN fell. This may have also diffused possibly inefficient prices across the U.S. geography.

Total volatility spillovers and spillovers received by Chicago from other markets have a relatively similar pattern, with the former being smoother than the latter. Both reach peaks at around 2015-16 and troughs in 2018-19, to then recover up until the end of the sample. Notice that spillovers received by Chicago from all other markets are always lower than spillovers transmitted by Chicago to others. Consistent with the RIN ratio being an indicator of policy-driven increased
demand for ethanol, spillovers from other markets to Chicago bear some resemblance with the RIN ratio. Also, these spillovers tend to increase during ethanol price decline periods, suggesting demand markets play an increased role in driving prices down. In the next section, we formally investigate the determinants of volatility spillovers through regression analysis.

4.3. Drivers of Connectedness

In this section, we assess the determinants of the volatility spillovers transmitted by Chicago to the other terminals, received by Chicago from the other terminals and the grand-total spillovers. We first discuss the explanatory variables that we include in the regressions. We consider the role of ADM as a trader in the MOC eWindow. Specifically, we calculate the firm’s market share both as a buyer and a seller by dividing the daily volume of ethanol bought and sold by ADM over the total daily volume of ethanol sold through the MOC eWindow. Through this variable, we investigate the degree to which possible price inefficiencies can be spread throughout the domestic market. As discussed earlier, we capture the impacts of policy on volatility spillovers through the RIN price ratio, an indicator of policy-driven increased demand for ethanol (Figure 2b). We expect policy support to increase spillovers overall, especially from demand to supply markets. We also examine the influence of a series of market fundamentals that may influence price volatility spillovers. An increase in ethanol production, which is essentially concentrated in the Midwest, may increase Chicago’s relevance as a driver of price changes in the price system, as it is the main market in the production region. This is especially true for our sample period, with an implied ethanol blend rate close to the 10% blend wall (Figure 2a). As discussed, this causes the domestic demand to be virtually vertical (zero price elasticity), which should increase the supply market’s ability to set prices. Increased domestic production and less reliance on international markets may also result in a higher degree of overall market integration. Ethanol imports in the U.S. essentially
come from Brazil (EIA, 2021) which produces sugarcane ethanol. The destination of these imports is the California market, that uses advanced biofuels to satisfy the state’s stricter environmental regulations. According to the California LCFS scoring system, Brazil’s sugarcane ethanol is considered an advanced biofuel relative to corn ethanol since it has a lower carbon intensity score. As a result, sugarcane ethanol displaces corn ethanol by increasing available domestic ethanol supply in the U.S. We thus consider ethanol imports as a possible determinant of the domestic ethanol price system dynamics, and we expect its impact to be positive (through increasing domestic ethanol supply). We also consider ethanol exports which may shift attention to foreign markets and reduce the role of Chicago in driving the price signal. We summarize the role of imports and exports by calculating net ethanol exports and use them as an explanatory variable in the regression analysis. We expect net ethanol exports to reduce overall spillovers. Corn and gasoline prices are both included in the regression as indicators of ethanol production costs and transportation costs, respectively, in the U.S. We expect gasoline prices to be negatively related to volatility spillovers since an increase in transportation costs may reduce arbitrage across markets. Consistent with the idea of a dominant market being more willing to increase than reduce prices, we further expect corn prices to be positively related to the spillovers transmitted by Chicago to the rest of the markets. Related to this, we include a dummy variable that covers the large drop in ethanol prices in 2014. The dummy equals 1 since the beginning of our sample of rolling windows (06/11/2014)\(^6\) up to the point in which ethanol prices reach a trough on 01/12/2015 and 0 otherwise. Finally, we consider the impact of the Covid-19 pandemic. We anticipate that the noticeable price pattern in 2020 may be connected to the pandemic, whose consequences hit the ethanol market. Consistent with previous research (i.e., Diebold and Yilmaz, 2012; Corbet et al.,

\(^6\) Recall that we lose the first years of data to the rolling window.
22

2020; Farid et al., 2021; Zhang and Hamori, 2021), we expect market spillovers during relevant crises to increase. Based on the visual inspection of the ethanol price series (see Figure 3) we create a dummy that takes the value of 1 over the period 02/06/2020<\textless t<04/07/2020 and zero otherwise.

