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Spatial market efficiency of grain markets in Russia: Implications of high trade costs for export potential

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ABSTRACT

Using a threshold vector error correction model approach, we find the wheat market of Russia to be segmented, with the primary grain export region poorly integrated with the domestic market. Results also indicate that trade costs are high, hindering the spatial market efficiency of wheat markets in Russia. This study demonstrates that an empirical benchmark allows for a more comprehensive assessment of the spatial market efficiency compared to the theoretical benchmark that is normally applied. The study shows that the distinction between grain production and export potential, especially for markets located in peripheral regions of Russia, is essential to correctly identify Russia's future role for global food security. As a general conclusion, apart from increasing agricultural production potential, it is also essential to strengthen spatial market efficiency in the agricultural sector to boost Russia's agricultural export potential and the country's prominent role in global food security.

1. Introduction

Grain production in Russia has witnessed impressive growth during the country's transformation process from a centrally planned to a market economy. While Russia had been a large wheat importer during the Soviet period, the country did not become a major wheat exporter until the 21st century. In recent years, Russia has advanced to be the largest wheat exporter in the world, with wheat exports amounting to 15% and 22% of global wheat exports in 2016 and 2017, respectively (USDA-WASDE, 2017).

It is expected that Russia's role in international wheat export markets—and thus global food security—will gain further importance into the future. Grain production in Russia could be boosted further by increasing grain production efficiency, as well as re-cultivating formerly abandoned agricultural land (Bokusheva and Hockmann, 2006; Lioubimtseva and Henebry, 2012). Swinnen et al. (2017) have assessed Russia's additional grain production potential to range between 25 and 65 million tons, while Deppermann et al. (2018) have estimated between 21 and 86 million tons.

Nevertheless, to further increase Russia's global wheat exports, not only does the country's wheat production need to increase, but it's also necessary for this sector to undergo major changes. A spatially efficient domestic grain market is required to ensure a comprehensive and quick transmission of price changes from the grain export markets to the grain-production regions.

In this study, we address the spatial market efficiency of grain markets in Russia from a regional perspective. Using a price transmission approach, we focus on the primary grain-production regions in Russia and measure their integration with each other; we investigate wheat price relationships at the interregional and intraregional levels. The interregional analysis centers on price relationships between different grain production regions separated by large distances. In contrast, price relationships within one individual grain production region with small distances between markets are the focus of the intraregional analysis.

Furthermore, in this study, the corn market of the USA serves as an empirical benchmark (rather than a theory-based one) for assessing the efficiency of the Russian wheat market. By comparing the values of the estimated model parameters obtained for Russia vis-à-vis the USA, we measure the degree of spatial market efficiency of the Russian wheat market against the maximum degree of efficiency obtainable for grain markets in an empirical context. Although the EU wheat market is also large enough for comparison purposes in this case, it is not yet uniform due to several rounds of rather recent enlargements with formerly centrally-planned transition countries in 2004, 2007 and 2013 (Tocco et al., 2015).

Because corn is the primary feed grain in the USA, similar to wheat in Russia, we choose the corn market of the USA as an empirical benchmark for the wheat market in Russia. Constituting 60% of total grain production, wheat is the primary grain produced in Russia, while

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corn represents 80% of total grain production volume in the USA (USDA-WASDE, 2017). In contrast, the share of wheat in total grain production in the USA is only 15%, with a likely tendency to decrease further.

Corn is also mainly produced and consumed domestically and heavily traded within the USA, which is similar to wheat in Russia. Furthermore, grain trade in both countries is characterized by large distances, which is decisively important for the analysis of spatial price relationships.

The analysis is based on the assumption that, in a spatially efficient market, price shocks in one region are quickly and to a large degree transmitted to the other regions, inducing interregional trade flows when price differences exceed trade costs (Fackler and Goodwin, 2001). Moreover, an efficient market is characterized by low trade costs, which are determined by, for example, distance to other markets, quality and quantity of transport infrastructure, search costs and market risk (Tomek and Robinson, 2003).

We measure market integration based on a threshold vector error correction model (TVECM) to explicitly account for the trade costs. We choose a novel Bayesian estimator suggested by Greb et al. (2013), which outperforms the conventional maximum likelihood approach, especially in small samples (Greb et al., 2014). However, with its bivariate setup, this model framework only allows for pairwise price analysis.

This study adds to the existing body of literature in the following ways: First, this study is unique in that it investigates the integration of wheat markets of Russia in comparison to the corn market of the USA. As the empirical evidence suggests, the corn market of the USA is one of the most efficient grain markets in the world because of a high degree of market transparency and liquidity of futures markets (McKenzie and Holt, 2002; Peri et al., 2013). US farmers also participate regularly in futures markets to hedge price risk and discover market prices (Mattos, 2017).

Secondly, this study contributes to the price transmission literature by measuring the interregional and intraregional spatial integration of wheat markets within Russia. Götz et al. (2016) have also investigated the integration of regional wheat markets of Russia, but with respect to the world wheat market. In addition, Serebrennikov and Götz (2015) confirm that regional wheat trade reversal during Russia's 2010 wheat export ban caused a change in the direction of price adjustment between markets compared to the free trade regime. For the USA, several studies have investigated the integration of commodity markets at the interregional (Benirschka and Binkley, 1995; Brorsen et al., 1985; Goodwin and Schroeder, 1991) and intraregional level (Goodwin and Piggott, 2001; Schroeder, 1997). Goodwin and Piggott (2001) confirm a strong market integration of the corn market in the USA. In contrast, Holst and von Cramon-Taubadel (2013) find stronger integration of EU pork markets within old or new member states, whereas market integration is weaker between old and new member states.

