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“Who pays the piper calls the tune” – Networks and transaction costs in commodity markets

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Abstract

A new dataset of weekly wheat prices during the 1898 - 1914 is generated. Using variance decompositions from vector autoregressive (VAR) models, a network of 9 wheat markets during the sample period is constructed and information spillovers between these markets are analyzed. Our results indicate that transaction costs are a significant determinant of the relative importance of market places in the continental European wheat trade.

Keywords: Early commodity futures markets, Information transmission, Connectedness, Network analysis

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1 Introduction

Almost instantaneous transmission of information is a fundamental property of modern commodity markets. The spread of information technologies during the last decades has facilitated information transmission and price discovery in modern commodity markets and has enabled the use of new forms of commodity trading.[1] In contrast, traders in early stock and commodity markets operated under significantly different conditions. This is certainly the case for the European grain markets of the late 19th and early 20th centuries. Before the establishment of reliable telegraph connections, traders who relied on supply and demand information from across the globe, had to base their decisions on possibly outdated information. In the case of the transatlantic grain trade, this implied an average information lag of up to two weeks. Even after the introduction of reliable telegraph and later on telephone networks, the majority of traders relied on information published by the press due to high information gathering costs (Ejrnaes and Persson, 2010). Although extensive research has been carried out on commodity market integration, little is known about the transmission of information between markets and its not clear what factors determine the presence of information spillovers.[2]

Hence, there is an important opportunity to advance our knowledge of trading in absence of modern technical means of information diffusion and the outcome is relevant for policy makers and regulators. Commodity markets at the beginning of the 20th century provide an ideal reference point: Key institutional settings and financial instruments are well estab-

[1] Traditionally, the economic literature has subscribed to the belief that computer based trading enhances liquidity and facilitates the transmission of information (e.g. Pirrong, 1996; Hendershott et al., 2011; Chaboud et al., 2014; Frino et al., 2014). Along with the growth in computer based trading and the abolition of open-out-cry auctions in favor of computer based trading systems on major exchanges, there is increasing concern over adverse effects on the functionality of markets (e.g. Kirilenko et al., 2017).

[2] A considerable amount of literature has been published on the integration of early commodity markets (e.g. Metzer, 1974; Garbade and Silber, 1978; Goodwin and Grennes, 1998; Persson, 1999; Ejrnaes and Persson, 2000; Jacks, 2004; Ejrnaes and Persson, 2010; Jacks et al., 2011; Uebele, 2011; Volosovych, 2011; Federico, 2012; Dobado-González et al., 2012; Chilosi et al., 2013; Sharp and Weisdorf, 2013; Brunt and Cannon, 2014; Engel, 2015), providing strong evidence for market integration. Research on the subject has been mostly restricted to limited investigations of the law of one price or the adjustment of short run deviations from the equilibrium between city pairs (Brunt and Cannon, 2014).

lished. The foundations of today's means of production are consolidated while long-distance communications was only slowly gathering pace (Persson and Sharp, 2015).

The main purpose of our analysis is to develop an understanding of information transmission[3] in absence of the latest trading technologies. Additionally, by examining the European grain market in the period from January 1898 to July 1914, information transmission in markets that range from the highly protectionist markets (e.g. Austria-Hungary, Germany and France) to liberal markets (e.g. Netherlands and Belgium) is considered. Since tariffs and trade restrictions could hamper the possibility of arbitrage by raising transaction costs, they may affect the transmission of information between markets as well. Given that established rules on international trade are currently under pressure, analyzing information transmission within a system of disparate protectionist and liberal trade regimes may provide useful lessons for policy makers and traders.

In contrast to previous studies, we utilize spillover measures widely applied in the literature on risk transmission (e.g. Alter and Beyer, 2014; Maghyereh et al., 2016; Kang et al., 2017; Demirer et al., 2018) to investigate information flows between commodity markets. As proposed by Diebold and Yilmaz (2012, 2014), generalized forecast error variance decompositions (GFEVD) are used to measure information spillovers. Traditional methods either examine individual market pairs, which neglects the multilateral dimension of information transmission across several markets, or provide aggregated measures (for example based on dynamic factor models), which do not allows making inferences about the contribution of market i to the information present in market j. In contrast, the GFEVD enables the analysis of information flows in a multilateral framework without neglecting the relative contribution of an individual market to the price discovery in an alternative market or to the overall network. Additionally, this method recognizes the endogeneity of the variables and exploits cross-sectional variation. To examine the effect of transaction costs on information transmission, we calculate the Fong et al. (2017) transaction cost measure for all markets

[3] In this paper, we use the terms information transmission, information spillover and conectedness interchangeably.

under scrutiny.

Our study makes contributions to the existing literature on commodity markets in several ways. First, by identifying important markets which contribute significantly to the global price discovery process. Second, by analyzing observed information flows from a network perspective. Third, by introducing a new consistent dataset of weekly wheat prices for 13 markets located in Europe and North America covering the period from 1898 to July 1914. Finally, we examine transaction costs in the markets under scrutiny and analyze their effect on information transmission via regression analysis.

The remainder of the paper is structured as follows: Section 2 briefly introduces the markets under scrutiny. The introduction of the data and the description of the data collection process take place in Section 3. In Section 4, the methodology is presented. Thereafter, the results are discussed. Transaction costs as determinants of information spillovers are analyzed in Section 6. Finally, Section 7 provides concluding remarks.

2 Markets

Knowledge of the markets under scrutiny is crucial to understanding information transmission between markets and the resulting information flow network.

Tsarists Russia, despite competition from the United States, Canada, Argentina, Australia and India, was the world largest exporter of wheat at the onset of the First World War. The legal abolition of serfdom with the Act of Emancipation in 1861 and the growth in railroad connections lead Russia to outpace the United States in the share of exports of wheat and other grains (Falkus, 1966; Goodwin and Grennes, 1998). We incorporate two markets located in the Russian empire into our analysis, which are identified as major trading hubs for Russian wheat: Odessa, founded in 1794 by Catharine the Great, and Riga, which became part of the Russian Empire in 1721. The interaction of two factors, the presence of a deep-sea harbor and the proximity to the producing areas in Ukraine, determined the importance of Odessa as a wheat trading hub (Herlihy, 1979). In contrast, shifts in demand from other grains towards wheat, the spread of railroad connections and an pronounced growth in production of wheat in the Black Sea region, reduced the importance of the Baltic region as the breadbasket of Europe and of the Baltic grain trade in general (Falkus, 1966; Goodwin and Grennes, 1998; Andersson and Ljungberg, 2015). Despite its reduced importance during the 20th century in relation to markets as Odessa, Riga remained an important export hub for Russian grains.

