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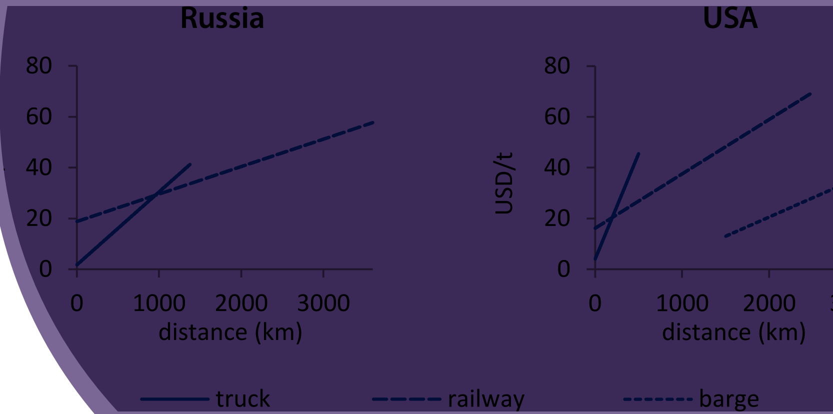

DISCUSSION PAPER 2019 # 187

Spatial market efficiency of grain markets in Russia and global food security: A comparison with the USA

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ABSTRACT

Using a threshold vector error correction model approach we find the wheat market of Russia segmented, with the primary grain export region poorly integrated into the domestic market. Results also indicate that trade costs are high, hindering spatial market efficiency of wheat markets in Russia. In addition, our study demonstrates that, by including the USA as benchmark country, a comparative approach enables a more comprehensive assessment of the spatial market efficiency of the wheat market in Russia. 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, besides raising agricultural production potential it is also essential to strengthen spatial market efficiency in the agricultural sector to boost agricultural export potential and to increase global food security.

KEYWORDS spatial market efficiency, grain production potential, Russia, TVECM, regularized Bayesian estimator

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1 \ Introduction

Grain production in Russia has shown an impressive growth since the dissolution of the Soviet Union in 1991. While Russia has previously been a large wheat importer, it had started to export wheat to the world market not until the beginning of the new century. Recently, Russia advanced to the largest wheat exporter in the world with wheat export amounting to 15% and 22% of global wheat export 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 further increase. Grain production in Russia could be further boosted by increasing grain production efficiency and also by re-cultivating formerly abandoned agricultural land (Bokusheva and Hockmann, 2006; Lioubimtseva and Henebry, 2012). Especially, Russia's additional grain production potential is assessed by Swinnen et al. (2017) to range between 25 and 65 million tons and by Deppermann et al. (2018) between 21 and 86 million tons.

However, the additional wheat production potential not only has to be mobilized but also has to be transformed into additional export potential to further increase Russia's importance for global wheat exports. This requires a spatially efficient domestic grain market, ensuring comprehensive and quick transmission of price changes from the grain export to the grain production regions.

In this study, we address the spatial market efficiency of the grain markets in Russia from a regional perspective. Following a price transmission approach, we focus on the primary grain production regions in Russia and measure their integration among each other. We investigate wheat price relationships between different grain production regions characterized by large distances and within selected grain production regions with relatively small distances.

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

We investigate the wheat market of Russia by contrast to the corn market of the USA. We assume that the corn market of the USA is one of the most efficient grain markets in the world and serves as an empirical benchmark (rather than a theory-based benchmark) for assessing the efficiency of the wheat market of Russia. Comparing the values of the estimated model parameters obtained for Russia vis-a-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. EU wheat market is also large to serve for comparisons, however, 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, we choose corn market rather than the wheat market of the USA for comparisons. Corn is also mainly produced and consumed domestically and heavily traded within the USA, similar to wheat in Russia. Further, grain trade in both countries is characterized by large distances, which is decisively important for the analysis of spatial price relationships.

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 conventional maximum likelihood approach especially in small samples (Greb et al., 2014). However, this model framework with its bivariate setup is only allowing pairwise price analysis. We utilize a data set consisting of 40 price pairs for Russia and 106 price pairs for the USA.

This study adds to the existing body of literature in the following ways.

First, it contributes to the price transmission literature by measuring spatial integration of regional grain markets within Russia. Götz et al. (2016) have also investigated the integration of regional wheat markets of Russia, however, with respect to the world wheat market. Further, Serebrennikov and Götz (2015) confirm that regional wheat trade reversal during the export ban in 2010 caused a change in direction of price adjustment between markets as 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 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.