Third, our study is unique as it adds to the strand of literature investigating the role of trade costs in agricultural market integration. For Russia, Renner et al. (2014) indicate that the volume of interregional grain trade decreases with increasing trade costs and less developed transport infrastructure. Trade costs also influence spatial market integration, as found by Moser et al. (2009) for rice markets in Madagascar. Furthermore, Jamora and von Cramon-Taubadel (2016) demonstrate that rice prices in 47 importing countries adjust at a lower speed with increasing distances to international rice markets.

Fourth, our study contributes to the literature that assesses Russia's role in future global food security. Most studies on Russia's additional grain production potential (for an overview see Schierhorn et al. (2014) and Swinnen et al. (2017)) have focused on estimating Russia's capacity to increase its grain production via improvements in grain yields, expansion of agricultural land or changes in climatic conditions. This paper, on the other hand, adds to this literature by focusing on the importance of spatially efficient markets for transforming Russia's grain



Fig. 1. Map of grain producing regions of Russia.

production potential into grain export potential.

The remainder of this article is organized as follows: In section 2, Russia's wheat market characteristics are discussed and compared to those of the corn market of the USA, whereas section 3 addresses the methodological framework and model estimation. Section 4 discusses the data specifications and section 5 presents empirical results. Finally, we discuss results and draw conclusions in section 6.

2. Characteristics of the Russian grain market and its comparison with the USA

We follow a comparative approach and investigate the wheat market in Russia in contrast with the corn market of the USA.

Grain production in Russia, as in the USA, is concentrated in a limited, yet spatially protracted area. Six economic regions supply nearly all wheat produced in Russia (Fig. 1): North Caucasus, Black Earth, Volga, Ural and West Siberia are wheat surplus regions, whereas the Central region with Moscow is the primary wheat deficit region, depending largely on external supplies. Similarly, the “corn belt” region mainly dominates corn production in the USA. In this study, we consider seven corn belt states: Iowa, Illinois, Nebraska, Kansas, Minnesota, Missouri and South Dakota. These states account for nearly 70% of total US corn production and export (USDA-ERS, 2019; USDA-NASS, 2019).

Wheat production in Russia is strongly influenced by climatic and weather conditions. Owing to vast distances and favorable production conditions, relatively high yields might be observed in some regions, versus relatively low yields in others at the same time. The variation of wheat production within a region is also generally high (Table S1, supplementary material). In the Volga region, for example, yearly wheat production relative to the last three-year-average varied between 34% and 134% from 2009 to 2015. Large regional fluctuations also characterize corn production in the USA. In Illinois, for example, yearly corn production varied between 65% and 132% relative to the last three-year-average from 2009 to 2015 (Table S1, supplementary material).

In Russia, North Caucasus is the primary production region, which supplies wheat to the world market almost exclusively, while its role in domestic trade is rather limited. North Caucasus alone exports around 75% of total wheat exports from Russia (IKAR, 2018). With its high-capacity sea terminals, this region also serves as a gate-market for the other grain production regions, particularly Volga and Black Earth, for exports to the world market. In contrast, Ural and West Siberia are not only far away from the world market, with distance to the Black Sea ports amounting to 4000 km, but also from the grain consumption regions within Russia. In particular, Moscow is about 2000–3000 km away. Because of the large distances to the Black Sea ports and the respectively high transportation costs, the share of West Siberia and Ural together in total wheat exports does not exceed 3% (IKAR, 2018). Even the grain exports from Ural and West Siberia during the 2017–18 marketing season relied heavily upon large transport subsidies provided

by the Russian government to help farmers sell their wheat (USDA-GAIN, 2018).

The concentration of human grain consumption in a few urban centers (Moscow, St. Petersburg) and livestock production regions (Central and Black Earth) requires a large amount of wheat to be transported from production to consumption sites over long distances within Russia. In contrast, ethanol plants and livestock farms in the USA are concentrated in the main corn production states in the corn belt, meaning corn is primarily transported over small distances, although non corn-belt states like California and Texas heavily depend on grain transported over long distances of between 1000–3000 km. In addition, corn is transported over long distances to Washington, which is the grain export gateway to Asia.

In Russia, transport infrastructure differs between regions and is outdated and insufficient in some regions. For instance, the density of the railway network is highest in the European part of Russia, whereas it is much lower in Ural and West Siberia. Excessive crops are often difficult to transport beyond West Siberia as the only railway track connecting the area to the rest of the country has low throughput capacity and is shared by many other industries (Scherbanin, 2012). In addition, grain traders regularly complain that the number of grain wagons in peak seasons does not suffice (Agroinvestor, 2011).

Rail and road transport are the primary means of wheat transportation in Russia. Rail transport dominates if the transportation distance exceeds 1000 km, while road transport is preferred for routes up to 500 km. Waterway or river transportation is quite unusual for grain deliveries in Russia. Grain from West Siberia and Ural is transported by rail to the Black Sea ports, with the distance amounting to 4000 km. In contrast, river barge transport is a common practice for grain transport over long distances in the USA due to the large weight capacity of the barges used and low costs (Fig. 2). Furthermore, corn belt states, which account for nearly 75% of total US exports, largely rely on cheap and large-scale barges with the maximum distance to ports amounting to 2000 km.