The Austrian-Hungarian Empire, initiated with the Austrian-Hungarian Compromise of 1867, was a monetary and customs union ruled by the House of Habsburg. As stated by contemporary authors, under normal conditions sufficient grain for consumption was produced within the borders of the dual monarchy. However, grain was mainly supplied by the Hungarian part of the dual monarchy while the industrial and commercial hubs were predominantly located in Austria (e.g. USDA, 1897; Falkus, 1966). Our database covers the markets in Vienna and Budapest. Therefore, the main market of the net-importing and the surplus regions are incorporated.

The first documentary reference to Antwerp dates back to 726 after which the town evolved gradually as one of the European major trading hubs. The closure of the river Scheldt in 1585, which connects Antwerp with the North Sea, diminished the importance of the port of Antwerp and it was not until 1863 that the unrestricted use of the river was restored. Despite physical trading flows hampered by restrictions and tolls imposed on the usage of the river Scheldt until 1863, Antwerp was a focal point in the international grain trade. Beside its importance as a deep-sea harbor and grain depot, merchants in Antwerp where among the first to use standardized contracts in commodity trading beginning in the 16th century (Poitras, 2009; Popescu, 2014).

Amsterdam evolved as major financial and trading hub throughout the 15th and 16th century. Already an important trading hub prior to 1585, the Spanish occupation of Antwerp and the eviction of its protestant merchants contributed to the rise of Amsterdam as a financial center and focal point of the central European grain trade (Gelderblom and Jonker, 2005; Poitras, 2009). Competition from markets in Great Britain and corresponding shifts in transport routes decreased the importance of markets in the Lower Countries within the Baltic grain trade. Keeping in mind that the role of the Baltic region as a breadbasket of Europe was generally reduced through the establishment of new production areas, for example, in the United States or the Black Sea region. Amsterdam and Antwerp remained focal points of the European grain trade as entry points for wheat originating in the Black Sea region and across the Atlantic (Falkus, 1966; Andersson and Ljungberg, 2015; Popescu, 2014). Remarkably, after the protectionist backlash caused by the so called European grain invasion (O'Rourke, 1997), the Low Countries pursued a liberal trade policy even if Europe at this time is in general referred to as "an ocean of protectionism surrounding a few liberal islands" (Bairoch, 1995, p. 28).

The Cobden-Chevalier treaty of 1860 between France and Great Britain triggered shifts towards free trade across Europe. However, tariffs raised in response to increasing inflows of cheap grain from the United States and the Russian Empire at the end of the century caused a significant reduction in French wheat imports. In this connection, with domestic supply sufficient to meet demand under normal conditions and the possibility of imports from overseas territories, France became nearly independent from international markets (Falkus, 1966). Dating back at least to the 1760s, the commodity exchange in Paris forms a focal point for the wheat trade in France, which price quotations were frequently reported in the international press (e.g., the *Berliner Börsen Zeitung*, a daily newspaper focusing on business news).

The German Empire, founded in the wake of the German-French War of 1870/71, was a major importer of grain in central Europe. During the 1870s, Germany undertook a change from wheat exporter to a major importer. This development is highlighted by the fact that during the period from 1886 to 1890 around 87% of domestic demand could be satisfied by domestic supply. This ratio decreased to approximately 64% in the 1901 to 1905 period (Falkus, 1966; Popescu, 2014). Therefore, even with significant tariffs imposed on grain imports as a response to low cost imports especially from Russia and the United States, the German Empire was a significant source of demand from international wheat markets.

Contemporary authors state the importance of the Berlin Produce Exchange as a benchmark market of the German Empire (e.g. Schliep, 1912; Pinner, 1914; Jöhlinger, 1925). Additionally, as stated by Hirschstein (1931), Berlin and Breslau are two of three exchanges within the German Empire which dealt in on time transactions in grain. It it worth highlighting, that, with the German Exchange Act of 1892, trading in futures in grain and mill products was forbidden within the German Empire.

The coming into force of the law in 1897 was accompanied by the suspension of the Berlin Produce Exchange from 1897 to 1900 (Hooker, 1901; Jacks, 2007). This ban was reaffirmed in the revision of the German Exchange Act in 1908. However, the ban was restricted to exchange trading and futures trading continued in a smaller scale at the Over-the-Counter market. Additionally, alternatives to futures contracts which where in compliance with the legal requirements and named “contracts for future delivery” were created and traded. Another requirement of the Exchange Act of 1896 was that no price quotations could be published by exchanges. Price quotations after 1896 were published by the Central Quotation Office of the Prussian Chambers of Agricultural and constructed based on transactions of the respective spot market. With the reopening of the Berlin Produce Exchange in March 1900, actual exchange based price quotations resumed and are available beginning 1st April 1900 (Hooker, 1901).

A great number of factors determine the flow of information between markets and the following overview highlights those that aid in determining the relative importance of each market in the overall information network.

Our analysis covers four markets with direct access to a sea port (Amsterdam, Antwerp, Odessa, Riga), five markets are located in polities with protectionist tariffs on agricultural products (Berlin, Breslau, Vienna and Budapest), three markets are located in countries which are, under normal conditions, nearly self-sufficient (Paris, Vieanna and Budapest), while four markets are net-importers, either for consumption or commercial purposes (Antwerp, Amsterdam, Berlin, Breslau). Furthermore, a commodity exchange was established in all markets and a rail connection could be found between each market under scrutiny throughout the investigation period.

We now proceed to discuss the construction of the new database followed by the methodology used to investigate network spillovers in the markets considered.

3 Data

In order to investigate information spillovers and transaction costs in early commodity markets, we utilize weekly wheat spot prices for 13 markets located in Europe and North America. The data are obtained from the *Vierteljahreshefte zur Statistik des Deutschen Reiches* (Quarterly Journal of the Statistics of the German Empire). The markets covered in our analysis are located in Antwerpen, Amsterdam, Breslau, Vienna, Budapest, Odessa, Riga, Berlin and Paris. Additionally, we include the markets in London, Liverpool, Chicago and New York as exogenous variables in the VAR model. In this way, we also account for price movements and volatility in important global trading hubs. The sample starts in January 1898 and ends in the run-up to World War I in June 1914. The underlying prices are quoted in Reichsmark per 1000 kilogram and defined as weekly averages of price quotations on German and foreign exchanges for the respective year.

The majority of relevant studies use data at a comparably low sampling frequency (predominately, monthly data). Even in the absence of modern trading institutions and information technologies, efficient markets incorporate new information with considerable speed. In monthly data, it is most likely that shocks (e.g., a weather shock in one market) are already incorporated into prices. Therefore, the high frequency data utilized in the present study represents a major advantage. To our knowledge there is no other database for commodity prices at the weekly frequency which covers a comparably broad spectrum of markets.

On average approximately 28.5 (ca. 3%) observations in the examined price series are missing, with significant differences between markets. The number of missing values is most pronounced for Amsterdam and Liverpool with 143 (ca. 16%) and 100 (ca. 12%), respectively, missing observations. To extend the coverage of the utilized dataset, missing values are imputed using Kalman smoothing based on the state space representation of an ARIMA model see Table 1.