Ethanol import and export data are available from the EIA monthly and expressed in thousand barrels per day. We assume imports and exports are evenly distributed across the days in each month to pair the trade data with the daily price. Midwest production data are available from EIA weekly and expressed in thousand barrels per day. We pair these data with daily data by setting production in each day within a week equal to the average EIA daily production data for that week. Daily ethanol and biodiesel RIN prices (D6 and D4, respectively) expressed in $/RIN are obtained from OPIS. Daily corn prices are obtained from USDA and expressed in $/bushel. Daily gasoline prices are available from OPIS and expressed in $/gallon.

To control possible endogeneity issues, all right-hand side variables are lagged one period except the dummy variables. Given the rolling window nature of the spillover measures, in the regression analysis we use the average value of the explanatory variables within each rolling window, which results in the explanatory variables being measured as moving averages. Finally, we deal with the possibility of heteroscedasticity and other misspecification issues by deriving robust standard errors (Newey and West, 1987). Table 3 presents both the regression parameter estimates and, to facilitate interpretation, the elasticities at the sample means.\footnote{We take the means over the whole sample period, after removing the observations lost to the rolling window.}

Parameter estimates representing ADM shares either as a seller and buyer suggest that market concentration increases the ability of the Chicago terminal to generate price changes in the other terminals, thus spreading possibly inefficient prices within the domestic market. Notice that responses to concentration in the Chicago eWindow trading platform are largely inelastic, with a
100% increase in ADM seller (buyer) share generating an increase in spillovers from Chicago to other markets on the order of 7.37% (4.11%). Hence, the influence of Chicago does not increase commensurate with the increase in the eWindow trading platform concentration. On top of this, notice that during periods when ADM dominates market purchases, Chicago absorbs less price information from other markets, with an elasticity of -2.15%. The sign of ADM market share as a seller in the same regression is also negative, though not statistically significant. Total spillovers decline with an increase in the eWindow trading platform concentration, with elasticities around -2.24% and -2.64%, which results in a lower degree of overall market integration.

The coefficient representing production is found to be positive and statistically significant in the spillovers to, spillovers from, and grand-total spillovers equations. As production increases, Chicago becomes more sensitive to price changes in the demand markets. Specifically, a 100% increase in production increases the price volatility spillovers received by Chicago from other markets by 183%. In contrast, the same increase in production only boosts Chicago’s spillovers to other markets by 73.98%. This results in a decline in the net spillovers from Chicago to others. As discussed, the implied ethanol blend rate stayed close to the 10% blend wall over the sample period. This means that the ability of Chicago to place additional ethanol in the domestic market was very low, which resulted in Chicago being more sensitive to price changes in the demand markets, including important ethanol export hubs. This is consistent with Chicago net spillovers reaching minimum values when paired with the Gulf of Mexico (table 2). It is also consistent with our Granger-causality tests that point to Gulf as the only market that can Granger-cause Chicago. Finally, total volatility spillovers also grow with production, with an elasticity of 154.93%, which is consistent with increased production reducing the demand for imports to meet the blend wall
and Chicago paying more attention to export market prices. This results in a higher degree of market integration.

As discussed, sugarcane ethanol imports displacing domestic corn ethanol result in an increase in available domestic supply, which may cause an increase in market spillovers transmitted by Chicago to others, received by Chicago from others and grand-total spillovers through the same mechanism as an increase in production. In line with the argument that exports force the domestic market to focus attention on export market prices to ensure their competitiveness, overall market integration should fall as exports increase. Consistent with these arguments, we find net exports to have a negative and statistically significant impact on overall market integration, with an elasticity of -37.57%, -19.71 and -18.03% for spillovers to, from and grand-total, respectively.