Looking at land transport, grain transportation costs are lower in Russia compared to the USA (Fig. 2). Nonetheless, overall transport costs are higher in Russia due to inadequate transport infrastructure and logistics, which negatively influences regional wheat trade volumes within Russia (Renner et al., 2014). In addition to high transport costs, grain markets in Russia are also characterized by high business and market risk (PWC, 2015). Trade costs are especially high due to the difficulty of enforcing contracts and unforeseen grain market policy interventions (Götz et al., 2016).

3. Methodological framework and model estimation

Market integration between two geographically separated regions

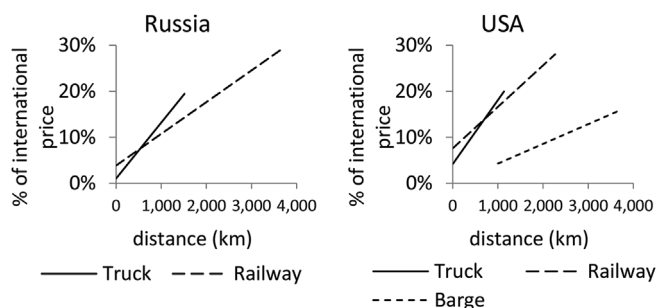


Fig. 2. Grain transportation costs (as a % of international prices) in Russia and the USA. Note: We linearly approximate transportation costs based on actual rates given for different distance routes in October 2010; we use international corn prices (US no. 2, yellow) for the USA and the Black Sea international price of wheat (milling) for Russia in October 2010. Source: AEGIC (2016), FAO-GIEWS (2019), Rosstat (2015), US Rail Waybill Samples (2017) and USDA-AMS (2017).

can be analyzed based on the Law of One Price (LOP). The LOP implies the same price for a homogeneous good in different locations once the differences in currency units and trade costs are accounted for. Market integration is achieved via efficient commodity arbitrage, which ensures price information is transmitted between markets, eventually resulting in a long-run price parity (Ardeni, 1989).

Therefore, a spatially efficient market is an integrated market characterized by a complete transmission of price changes between markets in the long-run. However, short-run transitory inefficiencies that are quickly eliminated via profitable arbitrage are allowed in a spatially efficient market. Furthermore, spatial market efficiency could be enhanced by decreasing trade costs.

Prices in spatially separated markets in region 1 and region 2 linked by a spatial price equilibrium are represented by

$$p_{1t} = \alpha + \beta p_{2t} + \varepsilon_t \tag{1}$$

where p_{1t} and p_{2t} are domestic prices (in natural logarithm) observed in regional markets 1 and 2, α denotes the intercept and β is the coefficient of the long-run price transmission elasticity, characterizing the magnitude of price shock transmissions from one market to another. The theoretical value of β varies between zero and one, with $\beta = 1$ indicating that price information is completely transmitted in perfectly integrated markets. ε_t represents the stationary disturbance term that might not be white noise. Equation (1) is built on an implicit assumption that trade costs are stationary, ensuring that the long-run price equilibrium can be correctly identified (Fackler and Goodwin, 2001).

The concept of a long-run equilibrium is a static notion. It is natural that prices in spatially separate markets often diverge from this parity, owing to unexpected market shocks. Dynamic linear and threshold vector error correction models (VECM and TVECM) offer measuring the speed at which prices converge back to the long-run equilibrium as a result of profitable arbitrage activities by agricultural traders.

If the price series are linearly cointegrated, then a linear vector error correction model developed by Johansen (1988) enables quantifying the short-run price dynamics as

$$\Delta p_t = \rho \varepsilon_{t-1} + \sum_{m=1}^M \Theta_m \Delta p_{t-m} + \omega_t \tag{2}$$

where the vector of dependent variables $\Delta p_t = (\Delta p_{1t}, \Delta p_{2t})$ denotes the difference between the prices in periods t and $t - 1$ for markets 1 and 2. The error correction term ε_{t-1} , i.e. the lagged residuals retrieved from equation (1), represents the price deviation from the long-run price equilibrium. The short-run dynamics of prices p_{1t} and p_{2t} are characterized by the speed of adjustment parameter $\rho = (\rho_1, \rho_2)$, with the expected value of $\rho_1 \leq 0$ and $\rho_2 \geq 0$, which measures how quickly deviations from the long-run equilibrium are eliminated. In order to ensure a smooth convergence to equilibrium, total speed of adjustment should range between zero and one achieved by satisfying the condition $0 < \rho_2 - \rho_1 < 1$ (Greb et al., 2014). $\Theta_m = (\Theta_{1m}, \Theta_{2m})$ indicates the lagged influence of the price changes Δp_{t-m} with lags $m = 1, \dots, M$, ensuring that the model residuals are serially uncorrelated. $\omega_t = (\omega_{1t}, \omega_{2t})$ denotes a white noise process with expected value $E(\omega_t) = 0$ and covariance matrix $Cov(\omega_t) = \Omega \in (\mathbb{R}^+)^{2 \times 2}$.

In practice, however, trade costs often determine the intensity of spatial trade arbitrage, such that price deviations larger than the trade costs are more quickly eliminated compared to smaller price deviations. Thus, a “regime dependent” price adjustment process may be observed, which can be depicted by a threshold error correction model, whereby the threshold corresponds to the size of transaction costs.