Subsequently, logarithmic price differences, defined as $\Delta P_{i,t} = log(P_{i,t}) - log(P_{i,t-1})$, are calculated. Table 1 displays descriptive statistics of the original price series as well as for the imputed return series.

[Table 1 about here]

The stationarity of the time-series is tested by applying the augmented Dickey and Fuller (1981)(ADF) and the Kwiatkowski et al. (1992)(KPSS) unit-root tests. Table 2 displays the unit-root test results for each market. From Table 2 it becomes obvious that the price series under scrutiny are non-stationary in levels. Stationarity is achieved by calculating log-differences for each series.

[Table 2 about here]

Transaction costs are calculated in accordance with Equation 4 using rolling sample windows of 5, 8 and 10 years (using 260, 416 and 520 observations, respectively). Table 3 displays descriptive statistics of the calculated transaction cost time-series depending on the underlying window size.

[Table 3 about here]

Table 3 is quite revealing in several ways. First, it becomes apparent that average transaction costs are comparable across window sizes. Second, transaction costs seem to vary across markets even if markets are part of the same polity. Third, whether a market is classified as protectionist or not seems not to affect transaction costs in an systematic way.

Before proceeding to examine the relationship between information spillovers and transaction costs, it is important to provide general insights into the transmission of information between early commodity markets and the underlying information network. We turn to this issue next.

4 Methodology

To investigate information spillovers in early commodity markets, we follow Diebold and Yilmaz (2012, 2014). The authors assume that markets are highly connected if a large proportion of the variance in the forecast errors in variable i can be explained by shocks originating from other variables in the system. This concept of connectedness is translated by the authors into an econometric procedure by using generalized forecast error variance decompositions (GFEVD) (Diebold and Yilmaz, 2014).

Our analysis is based on the following covariance stationary VARX(p,q) model:

$$Y_t = \sum_{p=1}^{P} A_n Y_{t-n} + \sum_{q=0}^{Q} B_{i,n} X_{i,t-n}. \tag{1}$$

$Y_t = (y_{1t}, y_{2t}, \cdots, y_{nt})'$ denotes a vector of time-series variables, with dimension $n \times 1$. The corresponding $n \times n$ coefficient matrix is denoted by A. Even though, the present analysis focuses on information spillovers between continental European markets, contemporary authors nevertheless state that markets located in Great Britain and North America are of great importance for the determination of prices in Europe. Therefore, we include important markets located in Great Britain and North America as exogenous variables into the model, which are denoted by $X_{i,t}$ and the corresponding coefficient matrices by B_i. In line with Diebold and Yilmaz (2012, 2014), the generalized impulse-response framework proposed by

Koop et al. (1996) and Pesaran and Shin (1998) is used. The entries of the h-step GFEVD matrix are defined as $\varphi_{i,j}$, which are normalized by using the sum of all entries in row i:

$$\phi_{i,j} = \frac{\varphi_{i,j}}{\sum_{j=1}^{n} \varphi_{i,j}} \ , \tag{2}$$

with $\phi_{i,j} \in \{0, 1\}$. The entries of the normalized h-step GFEVD matrix can be interpreted as the share of the forecast error of variable Y_i that can be explained through shocks arising in all other variables. The resulting $n \times n$ normalized variance decomposition matrix D has the following form:

$$D = \begin{bmatrix} \phi_{11} & \phi_{12} & \cdots & \phi_{1n} \\ \phi_{21} & \phi_{22} & \cdots & \phi_{2n} \\ \vdots & \ddots & \vdots & \\ \phi_{n1} & \phi_{n2} & \cdots & \phi_{nn} \end{bmatrix} \tag{3}$$

and contains all information necessary to calculate measures of information transmission in various levels of aggregation (Diebold and Yilmaz, 2012, 2014). The off-diagonal elements $\phi_{\substack{i,j \\ i \neq j}}$, can be interpreted as pairwise directional connectedness ($C_{i \leftarrow j}$). Net pairwise directional connectedness is defined as shocks originating from variable j to i minus shocks from variable i to j ($C_{ij} = C_{j \leftarrow i} - C_{i \leftarrow j}$). In addition to the individual entries of the normalized variance decomposition matrix, sums of the pairwise connectedness measures also provide useful information regarding the interconnection of the variables in the system. The column-sums of the off-diagonal elements describe the proportion of shocks arising in variable i to all other variables in the system ($C_{\bullet \leftarrow i} = \sum_{\substack{j=1 \\ j \neq i}} \phi_{ij}$). Accordingly, the row-sums describe the proportion of the h-step ahead forecast error variance caused by all other variables ($C_{i \leftarrow \bullet} = \sum_{\substack{i=1 \\ i \neq j}} \phi_{ij}$). Total connectedness of the system is given through the mean of all off-diagonal elements of the matrix ($C = \frac{1}{N} \sum_{\substack{i,j=1 \\ i \neq j}}^{N} \phi_{ij}$) or, alternatively, by summing up the row- or column-sums. In addition, several other levels of aggregation are imaginable, e.g. summing up pairwise-connectedness measures within a sector or country (Diebold and Yilmaz, 2012, 2014).

The results of the variance decomposition can be easily transferred into the context of network analysis and interpreted as an adjacency matrix (Diebold and Yilmaz, 2014). Every network is composed of a set of vertices (or nodes) and edges (or links). The utilization of the variance decomposition matrix as an adjacency matrix leads to a weighted and directed network. The pairwise directional connectedness ϕ_{ij} determines the presence of links between the nodes. Commonly, the pairwise connectedness between the entities in the system varies. Therefore, particularly strong or weak links can be identified by interpreting the elements of D as weights. Additionally, the impact of j on i is commonly not equal to the effect of i on j. Hence, the direction of the information flow between two entities can be identified.

The utilization of the matrix D without adjustments results in a network with n nodes and $n \times n$ edges. Even for a small number of entities, the number of edges increases rapidly and prevents a meaningful display of the resulting network. To ensure clarity of presentation the edge list is constructed by using net pairwise directional connectedness and by considering only the dominant link ($C^{Net}_{i \leftarrow j} > 0$). The importance of a connection between two markets is visualized through the thickness of the link. The node size represents the total directional connectedness of variable i to all other variables in the system ($C_{\bullet \leftarrow j}$). It is assumed that markets with systemic importance contribute more to the forecast error variance of the other variables in the system. Therefore, the node size is directly informative about the systemic importance of the respective market. Using the Fruchterman and Reingold (1991) algorithm, the node location is determined by the pairwise directional connectedness. Strongly linked markets are placed closely to each other, whereas weakly linked markets are placed in greater distance to each other. Accordingly, markets, will be placed in the center of the network, if they are indicated as systemically important by strong pairwise connectedness to several markets, whereas weakly linked markets will be placed at the periphery (Gross and Siklos, 2019).[4]

[4] The visualization of the network follows Gross and Siklos (2019). Networks presented in this paper are visualized using the software R and the packages *igraph* and *ggplot2*. The estimation of the underlying VARX model uses the package *vars*.