Second, our study 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 distance to the international rice markets.

Third, our study contributes to the literature assessing Russia's role for 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 adds to this literature by focusing on the importance of spatially efficient markets for transforming Russia's grain production potential into grain export potential.

2 \ Characteristics of the grain market in Russia and its comparison with the USA

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

Whereas wheat is the primary grain produced in Russia constituting 60% of grain production, corn represents 80% of total grain production in the USA (USDA-WASDE, 2016). Contrasting, the share of wheat in total grain production in the USA is only 15% with further decreasing tendency.

Grain production in Russia, as in the USA, is concentrated on a limited, yet spatially protracted area. Six economic regions supply nearly all wheat produced in Russia (Figure 1). North Caucasus, Black Earth, Volga, Ural and West Siberia are wheat surplus regions, whereas Central region with Moscow is the primary wheat deficit region, which largely depends on external supplies.

Figure 1 Map of grain producing economic regions of Russia

The concentration of human grain consumption in few city centers (Moscow, St. Petersburg) and livestock producing regions (Central and Black Earth) in Russia requires that a large amount of wheat is transported from production to consumption sites over large distances. Contrasting, ethanol plants and livestock farms in the USA are concentrated in the main corn production regions, ensuring that corn is primarily transported over small distances. Only a few large corn net-consuming states of the USA, such as California, Texas and Washington, heavily depend on grain transported from other production regions. Washington is the grain export gateway to Asia, whereas Texas and California are among the largest livestock producing regions in the USA.

Wheat production in Russia is strongly influenced by climatic and weather conditions. Owing to vast distances, favorable production conditions and thus relatively high yields might be observed in some regions but relatively low yields in others at the same time. The variation of wheat production within a region is also generally high (Götz et al., 2016). In the Volga region, for example, average wheat production varied between 34% and 134% in 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% .

In Russia, North Caucasus is the primary production region, which almost exclusively supplies wheat to the world market, while its role in the domestic trade is rather limited. With its high-capacity sea terminals, North Caucasus also serves as a gate-market for the other grain producing regions, particularly Volga and Black Earth, to export to the world market. In contrast, Ural and West Siberia are far away not only from the world market, with the distance to the Black Sea ports amounting to 4000 kilometers, but also the grain consumption regions within Russia. In particular, Moscow is about 2000–3000 kilometer apart. Even the grain exports by Ural and West Siberia to the world market during the 2017/18 marketing season were heavily relying on large transport subsidies provided by the Russian government (USDA-GAIN, 2018).

Similarly, corn is transported over large distances between 1000 to 3000 kilometers in the USA especially from "Corn Belt" area states to California and Texas for livestock production and Washington seaports for further export.

Transport infrastructure is outdated and insufficient in some regions and strongly differs between regions in Russia. 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 transports are the primary means of wheat transportation in Russia. Rail transport dominates if the transportation distance exceeds 1000 kilometer, while road transport is preferred for routes up to 500 kilometers. River transportation is quite unusual for grain deliveries in Russia.

In contrast, river barge transport is common practice for grain transport over long distances in the USA due to the large weight capacity of barges and low costs (Figure 2).

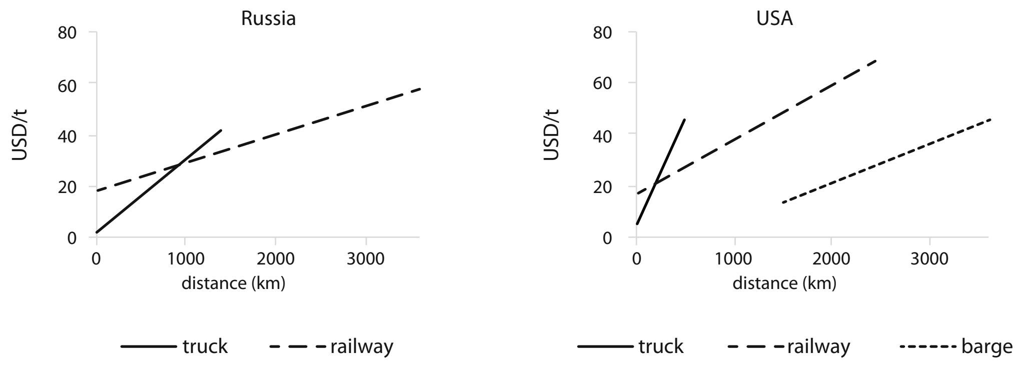


Figure 2 Grain transportation tariffs in Russia and the USA

Note: We linearly approximate transportation tariffs based on actual rates given for different distance routes in 2010.