A non-linear three-regime TVECM with two thresholds (Greb et al., 2013) makes it possible to account for the influence of trade costs, which is highly relevant to trade in the Russian wheat market because of large distances:

$$\Delta p_t = \begin{cases} \rho_1 \varepsilon_{t-1} + \sum_{m=1}^M \Theta_{1m} \Delta p_{t-m} + \omega_{1t}, & \text{if } \varepsilon_{t-1} \leq \tau_1 \\ \rho_2 \varepsilon_{t-1} + \sum_{m=1}^M \Theta_{2m} \Delta p_{t-m} + \omega_{2t}, & \text{if } \tau_1 < \varepsilon_{t-1} \leq \tau_2 \\ \rho_3 \varepsilon_{t-1} + \sum_{m=1}^M \Theta_{3m} \Delta p_{t-m} + \omega_{3t}, & \text{if } \tau_2 < \varepsilon_{t-1} \end{cases} \quad (3)$$

The speed of adjustment parameter is constant in a linear VECM, whereas it may differ between the regimes $r, r = \{1,2,3\}$ in a non-linear TVECM. The speed of adjustment is usually higher in the lower ($r = 1$) and upper ($r = 3$) regimes compared to the middle ($r = 2$) regime due to trade arbitrage. However, profitable arbitrage opportunities do not exist in the middle regime, as trade costs exceed price deviations. Nonetheless, the price adjustment may be observed in this regime due to information flows or third markets (Stephens et al., 2012).

The error correction term ε_{t-1} also serves as a threshold variable τ in TVECM. The three-regime TVECM is based on the assumption that two thresholds (τ_1 and τ_2) exist corresponding to the size of trade costs in both directions, i.e. from one market to the other and vice versa. Trade reversal is captured by the restriction $\tau_1 < 0 < \tau_2$. The model further assumes that trade costs are a constant fraction of prices as the model variables are transformed into a natural logarithm. The size of trade costs is also captured by the band of inaction, defined as the difference between the absolute value of the upper and lower threshold. Thus, a large band of inaction indicates that trade costs are substantial.

In a TVECM, the threshold variable τ determines the state of the regime $r, r = \{1,2,3\}$ depending on the size of the error correction term relative to the size of the thresholds. To identify optimal thresholds, we apply the novel regularized Bayesian estimator (Greb et al., 2014) as an alternative to the classical maximum likelihood (Hansen and Seo, 2002) and the least squares (Chan, 1993) estimator. Different to the traditional estimators, which use the grid search procedure to identify the optimal threshold values, the regularized Bayesian estimator uses informative priors to achieve the desired distribution of observations across regimes, which is well defined along the entire space of threshold parameters. Furthermore, the regularized Bayesian estimator outperforms maximum likelihood and non-informative Bayesian estimators, especially in small samples (Greb et al., 2014). Upon identification of the optimal thresholds, we estimate the additional parameters of the TVECM by restricted maximum likelihood.

In the price transmission analysis, we proceed as follows: Given that price series are identified as integrated of order one (Dickey and Fuller, 1981), we proceed to test whether the price pairs of interest are linear or threshold cointegrated, and thus whether a long-run price equilibrium exists. We examine the existence of linear cointegration based on the Johansen (1988) test. Threshold cointegration is tested within the Hansen and Seo (2002) framework in a two-regime TVECM with one threshold. Additionally, we use the Larsen (2012) extension to the Hansen and Seo (2002) test, which allows for non-linear cointegration within a three-regime TVECM with two thresholds. Given that linear or threshold cointegration is confirmed, we estimate a VECM or a TVECM, respectively.

4. Data

The interregional analysis centers on price relationships between different grain production regions separated by large distances. In contrast, price relationships within one individual grain production region with small distances between markets are the focus of the intraregional analysis (Table 1).

For the interregional analysis of the grain market of Russia, we make use of a unique data set of weekly prices of class three wheat (Ruble/ton). This data is collected by the Russian Grain Union and is not publicly available. Our data set comprises regional price series for the six primary grain production regions of North Caucasus, Black Earth, Central, Volga, Ural and West Siberia from 2005 to 2013 (Fig. 3).

However, the regional price relationships in Russia are not stable, but rather differ from marketing year to marketing year. Due to the

Table 1 Database of grain price series underlying price transmission analysis.

Country	Price pairs	Data frequency	Data source
<i>Interregional analysis (between regions/federal states), 2009-10</i>			
Russia (6 regions)	15	weekly	Rus. Gr. Union (2014)
USA (16 federal states)	63	weekly	USDA-AMS (2016)
<i>Intraregional analysis (within regions/federal states), 2014-16</i>			
Black Earth (region)	10	biweekly	Ministry of Agriculture of Russia, (2016)
West Siberia (region)	15	biweekly	GeoGrain (2016)
Iowa (federal state)	28	weekly	GeoGrain (2016)
North Carolina (fed. state)	15	weekly	NCSU (2017)

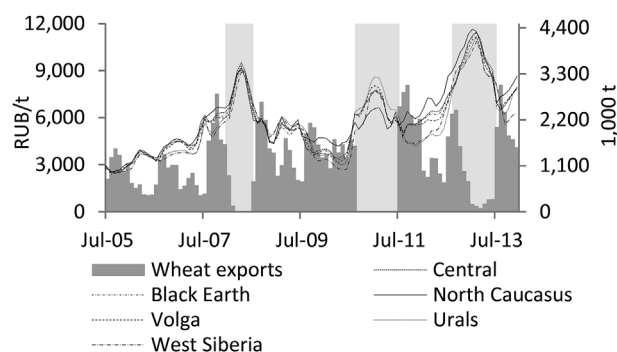


Fig. 3. Development of regional wheat prices in Russia: 2005–2013. Note: The bold area on the graph represents the periods of export tax (Nov 2007–May 2008), the export ban (Aug 2010–Jul 2011) and draught season (2012–2013). Source: Russian Grain Union (2014), GTIS (2013).

common harvest shortfalls in Russia, and thus the large variation in regional grain production, the size and direction of trade flows between surplus and deficit regions varies strongly (Götz et al., 2016).