To measure transaction costs we are restricted to methods which are solely based on return series. A considerable number of transaction cost measures have been proposed in the literature. However, data limitations render these methods inapplicable in studies of early commodity markets.[5] In this work, transaction costs are measured according to the FHT procedure proposed by Fong et al. (2017), which is a recent extension of the Lesmond et al. (1999) measure. This method is particularly useful in studying transaction costs in early commodity markets due to its sole reliance on price series, its reliability in comparison to other low-frequency transaction cost proxies and its high computational speed. Additionally, the method is frequently applied in the literature as, for example, by Marshall et al. (2012, 2013), Edmans et al. (2013), Karnaukh et al. (2015) or Schestag et al. (2016).

The approach of Fong et al. (2017) is based on the idea that returns can be separated into an observable and an unobservable component. A trade will only take place if the expected return exceeds the transaction costs. Traders will refrain from trading, even if an information justifies a price change, if the expected revenue does not cover the necessary costs. The FHT measure is based on the assumption that the transaction costs band is symmetric, i.e. the cost of buying or selling a stock is identical. On days where the true return does not exceed the transaction costs band, the observed return will take on zero value and vice versa. Accordingly, the probability of observing a zero return equals the probability of being inside the transaction costs band. Based on the assumption that the true return is normally distributed with zero mean and variance σ^2, the FHT measure is calculated in accordance with the following formula:

$$FHT = 2\sigma N^{-1}\left(\frac{1+z}{2}\right) \ , \tag{4}$$

with z denoting the number of zero returns relative to the number of trading and non-trading days in a given period and $N^{-1}(\cdot)$ the inverse function of the cumulative normal distribution.

[5] For a comprehensive overview see for example Marshall et al. (2012).

5 Information spillovers

In a first step, static information spillovers between early commodity markets are examined using the full sample. Table 4 shows the full-sample connectedness table. The main body of Table 4, or more precisely the upper-left 9×9 submatrix, presents the results of the generalized forecast error variance decomposition. The ij-th entry of this submatrix displays the pairwise directional information spillover from market j to i, i.e. the contribution of market j to the 10-weeks-ahead forecast error variance of market i. Total shocks from and to market i are illustrated in the last column (FROM) on the right side as well as in the bottom (TO) row, respectively. The total information connectedness of the system is displayed in the lower-right corner and could equivalently be interpreted as average *to* or average $from$ spillovers of all variables in the system (Diebold and Yilmaz, 2014).

[**Table 4 about here**]

From Table 4 it appears that not all pairwise information connectedness measures are statistically significant. Statistical insignificance does not imply that links do not exist, just that they are from a probabilistic point of view unimportant. Therefore, insignificant pairwise connectedness measures should generally be regarded as weak connections and those markets as only loosely connected.

The biggest share of the 10-week-ahead forecast error variance can be explained by own-shocks as described through the diagonal elements of the variance decomposition matrix. Therefore, own-connectedness tends to be much larger than total connectedness with other markets, i.e. own-connectedness exceeds the cumulated shocks originating in and received by market i. On average 23.69 percent of the forecast error variance can be explained by shocks arising in other variables of the system.

To create a reference value for the transmission of information, we rerun the analysis 1000 times using individually simulated random walks and calculate the average of the simulated total connectedness measures. This way, we obtain a benchmark wherein connectedness is only a statistical artefact. The calculated average connectedness of 23.69 percent exceeds strongly the benchmark of 1.95 percent.[6] Given the fact that total connectedness exceeds the benchmark of a non-integrated market, we obtain preliminary evidence for information transmission within the continental European grain trade.

By examining the upper-left part of the connectedness table more closely, blocks of high pairwise directional connectedness can be identified. Notable is the strong linkage between the markets in Vienna and Budapest. For these markets own-connectedness tends to be comparably small, and a remarkably large share of the forecast error variance can be explained by shocks from Vienna to Budapest or vice versa. Shocks from Vienna to Budapest account for 38.8% ($C_{BU \leftarrow VI} = 38.83$) and from Budapest to Vienna for 33.16% ($C_{VI \leftarrow BU} = 33.16$) of the forecast error variance in the respective market. The strong connectedness between those markets may be explained through the geographical proximity and by the shared affiliation to the Austrian-Hungarian Empire. Exports from Hungary, a main supplier of wheat to the German Empire during the 1890s, decreased due to increasing demand from Austria, leading the Danube monarchy to become nearly self-sufficient (Falkus, 1966). A similar observation of much smaller magnitude is observable for Berlin and Breslau, which are both located within the German Empire.

Russian exports, an important source of wheat for central Europe, originated mainly from the Black Sea ports and entered the European markets through ports in Belgium and the Netherlands (Falkus, 1966). The importance of ports in Belgium and the Netherlands as entry points for Russian wheat is highlighted by strong pairwise connectedness between Odessa and Antwerp as well as Amsterdam. Surprisingly, therefore, markets like Paris are less integrated into the continental European grain trade, which becomes obvious by examining pairwise directional connectedness but also with respect to total shocks sent to and received by other markets. Tariffs, raised in response to the cheap wheat supplied by the

6 Without exogenous variables the benchmark is higher by around 6 percent.

United States and the Tsarist empire from the 1870s, lead to a strong decrease of wheat imports and resulted in France becoming nearly independent from wheat imports to meet domestic demand. Shortages were offset by imports from overseas territories. Remaining demand, especially from wheat processing industries, was covered by purchases on the international wheat markets. Furthermore, domestic transport costs could make imports superior to domestic purchases. Nevertheless, despite high tariffs and sufficient domestic supplies, the French wheat markets were not completely decoupled from international wheat markets (Falkus, 1966). This finding is supported by the results of the connectedness analysis. Around 90 percent of the forecast error variance of Paris is explained through own-connectedness. Shocks sent and received by Paris are uniformly low, and nearly equally distributed across markets within geographical proximity.

Around 89.45 percent of the forecast error variance of Riga is explainable by own-connectedness, which is comparable to Paris. The pairwise connectedness measures from Riga to other markets are statistically insignificant. As stated above, this does not imply that no links exist but that those links are only weak from a probabilistic perspective. Hence, even weak connections may be informative. Shocks received by Riga mainly emerge in Odessa, which was also part of the Russian market with a direct excess to maritime trade, as well as Antwerp and Amsterdam. During the early modern period, grain produced in the Baltic area entered the central European markets mainly through seaports located in the lower countries, especially Amsterdam. Despite the fact that the role of wheat as export product was replaced by other grains and grain exports where increasingly shipped to markets in Great Britain (Andersson and Ljungberg, 2015), our results indicate path dependency and remaining influence of markets in the Low countries.