Source: AEGIC (2016), Rosstat (2015), US Rail Waybill Samples (2017) and USDA-AMS (2017)

Considering land transport, grain transportation tariffs are lower in Russia compared to the USA (Figure 2). Nonetheless, overall transport costs are higher in Russia due to inadequate transport infrastructure and logistics, negatively influencing 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). Especially, trade costs are high due to the difficulty to enforce contracts and unforeseen policy interventions on grain markets (Götz et al., 2016).

3 \ Methodological framework and model estimation

Market integration between two geographically separated regions can be analyzed based on the Law of One Price (LOP). 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 the 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. Further, 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

$$p_{1t} = \alpha + \beta p_{2t} + \varepsilon_t \qquad (1)$$

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 transmission of price shocks 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, which 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 to measure 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

$$\Delta \boldsymbol{p_t} = \boldsymbol{\rho}\varepsilon_{t-1} + \sum_{m=1}^{M} \boldsymbol{\Theta}_m \Delta \boldsymbol{p}_{t-m} + \boldsymbol{\omega}_t \qquad (2)$$

where the vector of dependent variables $\Delta\boldsymbol{p}_t = (\Delta p_{1t}, \Delta p_{2t})$ denotes 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 $\Delta\boldsymbol{p}_{t-m}$ with lags $m = 1, \ldots, M$, ensuring that the model residuals are serially uncorrelated. $\boldsymbol{\omega}_t = (\omega_{1t}, \omega_{2t})$ denotes a white noise process with expected value $E(\boldsymbol{\omega}_t) = \mathbf{0}$ and covariance matrix $Cov(\boldsymbol{\omega}_t) = \Omega \in (\mathbf{R}^{+})^{2\times 2}$.

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 where 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 are due to large distances highly relevant to trade in the Russian wheat market:

$$\Delta \boldsymbol{p_t} = \begin{cases} \boldsymbol{\rho}_1 \varepsilon_{t-1} + \sum_{m=1}^{M} \boldsymbol{\Theta}_{1m} \Delta \boldsymbol{p}_{t-m} + \boldsymbol{\omega}_{1t}\,, if \qquad \varepsilon_{t-1} \le \tau_1 \\ \boldsymbol{\rho}_2 \varepsilon_{t-1} + \sum_{m=1}^{M} \boldsymbol{\Theta}_{2m} \Delta \boldsymbol{p}_{t-m} + \boldsymbol{\omega}_{2t}\,, if\ \tau_1 < \varepsilon_{t-1} \le \tau_2 \\ \boldsymbol{\rho}_3 \varepsilon_{t-1} + \sum_{m=1}^{M} \boldsymbol{\Theta}_{3m} \Delta \boldsymbol{p}_{t-m} + \boldsymbol{\omega}_{3t}\,, if \qquad \tau_2 < \varepsilon_{t-1} \end{cases} \tag{3}$$

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 on 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 if the price pairs of interest are linear or threshold cointegrated and thus if a long-run price equilibrium exists. We examine the existence of linear cointegration based on 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 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. Contrasting, price relationships *within* one individual grain production region with small distances between markets are in the focus of the intraregional analysis (Table 1).

Table 1 Database of grain price series underlying price transmission analysis

Country	Year	Price airs	Data frequency	Data source
Interregional analysis (between regions/federal states)				
Russia (6 regions)	2009–10	15	weekly	Rus. Gr. Union (2014)
USA (16 federal states)		63	weekly	USDA-AMS (2016)
Intraregional analysis (within regions/federal states)				
Black Earth (region)	2014–16	10	biweekly	Min. of Ag. (2016)
West Siberia (region)		15	biweekly	
Iowa (federal state)		28	weekly	GeoGrain (2016)
North Carolina (federal state)		15	weekly	

For the interregional analysis of the grain market of Russia, we make use of a unique data set of weekly prices of wheat of class three (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 North Caucasus, Black Earth, Central, Volga, Ural and West Siberia during 2005–2013 (Figure 3).