In particular, the price in North Caucasus is in some years higher and in other years lower than prices in, for example, Volga and West Siberia regions (Fig. 4). The oscillating price behavior coincides with changes in the direction and size of interregional trade flows resulting from large variations in the regional grain harvest due to weather conditions.

Beside weather-driven production shortfalls, government interventions also influence the pattern of domestic and international trade and wheat price developments in Russia. During the 2007-08 global food price crisis, the Russian government imposed a 40% export tax, which suspended wheat exports from Russia (Fig. 3). Similarly, because of the extreme weather conditions and wildfires in 2010, the Russian government imposed a wheat export ban for the entire 2010 marketing year until July 2011, which had a profound effect on domestic regional wheat trade in Russia (Götz et al., 2013).

This implies that the interregional price relationships, which are depicted in the price transmission model, are not stable, and thus

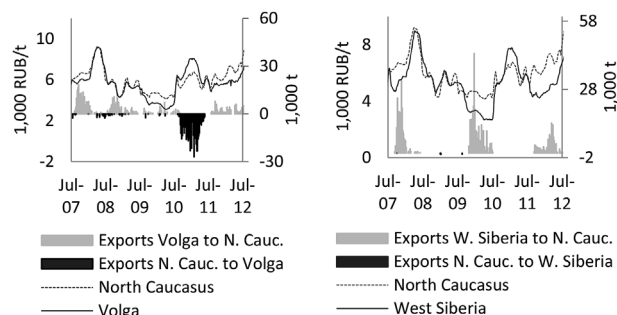


Fig. 4. Wheat prices and regional trade: North Caucasus and Volga (left), North Caucasus and West Siberia (right). Source: Reproduced from Götz et al. (2016).

parameter estimates may not be constant. We suspect that the data generating process differs from one marketing year to another. This requires the price transmission model for Russia to be estimated based on one marketing year alone that is characterized by relatively stable price relationships.

Therefore, to assess the strength of market integration in Russia at the interregional level, we focus our analysis on the price data of the individual grain production regions for the 2009-10 marketing year only, in which grain harvest was productive and trade was freely possible, unlike 2007–08 and 2010–11 (wheat export restrictions), and 2012–13 (a year with wheat harvest failure, although trade remained open) (Fig. 3). Utilizing all possible pairwise combinations of the six price series, we construct 15 price pairs altogether, comprising 52 weekly observations for each price series.

Correspondingly, we employ 52 weekly price observations for corn (US no. 2, yellow) for 16 federal US states for the 2009-10 marketing year (USDA-AMS, 2016). We generate 63 price pairs by combining prices observed in seven corn belt area states with prices monitored in nine net-consuming corn states. We could have constructed 120 unique price pairs total using 16 price series. Yet, since estimating the threshold models is a time consuming routine in R statistical software, we optimized the number of price pairs for the USA by focusing on price pairs constructed by combining prices from consumption and production states.

For the analysis of intraregional price relationships in the wheat market of Russia, we select two regions and analyze the wheat market integration (a) in a grain production region that is also an export region, and (b) in a grain production region that is mainly active on the domestic market.

North Caucasus is a main wheat production and export region in Russia with direct access to its ports at the Black Sea. Therefore, prices in this region can be used to analyze market integration at the intraregional level. Nonetheless, since the quality of the price data for North Caucasus does not suffice the data requirements for a rather complex TVECM, we choose its neighboring Black Earth region as an alternative (Fig. 5).

We choose West Siberia as one of the largest grain production regions in Russia, but in contrast to North Caucasus and Black Earth, it is primarily involved in domestic wheat trade due to its large distances to

the world market.

Therefore, we use prices observed within the two primary wheat production regions of Black Earth and West Siberia (Fig. 5). These prices represent the selling price of wheat in various provinces (Krays and Oblasts) of Russia and are provided by the agricultural agency affiliated with Russia's Ministry of Agriculture (2016). Since price series for Russia are only available on a biweekly frequency, we increase the sample size to two years to ensure a relatively sufficient number of observations for the price transmission analysis. Thus, we utilize the maximum number of available price pairs: 10 price pairs for Black Earth and 15 price pairs for West Siberia, with each price series comprising 52 biweekly observations for the period of July 2014 to August 2016.

Likewise, the intraregional analysis for the USA covers Iowa, a leading corn production and export region, and North Carolina, which, similarly to West Siberia in Russia, mainly supplies its excess corn production to the domestic market and is the second largest pork production state in the USA. The eight price series for Iowa are supplied by the consultancy company GeoGrain (2016) and the six price series for North Carolina are provided by the North Carolina State University (NCSU, 2017). Thus, we analyze 28 price pairs for Iowa and 15 price pairs for North Carolina, with each price series comprising 110 weekly observations (July 2014 to August 2016).

In total, at the interregional and intraregional levels, we utilize a data set consisting of 40 price pairs for Russia and 106 price pairs for the USA.

5. Empirical results

5.1. Data properties

The results of the Augmented Dickey-Fuller test (Dickey and Fuller, 1981) suggest that all price series included in the interregional and the intraregional analysis are integrated of order one (Table S2, supplementary material).