In contrast to markets with direct access to ports, the influence of Berlin and Breslau is lower but still comparably high, indicating the role of the German empire as a significant importer of wheat in Europe. By looking at the shocks originating in Riga, it is remarkable that Breslau is nearly unaffected whereas Berlin incorporates a large share of the forecast error variance. Contemporaneous sources state that Berlin, especially the Berlin Produce Exchange (e.g. Schliep, 1912; Pinner, 1914; Jöhlinger, 1925), were the benchmark markets within the German Empire. Since we only incorporate two markets within the German Empire, we do not provide evidence on this issue, but the observation that shocks sent by Berlin commonly exceed those by Breslau provides a hint about the importance of Berlin as a benchmark inside the German Empire.

In summary, the empirical evidence shows that own market shocks are far more important than shocks from other markets. Additionally, information spillovers tend to be more significant in case the corresponding markets belong to the same polity.

Trade and information flows are further examined using network analysis. Table 4 reveals a strong geographical component with respect to the systemic importance of markets within the European grain trade. To further investigate geographical patterns, we visualize the inter-market information spillovers and specify the node location via their geographical location. Figure 1 displays the network with nodes fixed at the geographical coordinates of the underlying market. To further enhance the visualization of the models' geographical component, the network is visualized using a map of modern day Europe. The network, presented in Figure 1, is based on the results of the previously introduced variance decomposition matrix. In Figure 1 only the dominant information flow from market i to j is visualized using positive net-connectedness to determine size and direction of linkages.

[**Figure 1 about here**]

Figure 1 confirms the observations made by analyzing the connectedness table presented in 4. What is striking in Figure 1 is the dominance of the port cities Amsterdam, Antwerp and Odessa in the overall information flow network. While individual linkages, especially between the markets located in one polity, particularly between Vienna and Budapest, are more pronounced, the overall contribution of these markets is striking.

An implication of this is the possibility that the geographical location of one market does not necessarily reflects its central location within the network. Information channels between two markets may be significantly shorter than geographical distance would imply. Therefore, we redraw the map of Europe to reflect, from a network perspective, the *true* distance between markets. Hereafter, node location is determinded by the force-directed Fruchterman and Reingold (1991) algorithm. As previously introduced, the Fruchterman and Reingold (1991) algorithm balances the attracting and repelling forces between all markets in the network, which leads strongly linked markets be placed in close proximity to each other and weakly linked markets at the periphery of the network.

Figure 2a displays all linkages based on positive net-connectedness, whereas Figure 2b shows only economically significant linkages, with economic significance defined as shocks larger than 1 percent using the Fruchterman and Reingold (1991) algorithm.

[**Figure 2 about here**]

The findings of the network analysis are in line with the conclusions drawn from the connectedness table, irrespective of whether or not a threshold shock size is applied. We find strong linkages between the markets in Vienna and Budapest. The node size, determined by the sum of the forecast error variance which could be explained by shocks originating in market i, corroborates the previous finding that both markets account for a large share of the connectedness in the system. Nevertheless, both markets are located at the periphery of the network, indicating that they are of significant importance to each other but of minor importance to the functioning of the overall network. In contrast, the central location of Antwerp and Odessa within the network, as determined by the force-directed Fruchterman and Reingold (1991) algorithm, illustrates the systemic importance of these market for the European wheat trade. The German Empire, located in the center of Europe, was a major importer of grain products and Berlin was known as its benchmark market. Therefore, its comparably low systemic relevance in comparison to the contemporaneous literature is remarkable (e.g. Schliep, 1912; Pinner, 1914; Jöhlinger, 1925).

The ban on futures trading in grain and mill products in the German Empire, introduced by the German Exchange Act of 1896, may explain the low systemic relevance of German markets in the European wheat trade system. Without the existence of standardized futures contracts the German market lost its attractiveness for foreign investors, its functionality was significantly reduced, and the market lost its importance in the European context (Jacks, 2007). In line with the previous analysis, the markets in Riga and Paris are only weakly connected to the system.

By examining Figure 2b, these findings are even more pronounced. None of the shocks sent or received by Paris exceed the threshold of a shock size greater 1 percent, indicating that Paris is mainly disconnected from the European wheat trade system. Riga, in contrast to Paris, remains integrated in the network. It is notable that shocks to Riga which exceed the threshold originate in markets with direct access to the maritime trade. By visual inspection, it seems that three clusters are identifiable.

To confirm the inference drawn from the visual inspection, a community analysis is conducted. We use the walktrap community detection algorithm proposed by Pons and Latapy (2006). The walktrap-algorithm utilizes short random-walks to detect strongly integrated subgroups based on the idea that short random-walks are prone to stay within a strongly linked subgroup. Nodes with the same colour are part of the same subgroup, as identified by the walktrap-algorithm. The algorithm identifies four clusters. The first two clusters are composed of markets within the same polity, Berlin and Breslau on the one hand and Vienna and Budapest on the other. The third cluster consists of the markets with direct access to seaborne trade, namely Amsterdam, Odessa, Antwerp and Riga. Paris forms a one-entity cluster, since no economically significant linkages to the network are present. If no minimum shock-size is imposed, the walktrap-algorithm identifies two clusters as presented in Figure 2a.

Summarizing our results, it becomes obvious that markets within the Austrian-Hungarian Empire were well integrated but of minor importance for the overall network. Within Europe, the size of shocks sent and received is commonly low and own-connectedness accounts for the largest share of the forecast error variance. With the exception of shocks from Vienna to Budapest and vice versa, pairwise directional connectedness is comparable between the majority of markets under scrutiny. Riga and Paris are significantly less integrated. While for Paris, protectionist tariffs are the most likely cause for partially decoupling, Riga's minor role in the system in comparison to previous centuries (e.g. Jacks, 2004; Andersson and Ljungberg, 2015) seems to be caused by changing patterns in trade and the access to production areas and ports at the Black Sea, obtained in the reign of Catherine the Great (Falkus, 1966).

However, the most interesting aspect of this graph is that a geographically central position within Europe does not necessarily implies a central location within a trade network from a informational perspective.[7]

This section has demonstrated that the centrality of one market is not fully captured by geographical aspects or the affiliation to one polity. We now turn to explaining the forces that drive information spillovers.

6 Transaction costs and information spillovers

So far this paper has focused on information spillovers using static connectedness measures and network methods. In doing so, we analyzed wheat market information transmissions primarily graphically or through the comparison of entries within the connectedness table.

The following section will explain the nature of these spillovers by the relative transaction costs of the different markets in the network. We hypothesize that transaction costs are an important factor in determining the contribution of market i to the overall network.

[7] To check the robustness of results, several robsutness checks have been performed as to exclude all exogenous variables or to forego the imputation of missing values. The overall results are unaffected by these changes and available on request.