Larger values of the RIN ratio are indicative of expected policy-driven increased demand for ethanol that may shift the largely inelastic domestic demand for ethanol to the right and result in higher prices. Consistent with the RIN price ratio motivating shifts in the demand, the spillovers from other (demand) markets to Chicago show a statistically significant increase, with an elasticity of 7.83%. The RIN ratio, however, does not cause shifts in supply. This results in the RIN ratio being positive but not statistically significant in the spillovers from Chicago to others equation. The RIN ratio is not statistically significant either in the grand-total spillovers equation, thus suggesting that market intervention may not necessarily favor overall market integration.

Corn price is used as an indicator of ethanol production costs and is statistically significant in the to and from spillovers equation, with a positive and negative sign, respectively. This is consistent with the supply market transferring increased production costs to the other markets and absorbing less information from the demand markets in the process, with elasticities being 55.96% and -22.18%, respectively. We find corn prices to have no effect on overall market spillovers.
Gasoline prices are included as indicators of transportation costs which may reduce the degree of overall market integration by limiting regional arbitrage. Consistently, gasoline prices are negative and statistically significant, with elasticities -21.20% and -7.53% in the spillovers from and grand-total equations, respectively.

The covid-19 pandemic significantly reduced the demand and price for crude oil and gasoline and spilled over to ethanol (Irwin and Hubbs, 2020). This led to a drastic drop in ethanol prices in February-March 2020, followed by a subsequent recovery to pre-pandemic levels. Consistent with previous literature findings, during important economic shocks volatility spillovers across markets usually increase, which is confirmed by the positive and statistically significant parameters in the three equations. Finally, the dummy that captures the large drop in ethanol prices in 2014 is statistically significant in all regressions. The dummy suggests that spillovers from Chicago declined, while those to Chicago and the grand-total increased. This suggests that during price declines, the price system is more strongly driven by markets other than Chicago. In addition to the impacts of the corn price, this is another example of asymmetric price transmission where the dominant market, Chicago, is slow at incorporating price declines. Also, as usually happens during large price changes, the degree of market integration increases.

5. Conclusions

This article quantifies the connectedness between the domestic U.S. ethanol markets for the first time. Connectedness measures are based on forecast error variance decompositions that inform which prices drive market dynamics. We consider major ethanol markets in the country that cover the Midwest, where ethanol production is concentrated, and East, West and Gulf Coast markets. We pay special attention to spillovers to and from Chicago, as it is equipped with one of the largest terminals in the U.S. and is widely regarded as the center of ethanol price discovery in the country.
Ethanol prices in Chicago are also suspected of being manipulated over the 2017-2019 period. We use daily spot prices from January 2, 2013 to February 4, 2021. This sample covers a critical period during which Archer Daniels Midland (ADM) played an important role as a seller in the Chicago market, which led to accusations of price manipulation by other competitors. Our analysis does not allow us to prove or refute the existence of manipulation, but it does allow us to assess the implications of ADM activity for the price volatility spillovers across markets. Our sample also covers a period where ethanol demand was essentially vertical, with an implied ethanol blend rate close to the 10% blend wall.

We employ Diebold and Yilmaz’s (2012, 2014) connectedness measures and a rolling window approach that allows us to observe dynamics over time. We explain the drivers of connectedness using regression analysis. We find Chicago to be the market that receives the smallest directional spillovers (74.9%) from other markets and the one that transmits the largest spillovers to other markets (104.0%), which results in a positive net spillover ratio of +29.1%. This places Chicago at the center of the domestic price system dynamics. Chicago’s net pairwise connectedness measures are positive though relatively small when paired with export terminals and positive and relatively large when paired with West coast markets. The latter import ethanol for the California market, which is less integrated with the domestic market due to its regulatory framework. This results in Chicago absorbing less information from these markets.