The tests on cointegration of the price pairs involved in the interregional analysis indicate that linear or threshold cointegration exists for all 15 price pairs representing the Russian wheat market, and 53 out of 63 price pairs for the US corn market, whereas, at the intraregional level, cointegration is confirmed for all price pairs for Russia and 40 out of 43 price pairs for the USA (Table 2). Therefore, we exclude the 13 price pairs (out of 106) for the corn market of the USA for which neither linear nor threshold cointegration is confirmed from the analysis. We suspect that the lack of cointegration may be related to our methodology selection or, as Fackler and Goodwin (2001) indicate, if trade costs are non-stationary, then the lack of cointegration can be wrongly interpreted as evidence of market inefficiencies.

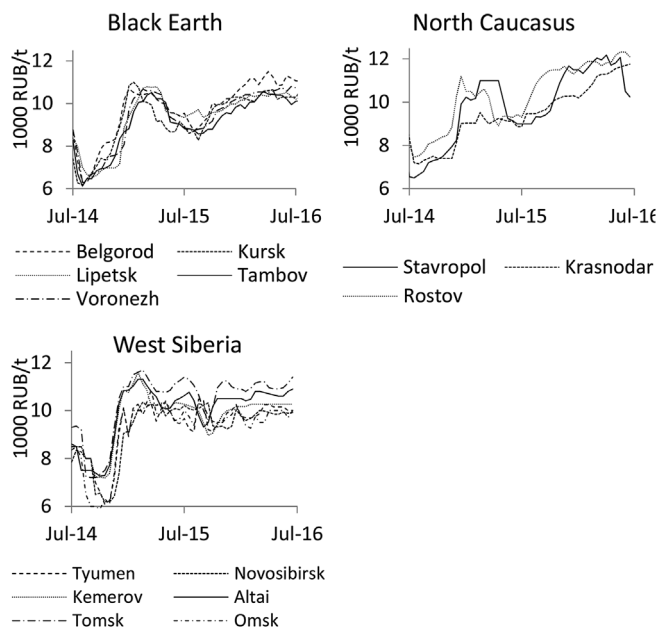


Fig. 5. Development of regional wheat prices in Black Earth, North Caucasus and West Siberia during 2014–2016. Source: Ministry of Agriculture of Russia (2016).

Table 2 Summary of the cointegration tests' results.

	Russia	USA
Number of interregional price pairs (between regions/federal states)	15 (total)	63 (total)
Threshold cointegration	15	35
Linear cointegration	13	48
Linear or threshold cointegration	15	53
Number of intraregional price pairs (within regions/federal states)	25 (total)	43 (total)
Threshold cointegration	21	32
Linear cointegration	25	25
Linear or threshold cointegration	25	40

Note: Estimated parameters are given in Tables S3 and S4 in supplementary materials.

Table 3
Long-run price transmission elasticities: Russia, interregional analysis.

Price pair	Distance (km)	Long-run price transmission elasticity (β)
Central – Black Earth	526	0.94
Central – Volga	801	0.70
N. Caucasus – Black Earth	870	0.33
Black Earth – Volga	1035	0.74
Volga – Ural	1235	0.68
N. Caucasus – Central	1300	0.35
Ural – W. Siberia	1310	0.83
N. Caucasus – Volga	1708	0.27
Black Earth – Ural	2027	0.47
Central – Ural	2044	0.43
Volga – W. Siberia	2537	0.57
N. Caucasus – Ural	2682	0.16
Black Earth – W. Siberia	3329	0.39
Central – W. Siberia	3346	0.36
N. Caucasus – W. Siberia	3984	0.13



5.2. Measurement of market integration

In this subsection, we present estimation results of the wheat price transmission analysis for Russia and its comparison with the corn market of the USA. Specifically, we focus on the long-run price equilibrium, the correction of temporary disequilibrium and the estimates of trade costs. Differences in the estimation periods at the interregional (2009–10) and intraregional level (2014–16) should be kept in mind when interpreting the empirical results. Even though the difference in wheat production levels are small (59 and 61 million tonnes) between these two time periods, we have shown in the previous section that wheat price developments in Russia may vary from one marketing year to another.

5.2.1. Long-run price equilibrium

Table 3 presents the long-run price transmission elasticities of the regional wheat prices in Russia (interregional analysis).

It becomes evident that the long-run price transmission elasticity decreases with increasing distance between the regions. Corresponding with the Law of One Price, according to which markets are perfectly integrated if the slope parameter of the long-run price equilibrium is equal to one, the weaker the integration of wheat markets between regions of Russia, the higher the distance between those regions.

In particular, long-run price transmission is the strongest between the neighboring regions of Central and Black Earth (0.940), with Central being the major consumption center and Black Earth a large production region, and the lowest between North Caucasus and West Siberia (0.132), the two grain production regions, which are the most apart.

Furthermore, results indicate that North Caucasus is the least integrated with the other grain production regions of Russia. Price changes are transmitted between markets by 13–35% if one of the two regions in question is North Caucasus, whereas prices are transmitted by 36–94% between other regions of Russia. Obviously, the export region is the least integrated with the domestic grain market. We trace this back to the strong influence of the world wheat price on wheat prices in North Caucasus, whereas in all other regions, domestic factors dominate the price formation process (Götz et al., 2016).

The previously discussed long-run price transmission elasticities of the 15 price pairs for Russia at the interregional level are presented together with the long-run price transmission elasticities of the 53 price pairs for the USA as boxplots in Fig. 6 (left). The long-run price transmission parameters estimated within the intraregional analysis for Russia and the USA are shown in Fig. 6 (right).