In a first step, we obtain time-varying pairwise information spillovers from rolling window estimation with window lengths of 260, 416 and 520 observations (approximately 5, 8 and 10 years). From these estimates, we construct panel data sets with a total of 33264, 24684 and 19096 observations, respectively. More precisely, we obtain for each combination of markets included in the system estimates of the pairwise connectedness for the period from 1902 to 1914 depending on the underlying window size. The rolling-window approach is appealing, since potential time-variation in transaction costs and information spillovers is not captured comprehensively by conducting the estimation based on non-overlapping intervals as for example by splitting the data into sub-samples.

Next, we consider the potential influence of transaction costs on the transmission of information between markets. The variable RT_S is defined as the relative transaction cost of the sending market i in relation to the receiving market j. The variable is calculated based on the transaction cost time-series presented in Table 3 and calculated in accordance with the following formula:

$$RT_S = \frac{FHT_{Receiver\ j}}{FHT_{Sender\ i}} \ . \tag{5}$$

Factors such as direct access to a port, the affiliation to the same polity, language barriers, the distance or whether a market is protectionist or not are constant during the investigation period. Data on agricultural output or the corresponding imports and exports are frequently not available or at best available on a yearly basis. Therefore, we refrain from including these variables directly in the regression analysis and instead use pairwise and yearly fixed effects to capture the influence of these variables. In this way, we estimate the following pooled OLS regression:

$$C_{i \leftarrow j,t} = \alpha + \beta \times RT_{S,i,t} + \sum_{i=1}^{K} \gamma_i \times FP + \sum_{n=1}^{N} \omega_i \times FY \ , \tag{6}$$

with FP denoting the market pair and FY indicating the respective year. We expect the estimated β to be positive. Lower transaction costs should facilitate trading and lead to information being incorporated more quickly into market prices. Therefore, if the sender has relatively lower transaction costs, it is more likely that the information shock is already reflected in its market prices before a less liquid market with wider transaction cost band could trade on this information.

The results of the pooled OLS model with pairwise and yearly fixed effects are reported in Table 5. The results provide strong evidence of that lower transaction costs facilitate the transmission of information even if we control for institutional or geographical characteristics of a market pair.

[**Table 5 about here**]

It may be that the imputation of missing values could have affected either the calculation of the information spillovers or the transaction costs measure. Therefore, we replicate the analysis without markets with a high number of missing values (namely, the endogenous market Amsterdam and the exogenous market Liverpool) and using only complete cases. From Table 6, it is apparent that the results are comparable to the previous analysis. However, closer inspection of Table 6 shows that while the size of the estimates is comparable to those reported in Table 5, significance levels are slightly lower and, using the 8 year window, become insignificant.

[**Table 6 about here**]

Overall, these results indicate that if the sender has relatively lower transaction costs, information spillovers tend to be significantly higher. The results presented highlight the potential of transaction costs in explaining commodity market information transmission and are merely indicative. Additional research is needed to reach a more definitive conclusion.

7 Conclusion

This paper utilizes recently developed network methods to analyze how early commodity markets, operating under varying levels of protectionist tariffs, different institutional settings and varying access to infrastructure, are interconnected.

This paper contributes threefold to the literature: First, by presenting a new dataset of weekly wheat prices from several markets located on both sides of the Atlantic from 1898 to July 1914. Second, by identifying trade and information flows in the continental European wheat trade in the run-up to the first world war. Finally, by highlighting the the impact of transaction costs on information flows and the analysis market efficiency (as measured by their transaction costs) in the early continental European wheat trade.

We provide strong evidence for information transmission in continental Europe wheat during the late 19th and early 20th century. The comparison of total information flows with a benchmark of no-integration reveals the presence of significant information spillovers during the examination period. Our results indicate that intra-national conectedness significantly exceeds cross-border connectedness. Additionally, we identify clusters of highly interlinked markets. These clusters could either be formed by affiliation to a common polity or by access to low-cost transport routes via seaborne trade. Nevertheless, transaction costs in one market may have an even more pronounced impact on information flows by affecting the efficiency of the underlying market. An explorative regression analysis provides strong evidence that transaction costs are an important determinant of information flows between markets, even if we control for several characteristics of the underlying market pair.

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Table 1: Summary statistics price and imputed return series

Statistic	N	Mean	St. Dev.	Min	Pctl(25)	Pctl(75)	Max
Panel A: Summary statistics original price series							
Antwerpen	857	150.433	20.907	117.300	133.600	167.200	216.900
Amsterdam	761	150.888	20.293	116.100	130.600	163.600	222.400
London	860	146.801	18.870	115.100	130.975	156.250	233.800
Liverpool	718	156.004	21.470	123.800	138.700	170.375	242.000
Chicago	861	135.952	23.231	96.500	116.100	151.000	229.200
New York	861	145.417	22.992	104.200	124.800	161.100	243.000
Breslau	835	173.912	26.450	130.000	156.600	189.500	272.500
Vienna	852	189.449	37.610	136.600	153.175	217.225	301.400
Budapest	861	172.774	37.861	117.900	136.100	200.600	285.400
Odessa	837	135.951	22.980	102.800	116.100	156.200	210.500
Riga	831	142.545	21.325	111.200	123.800	158.750	211.600
Berlin	855	184.952	25.655	147.400	163.100	204.100	271.000
Paris	861	193.294	23.809	141.000	175.800	210.300	264.200
Panel B: Summary statistics of the return series based on the imputed price series							
Antwerpen	860	−0.0001	0.019	−0.129	−0.007	0.007	0.172
Amsterdam	860	0.0002	0.019	−0.177	−0.005	0.008	0.106
London	860	−0.00003	0.028	−0.382	−0.006	0.007	0.381
Liverpool	860	−0.0002	0.017	−0.141	−0.01	0.01	0.132
Chicago	860	−0.0002	0.035	−0.449	−0.015	0.015	0.190
New York	860	−0.0001	0.035	−0.404	−0.013	0.013	0.407
Breslau	860	−0.0001	0.016	−0.117	−0.004	0.004	0.123
Vienna	860	0.0001	0.021	−0.229	−0.008	0.009	0.128
Budapest	860	0.00004	0.021	−0.263	−0.008	0.009	0.089
Odessa	860	0.0001	0.021	−0.132	−0.010	0.009	0.107
Riga	860	−0.0001	0.031	−0.521	−0.007	0.007	0.489
Berlin	860	0.0001	0.017	−0.102	−0.007	0.008	0.151
Paris	860	−0.0001	0.020	−0.108	−0.008	0.010	0.074

Notes: Panel A shows the original series of price levels as collected from the *Vierteljahreshefte zur Statistik des Deutschen Reiches*. The data frequency is weekly and the sample covers the period from January 1898 to June 1914. Panel B shows summary statistics of the log returns used for the analysis. These series are based on the original level data, where missing values are imputed. Sample period and frequency are equivalent.