From the regression analysis, we find that price volatility spillovers in the U.S. are strongly driven by market fundamentals, with domestic production increasing overall connectedness and having, by far, the largest impact. Other market fundamentals that prove to be relevant are production costs, transportation costs and net exports. Representing an ethanol supply market, Chicago transfers increased production costs to demand markets. Increased transportation costs
and net exports reduce overall domestic market connectedness. Demand-driven policy support is less relevant than fundamentals and increases the importance of demand markets within the price system dynamics. Concentration in the Chicago eWindow trading platform has the least relevance in terms of response elasticities. Nevertheless, increased concentration in the Chicago eWindow increases the spillovers from Chicago to other markets, which may result in inefficient prices spreading across the U.S. geography. Increased Chicago eWindow concentration also results in a decline in the overall degree of connectedness, which may indicate reduced market integration. While volatility spillover responses to trading platform concentration are inelastic and much smaller than responses to fundamentals, they have non-trivial effects on the domestic market.

Our results have implications for market participants and policy makers. The overall degree of market integration is relatively large, with total connectedness suggesting that almost 82% of price innovations come from volatility spillovers. This is suggestive of efficient regional arbitrage in a highly regulated market. Overall, Chicago is the market that drives most price changes in the system, especially price increases, which is informative for market participants and is consistent with Chicago being widely regarded as the center of domestic price discovery. While domestic ethanol price system dynamics are mainly driven by market fundamentals, they are also responsive to the trading platform concentration in Chicago. While our research does not allow us to prove or refute price manipulation by ADM over the 2017-2019 period, it sheds light on the non-trivial effects that concentration may have for the domestic market. For policy makers, the fact that increased concentration in the Chicago eWindow results in larger spillovers from Chicago to other markets may deserve further investigation.

Acknowledgements
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exemptions-and-ethanol-demand-destruction.html.


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Tables and Figures

Table 1. Statistics for Ethanol Price Series ($/gallon) (2013:01:02 to 2021:02:04)

<table>
<thead>
<tr>
<th>Series</th>
<th>Observations</th>
<th>Mean</th>
<th>Std Error</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHI</td>
<td>2112</td>
<td>1.64</td>
<td>0.42</td>
<td>0.81</td>
<td>3.76</td>
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<tr>
<td>DAL</td>
<td>2112</td>
<td>1.73</td>
<td>0.46</td>
<td>0.91</td>
<td>3.97</td>
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<tr>
<td>GUL</td>
<td>2112</td>
<td>1.73</td>
<td>0.44</td>
<td>0.90</td>
<td>3.96</td>
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<tr>
<td>LA</td>
<td>2112</td>
<td>1.85</td>
<td>0.46</td>
<td>0.93</td>
<td>4.04</td>
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<td>NY</td>
<td>2112</td>
<td>1.75</td>
<td>0.46</td>
<td>0.87</td>
<td>4.17</td>
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<tr>
<td>SF</td>
<td>2112</td>
<td>1.85</td>
<td>0.46</td>
<td>0.93</td>
<td>4.04</td>
</tr>
<tr>
<td>TAM</td>
<td>2112</td>
<td>1.85</td>
<td>0.46</td>
<td>0.98</td>
<td>4.07</td>
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<tr>
<td>WAS</td>
<td>2112</td>
<td>1.80</td>
<td>0.46</td>
<td>0.95</td>
<td>4.04</td>
</tr>
</tbody>
</table>

Note: the table summarizes log daily ethanol prices in $/gallon. The markets considered are Chicago (CHI), Dallas (DAL), Gulf (GUL), Los Angeles (LA), New York (NY), San Francisco (SF), Tampa (TAM) and WAS (Washington).
Table 2. Connectedness measures for the sample period