When assessing the price transmission elasticities obtained for the corn market of the USA against the theory-based benchmark, the results indicate that corn prices are very strongly related in the USA, as price

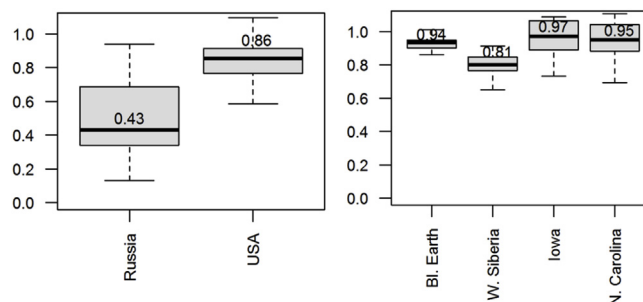


Fig. 6. Boxplots of the estimated long-run price transmission elasticity parameters: interregional analysis (left), intraregional analysis (right). Note: Plots are based on estimated parameters given in Table 3 and Tables S5 and S6 in the supplementary material.

transmission elasticities (0.86, 0.97 and 0.95) are nearly equal to one.

Concerning cross-country comparisons, the median long-run price transmission elasticity equals 0.43 for Russia and 0.86 for the USA at the interregional level. Thus, price changes between spatially separated markets are transmitted by twice as much in the USA compared to Russia.

Results of the intraregional analysis indicate median long-run price transmission elasticities equal to 0.97 and 0.95 for Iowa and North Carolina in the USA and 0.94 and 0.81 for Black Earth and West Siberia in Russia, respectively.

Thus, the differences in the long-run price transmission elasticities between Russia and the USA is much larger at the interregional level than at the intraregional level.

5.2.2. Correction of the temporary disequilibrium

Estimated price adjustment parameters for Russia are directly compared to the USA within the boxplots in Fig. 7.

The estimated adjustment parameters (at the biweekly frequency) suggest that the price disequilibrium is eliminated at a rate of 0.8 in every time period in the US corn market, whereas the theoretical value would be one in a spatially efficient market. This difference between the theoretical and empirical values is even more pronounced at the intraregional level, indicating that the empirical benchmark at the intraregional level is 0.6, which is 40% lower compared to the theoretically obtainable speed of the price adjustment parameter.

Results indicate that the median speed of adjustment is nearly 50% lower for Russia (0.42) compared to the USA (0.81) at the interregional level (Fig. 7, left).

Results at the intraregional level demonstrate that about 60% of the temporary price disequilibrium is eliminated in two weeks within Iowa (0.61) and North Carolina (0.61), whereas price adjustment is 30% and

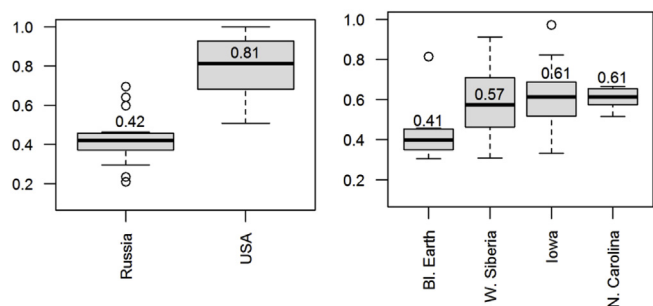


Fig. 7. Boxplots of the estimated speed of adjustment parameters: interregional analysis (left), intraregional analysis (right). Note: Plots are based on estimated parameters given in Tables S7 and S8 in the supplementary material. To compare the speed of adjustment parameters of different frequencies, we convert parameters from a weekly to biweekly frequency using the following formula: $|\rho|^{biweekly} = 1 - (1 - |\rho|^{weekly})^2$.

5% lower in Black Earth (0.41) and West Siberia (0.57), respectively (Fig. 7, right). This suggests that, at the intraregional level, spatial market efficiency of the wheat market in Russia is comparable to that of the corn market of the USA. If evaluated against the theoretical benchmark, one might conclude that the speed of adjustment of wheat prices in the Russian market is low, with the speed of price adjustment parameter amounting to only 50% of the theoretical benchmark value of 1.

Thus, the speed of adjustment in Russia is significantly lower compared to the USA at the interregional level, while differences are much smaller at the intraregional level.

5.2.3. Trade costs

We directly compare the estimated parameters of the band of inaction for Russia and the USA within the boxplots in Fig. 8.

Estimates of the threshold parameters for Russia generally confirm the influence of distance. Values of the band of inaction are lowest between neighboring regions and largest between regions the furthest apart. All price pairs that include Ural or West Siberia as a region are characterized by a relatively large band of inaction values in the range of 0.07 and 0.10 compared to other market pairs with the band of inaction varying between 0.04 and 0.06. This implies that the cost of interregional trade is particularly high for Ural and West Siberia.