Table 2: Unit root tests

Panel A: ADF and KPSS tests imputed price series

	Antwerpen	Amsterdam	London	Liverpool	Chicago	New.York	Breslau
ADF	-3.464**	-4.289***	-4.550***	-3.736**	-3.672**	-4.066***	-3.038
KPSS	5.640***	7.452***	3.702***	6.019***	4.471***	5.589***	6.352***

	Vienna	Budapest	Odessa	Riga	Berlin	Paris
ADF	-3.154*	-3.046	-3.553**	-3.754**	-3.437**	-4.690***
KPSS	5.773***	5.207***	6.147***	6.243***	5.703***	6.671***

Panel B: ADF and KPSS tests return series

	Antwerpen	Amsterdam	London	Liverpool	Chicago	New.York	Breslau
ADF	-14.074***	-14.246***	-15.756***	-13.717***	-14.490***	-16.838***	-16.777***
KPSS	0.059	0.030	0.037	0.073	0.037	0.039	0.072

	Vienna	Budapest	Odessa	Riga	Berlin	Paris
ADF	-14.331***	-19.178***	-17.023***	-22.318***	-17.346***	-20.258***
KPSS	0.186	0.227	0.061	0.050	0.065	0.118

Notes: Panel A displays the ADF and KPSS test results based on the imputed price series in levels. Panel B shows the results based on the corresponding log return series. ***, **, * denote the significance at the 1%, 5% and 10%, respectively.

Table 3: Summary statistics transaction costs time-series

	Odessa	Riga	Vienna	Budapest	Amsterdam	Paris	Berlin	Breslau	Antwerpen
Panel A: Window size 5 years									
Mean	0.004	0.011	0.004	0.001	0.009	0.001	0.001	0.013	0.005
St.Dev.	0.003	0.010	0.001	0.001	0.004	0.0003	0.0003	0.003	0.002
Max	0.011	0.034	0.006	0.003	0.015	0.001	0.001	0.024	0.009
Min	0.001	0.003	0.002	0.0004	0.003	0.0004	0.0002	0.009	0.001
Panel B: Window size 8 years									
Mean	0.005	0.010	0.004	0.002	0.010	0.001	0.001	0.013	0.005
St.Dev.	0.002	0.005	0.001	0.0005	0.002	0.0001	0.0001	0.002	0.001
Max	0.009	0.018	0.005	0.003	0.013	0.001	0.001	0.018	0.008
Min	0.002	0.004	0.002	0.001	0.005	0.001	0.001	0.010	0.003
Panel C: Window size 10 years									
Mean	0.004	0.010	0.004	0.002	0.009	0.001	0.001	0.013	0.006
St.Dev.	0.002	0.005	0.0005	0.0003	0.001	0.0001	0.0001	0.002	0.001
Max	0.008	0.017	0.005	0.002	0.011	0.001	0.001	0.017	0.006
Min	0.003	0.005	0.003	0.001	0.007	0.001	0.001	0.010	0.004

Notes: The Table presents summary statistics of the FHT transaction cost time-series based on the corresponding log return series. Panel A reports summary statistics for the 5 year (260 observations) window, Panel B for the 8 year (416 observations) window and Panel C for the 10 year (520 observations) window. The window sizes correspond to those used to calculate time-varying information spillovers in Section 5.

Table 4: Static full-sample connectedness of continental European wheat markets

	OD	RI	VI	BU	AM	P	B	BR	AN	FROM
OD	72.640***	1.020	2.920***	1.220	7.030***	1.750**	3.380***	2.600**	7.450***	27.360***
	(4.697)	(2.459)	(0.956)	(1.064)	(2.171)	(0.684)	(1.064)	(1.029)	(2.038)	(4.697)
RI	2.670	89.450***	0.400	0.180	1.790	0.360	1.250	1.140	2.760	10.550
	(2.717)	(7.954)	(0.358)	(0.381)	(1.474)	(0.501)	(0.973)	(1.009)	(2.289)	(7.954)
VI	0.830	0.050	61.270***	33.160***	1.110	0.720	0.920*	0.990*	0.950*	38.730***
	(0.676)	(0.305)	(3.053)	(2.985)	(0.736)	(0.775)	(0.480)	(0.585)	(0.570)	(3.053)
BU	0.630	0.040	38.830***	56.660***	1.050*	0.920	0.810*	0.510	0.560	43.340***
	(0.971)	(0.316)	(2.977)	(2.694)	(0.625)	(0.887)	(0.492)	(0.533)	(0.469)	(2.694)
AM	5.180**	0.330	1.920**	1.090	80.030***	1.050	1.580	2.050**	6.770***	19.970***
	(2.266)	(1.128)	(0.907)	(0.739)	(5.573)	(0.676)	(1.018)	(0.880)	(2.046)	(5.573)
P	1.300	0.290	1.040	1.450	1.060	90.540***	2.840**	0.130	1.340*	9.460***
	(0.736)	(0.544)	(1.112)	(1.274)	(0.767)	(3.329)	(1.431)	(0.291)	(0.747)	(3.329)
B	2.140**	0.910	1.450**	1.390**	2.520***	2.570**	82.010***	5.810***	1.200	17.990***
	(0.954)	(1.007)	(0.612)	(0.684)	(1.169)	(1.306)	(4.208)	(1.967)	(0.865)	(4.208)
BR	1.700	0.350	3.040***	1.610*	3.100**	0.410	7.780***	80.700***	1.310	19.300***
	(1.048)	(0.779)	(1.024)	(0.873)	(1.208)	(0.384)	(2.298)	(4.020)	(1.481)	(4.020)
AN	5.570***	1.220	2.880***	2.040***	8.190***	1.990***	2.320**	2.270*	73.520***	26.480***
	(1.809)	(1.630)	(0.777)	(0.690)	(1.737)	(0.743)	(0.918)	(1.324)	(4.800)	(4.800)
TO	20.010***	4.210	52.490***	42.130***	25.830***	9.770***	20.890***	15.510***	22.340***	**23.690*****
	(6.113)	(6.824)	(3.983)	(3.755)	(6.340)	(3.021)	(4.984)	(3.926)	(6.622)	(3.023)

Notes: The table reports the results of the generalized forecast error variance decomposition and the connectedness measures as proposed by Diebold and Yilmaz (2012, 2014). Bootstrapped standard errors obtained from 1000 draws are presented in parentheses. ***,**,* denote the significance at the 1%, 5% and 10% level, respectively. Markets are abbreviated: Odessa (OD), Riga (RI), Vienna (VI), Budapest (BU), Amsterdam (AM), Paris (P), Berlin (B), Breslau (BR) and Antwerp (AN). TO and FROM are defined as the sum of shocks send or received by market i.