<table>
<thead>
<tr>
<th></th>
<th>$S_{ij}(H)$ Transmitted by Chicago to others</th>
<th>$S_{ij}(H)$ Received by Chicago From others</th>
<th>$S_{ij}(H) - S_{ij}(H)$ Net spillovers</th>
<th>$S(H)$ Total spillovers</th>
</tr>
</thead>
<tbody>
<tr>
<td>DAL</td>
<td>14.78</td>
<td>12.95</td>
<td>1.83</td>
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<tr>
<td>GUL</td>
<td>18.53</td>
<td>15.58</td>
<td>2.95</td>
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<tr>
<td>LA</td>
<td>12.70</td>
<td>7.44</td>
<td>5.26</td>
<td></td>
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<tr>
<td>NY</td>
<td>17.46</td>
<td>13.81</td>
<td>3.65</td>
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</tr>
<tr>
<td>SF</td>
<td>12.63</td>
<td>7.18</td>
<td>5.45</td>
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<tr>
<td>TAM</td>
<td>14.24</td>
<td>10.25</td>
<td>3.99</td>
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<tr>
<td>WAS</td>
<td>13.63</td>
<td>7.67</td>
<td>5.96</td>
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</tr>
<tr>
<td>Overall</td>
<td>104.0</td>
<td>74.9</td>
<td>29.1</td>
<td>81.7</td>
</tr>
</tbody>
</table>

Note: The table presents the connectedness measures, with the second third, fourth and fifth columns measuring the directional spillovers from Chicago to all other markets, from all other markets to Chicago, net volatility spillovers for Chicago and total volatility spillovers across all markets. The other markets are Dallas (DAL), Gulf (GUL), Los Angeles (LA), New York (NY), San Francisco (SF), Tampa (TAM) and WAS (Washington).
Table 3. Regression analysis explaining connectedness measures

<table>
<thead>
<tr>
<th></th>
<th>Spillovers transmitted by Chicago to others</th>
<th>Elasticity</th>
<th>Spillovers received by Chicago from others</th>
<th>Elasticity</th>
<th>Total spillovers</th>
<th>Elasticity</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADM Seller share</td>
<td>Parameter Estimates: 29.425***</td>
<td>7.374</td>
<td>Parameter Estimates: 0.646</td>
<td>-0.293</td>
<td>Parameter Estimates: -5.304***</td>
<td>-2.240</td>
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<tr>
<td></td>
<td>(8.629)</td>
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<td>(2.345)</td>
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<td>(1.854)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(17.636)</td>
<td></td>
<td>(4.237)</td>
<td></td>
<td>(3.196)</td>
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<tr>
<td></td>
<td>(0.094)</td>
<td></td>
<td>(0.021)</td>
<td></td>
<td>(0.016)</td>
<td></td>
</tr>
<tr>
<td>Production of ethanol</td>
<td>Parameter Estimates: 0.079***</td>
<td>73.980</td>
<td>Parameter Estimates: 0.108***</td>
<td>183.000</td>
<td>Parameter Estimates: 0.098***</td>
<td>154.928</td>
</tr>
<tr>
<td></td>
<td>(0.022)</td>
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<td>(0.005)</td>
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<tr>
<td></td>
<td>(9.843)</td>
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<td>(2.563)</td>
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<td>Observations</td>
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<td>1600</td>
<td>1600</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>$Corr(y,\hat{y})^2$</td>
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<td>0.889</td>
<td>0.815</td>
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</table>

Note: The table presents the results of regressing the time-varying connectedness measures on a rolling window approach (each window has a size of 480 days) and the within-window average of the lagged explanatory variables. Newey-West standard errors are reported in parenthesis. We force the regression to run through
the origin, as volatility spillovers will not exist if all the explanatory variables are zero. We consider three connectedness measures: total connectedness across all markets and spillovers transmitted (received) by Chicago to (from) all other markets. ADM Seller (Buyer) share is computed based on the daily seller (buyer) share of Archer Daniels Midland (ADM) in the Chicago Platts eWindow market and expressed in proportion. Net ethanol exports are expressed in thousand barrels per day and assumed constant within each month. Ethanol production is expressed in thousand barrels per day and assumed constant within each week. The RIN ratio is the daily $\frac{D_6}{D_4}$ RIN price ratio. Corn and gasoline prices are daily corn and gasoline prices in $/bushel and $/gallon, respectively. The covid-19 dummy corresponds to the period 2020:02:06<t<2020:06:12. The High prices period is a dummy variable that takes the value of one in the early high price-level period (06/11/2014) up to 01/12/2015 when ethanol prices bottomed. Standard errors are in parentheses. $Corr(y, \hat{y})^2$ measures the squared correlation between the dependent and fitted variable. Statistical significance is denoted as *** p<0.01, ** p<0.05, * p<0.1.
Figure 1. ADM daily market share from January 2, 2013 to February 4, 2021