Since the literature does not provide any sense or guidance of what constitutes high trade costs and how they are reflected in the size of the threshold parameter, estimating thresholds for the corn market of the USA allows us to evaluate the magnitude of trade costs for the Russian wheat market against the size of trade costs identified for the corn market of the USA. The comparison of the size of the estimated band of inaction for Russia and the USA at the interregional level makes evident that the median band of inaction is 40% higher for Russia compared to the USA (Fig. 8, left). Results at the intraregional level suggest that the

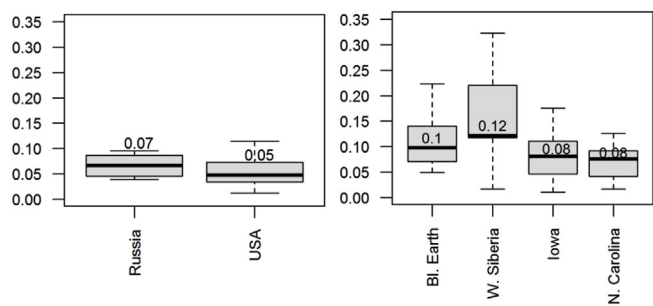


Fig. 8. Boxplots of the estimated band of inaction parameters: interregional analysis (left), intraregional analysis (right). Note: Plots are based on estimated parameters given in Tables S7 and S8 in the supplementary material.

band of inaction for Black Earth and West Siberia is between 25% and 50% higher compared to the USA (Fig. 8, right).

6. Discussion of results and conclusions

This study has made evident that the integration of regional grain markets within Russia is relatively low compared to the USA; however, differences in spatial market efficiency within grain production regions in Russia and the USA, where grain is traded over short distances, are much smaller. In particular, long-run price transmission elasticities, as well as the speed of adjustment parameters are 50% lower in Russia compared to the USA at the interregional level, whereas at the intraregional level differences are barely observable. On the other hand, irrespective to the regional level of analysis, trade costs are relatively high in Russia compared to the USA.

Further, our study demonstrates that a comparative approach facilitates a more comprehensive assessment of spatial wheat market efficiency in Russia. First, including the US corn market as an empirical benchmark enabled us to assess the spatial market efficiency of the wheat market of Russia against the maximum level of spatial market efficiency obtainable in an empirical context. As the results indicate, differences exist between the empirically obtained benchmark estimates and theory-based values, especially regarding the speed at which temporary deviations from the equilibrium are corrected. Second, including an empirical benchmark in our analysis prevented us from underestimating the price adjustment parameters obtained for the wheat market of Russia at the intraregional level. With comparisons to the theoretical benchmark, we would have misleadingly concluded that the wheat prices in Russia adjust slowly at the intraregional level. Third, since there is not a theory-driven benchmark value assigned to thresholds, estimated thresholds for the US corn market provide a good reference point for assessing how large trade costs are in the Russian wheat market.

Furthermore, concerning the wheat market in Russia, the analysis of the interregional price transmission in Russia has made evident that the Russian wheat market is not uniformly integrated, but rather subdivided into two clusters. Just North Caucasus specifically, which primarily exports grain to the world market, is poorly integrated with the other five large grain production regions, which are mainly involved in domestic grain trade within Russia. This implies that price developments in North Caucasus, which strongly co-move with prices on the world market (compare Götz et al., 2016), are transmitted further to grain production regions of Russia to a limited extent. Our results also show that trade costs in Russia are high, indicating that the transport infrastructure is inadequate and search costs and market risk are also high in Russia. Unforeseen policy interventions for grain markets further increase the level of grain market uncertainty and, hence, costs of grain trade in Russia. The trade costs are especially highest for the distant grain markets of Ural and West Siberia, explaining their extremely weak integration with the export market in North Caucasus.

This has meaningful implications for West Siberia and Ural, which have large additional grain production potential, accounting for between 25% and 35% of Russia's additional grain production potential of 25–65 million tons (Swinnen et al., 2017). However, under the current market conditions of a weakly integrated wheat market and high trade costs, the additional wheat production potential in Ural and West Siberia cannot be transformed into additional export potential. Thus, taking these two additional factors into account, Russia's additional grain export potential could increase by 15–45 million tons at most (for calculations see Table S9, supplementary material). Further, our results imply that Russia's additional grain export potential falls below the estimated 70 million tons by Deppermann et al. (2018), which assumes that 90% of the additional grain production is transformed into additional grain exports.

The mobilization of grain export potential in grain production regions will require substantial investments in the grain market and

transportation infrastructure to improve their integration with the export market. The enhancement of the efficiency of Russia's wheat market would ensure the faster transmission of price signals between regions, inducing concomitant flows of trade from surplus to deficit regions. This would contribute to cushioning the price increasing effects of regional harvest shortfalls, which are expected to become more widespread with climate change (Coumou and Rahmstorf, 2012). Strengthened domestic wheat price stability would reduce incentives for the government to implement export controls on the wheat market as a crisis policy, which induce welfare losses to farmers and traders and negatively affect the further development of the grain sector, and especially the development of the commodity futures markets.

Moreover, a spatially efficient wheat market in Russia would ensure that the additional wheat production potential is transformed into additional export potential, strengthening Russia's importance in future global wheat export markets, and thus for global food security, by becoming a breadbasket of the world. Future research may provide evidence on the determinants of the spatial market efficiency of wheat markets in Russia.

In general, this study has made evident the importance of distinguishing between agricultural production potential and agricultural export potential, especially if production potential is located in regions that are distant from the world markets. Since several large-scale countries beyond Russia are attributed high importance for future global food security (e.g. Brazil), spatial market efficiency should be given more attention as a further factor determining a country's role in future global food security. Therefore, we suggest that spatial market efficiency should be included in global scenario studies (for an overview see Le Mouél and Forslund (2017)) to assess future global food security.

Also, this study has shown that, in order to foster global food security, it is not sufficient to focus on raising agricultural production potential alone, e.g. by technological progress in plant breeding and agronomic practices. Explicitly boosting agricultural export potential by enhancing spatial market efficiency in the agricultural sector should also be considered a key priority.

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Declarations of interest

None.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.gfs.2019.07.004>.

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