Table 5: Imputation of missing values: Pair and year fixed effects

	Dependent variable:		
	Pairwise spillover		
Window size in Years	(5)	(8)	(10)
RT_S	0.004**	0.014***	0.010**
	(0.002)	(0.004)	(0.005)
Observations	33,264	24,864	19,096
R^2	0.014	0.008	0.006
Adjusted R^2	0.012	0.005	0.002
Note:	*p<0.1; **p<0.05; ***p<0.01		

Table 6: No imputation of missing values: Pair and year fixed effects

	Dependent variable:		
	Pairwise spillover		
Window size in Years	(5)	(8)	(10)
RT_S	0.003*	0.007	0.011*
	(0.002)	(0.005)	(0.006)
Observations	21,588	15,078	10,752
R^2	0.005	0.007	0.005
Adjusted R^2	0.002	0.004	0.001
Note:	*p<0.1; **p<0.05; ***p<0.01		

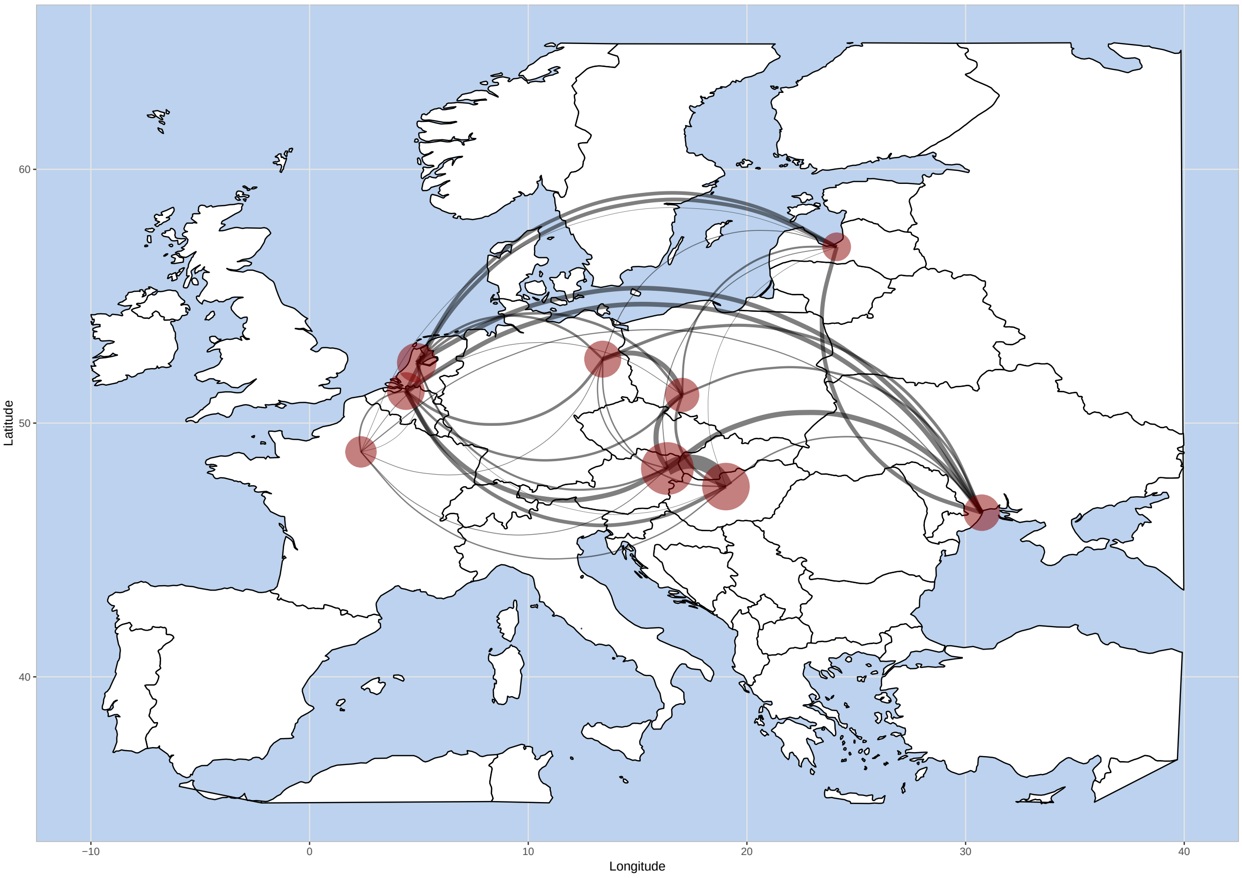
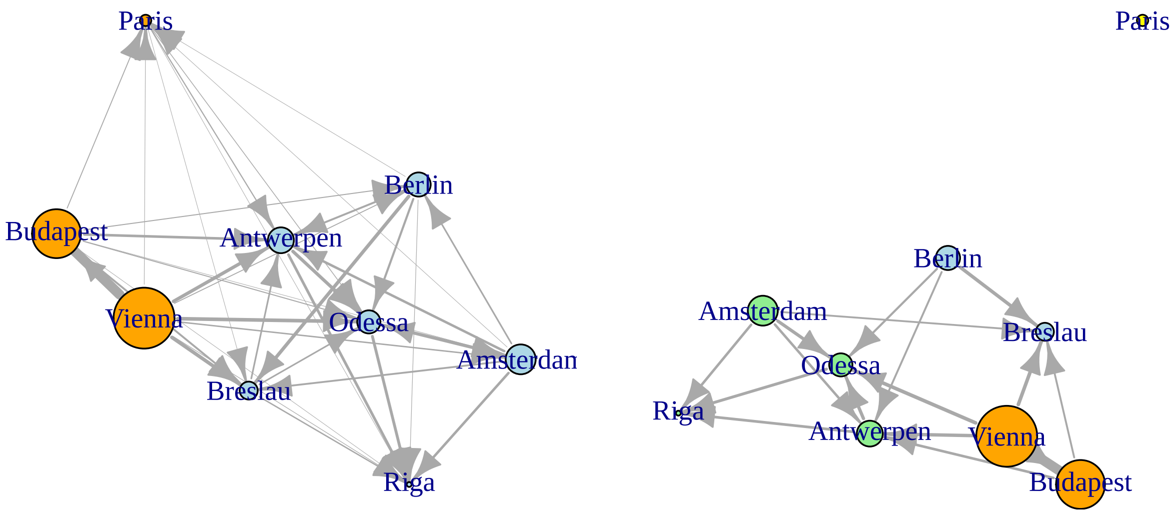


Figure 1: Network of continental European wheat markets with fixed node location

Note: In Figure 1 the size of the nodes represents the sum of shocks send from market i to all other entities in the system. The size of the edges shows the net pairwise spillover between market i and j. The node position is set to the geographical location of the respective market.



(a) no minimum shock size

(b) minimum shock size equal to one

Figure 2: Network of continental European wheat markets

Note: In Figure 2a and Figure 2b the size of the nodes represents the sum of shocks send from market i to all other entities in the system. The size of the edges shows the net pairwise spillover between market i and j. In Figure 2b a threshold shock size was imposed to ensure that only economic relevant linkages are presented, with economic significance defined as shocks larger than 1 percent. The node location is determinded by the force-directed Fruchterman and Reingold (1991) algorithm.