**Figure 1a. ADM daily share as a seller**

**Figure 1b. ADM daily share as a buyer**

Note: Figures 1a and 1b show the ADM daily share as a seller and buyer respectively. The shares are calculated by deriving the daily ratio of ADM sales (purchases) over total daily sales (purchases). Data are derived from Platts MOC eWindow. From 2013:01:02 to 2017:11:08 (2017:11:10 to 2019:12:13) ADM average seller market share is 6% (70%) (figure 1a). From 2013:01:02 to 2017:11:08 (2017:11:10 to 2019:12:13) ADM average buyer market share is 20% (0%) (figure 1b).
Figure 2. The implied blend rate and the D6/D4 RINs ratio from Jan. 2, 2013 to Feb. 4, 2021

**Figure 2a. Implied blend rate**

Note: The plot presents the implied concentration of ethanol in gasoline based on Radich and Hill (2011) for the sample period, based on EPA data. The flat line represents the 10% blend wall.

**Figure 2b. D6/D4 RINs ratio**

Note: The plot presents the $\frac{D_6}{D_4}$ RIN price ratio based on data from OPIS.
Figure 3. Ethanol price series from January 2, 2013 to February 4, 2021

Note: The plot is based on are daily spot prices expressed in $/gallon for the regional U.S. ethanol markets observed from January 2, 2013 to February 4, 2021. All prices are taken from the Oil Price Information Service (OPIS), except for the Chicago (PEPA) price which is obtained from S&P Global Platts. The markets considered are Chicago (CHI), Dallas (DAL), Gulf (GUL), Los Angeles (LA), New York (NY), San Francisco (SF), Tampa (TAM) and WAS (Washington).
Figure 4. Dynamic spillovers

4.a Directional Volatility Spillovers, Transmitted by Chicago to all other markets

4.b Directional Volatility Spillovers, Received by Chicago from all other Markets

4.c Total Volatility Spillovers

Note: Given the rolling window nature of the analysis, the horizontal axis is labeled in intervals of two years since every dot represents a price discovery share produced based on price data collected during 480 days.
Figure 5. Sensitivity of the DY Spillover index to Model Specifications

Figure 5a. Sensitivity of the index to VAR lag structure

Note: In both panels (a and b) the black solid line indicates the median values while the gray overlay depicts the range of minimum and maximum values. Panel a presents estimates from VAR models with lag orders 1 to 6 (at the 10-days forecast horizon). Panel b presents estimates from a VAR(2) model with a forecast horizon that varies from 5 to 15 days.
Figure 6. Chicago ethanol, corn and Chicago RBOB prices

Note: The plot is based on daily Chicago ethanol spot prices (CHI) expressed in $/gallon, corn prices (CORN) in $/bushel and Chicago RBOB (CHI_RBOB_UNL) prices in $/gallon observed from January 2, 2013 to February 4, 2021.
### APPENDIX

#### Table A1. Volatility spillover table

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<th>CHI</th>
<th>DAL</th>
<th>GUL</th>
<th>LA</th>
<th>NY</th>
<th>SF</th>
<th>TAM</th>
<th>WAS</th>
<th>From others</th>
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</tr>
<tr>
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<td>23.39</td>
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<tr>
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</tr>
</tbody>
</table>

**including own**

The markets considered are Chicago (CHI), Dallas (DAL), Gulf (GUL), Los Angeles (LA), New York (NY), San Francisco (SF), Tampa (TAM) and WAS (Washington).