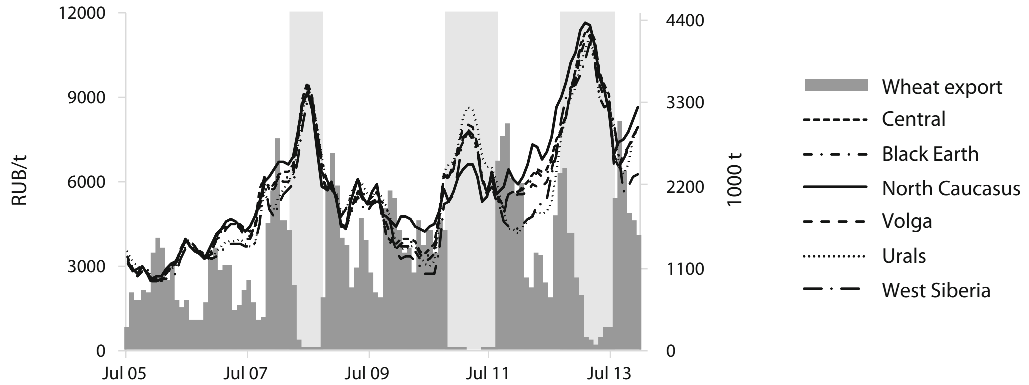


Figure 3 Development of regional wheat prices in Russia: 2005–2013

Note: The bold area on the graph represents the periods of export tax (Nov 2007–May 2008), export ban (Aug 2010–Jul 2011) and draught season (2012–2013).

Source: Russian Grain Union (2014), GTIS (2013)

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 (Figure 4). Oscillating behavior of prices coincides with the change in the direction and size of interregional trade flows resulting from large variations in the regional grain harvest due to weather conditions.

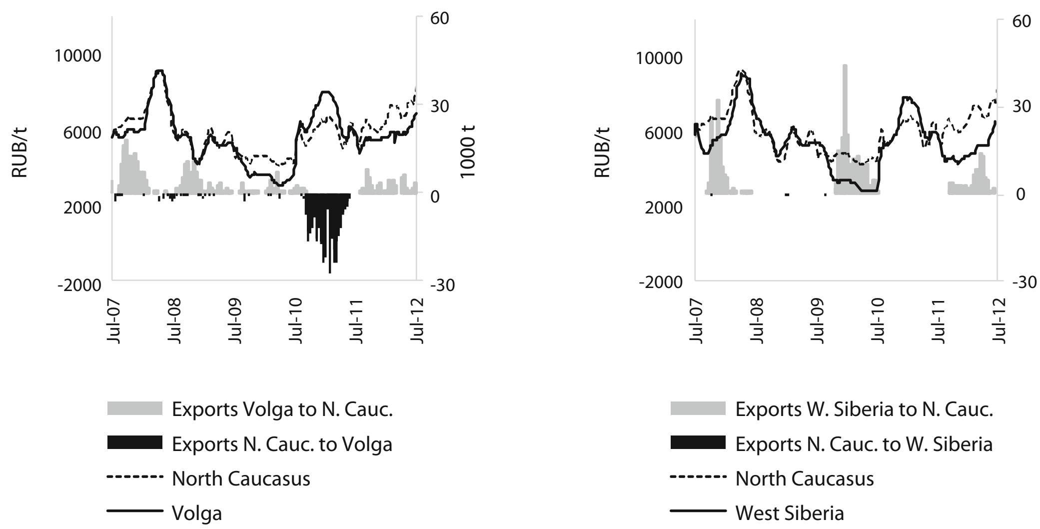


Figure 4 Wheat prices and regional trade: North Caucasus and Volga (left), North Caucasus and West Siberia (right)

Source: reproduced from Götz et al. (2016)

This implies that the interregional price relationships, which are depicted in the price transmission model, are not stable, and thus 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 only, which is characterized by relatively stable price relationships.

Therefore, to assess the strength of market integration in Russia at the interregional level, we confine our analysis to the price data of the individual grain production regions of the marketing year 2009–10 only, in which trade was freely possible. We construct altogether 15 price pairs comprising 52 weekly observations for each price series.

Correspondingly, we employ weekly corn prices for 16 federal states of the USA of 52 observations for the marketing year 2009–10 (USDA-AMS, 2016). We generate 63 price pairs, by combining prices observed in seven "Corn Belt" area states with prices monitored in nine corn net-consuming states.

For the intraregional integration of the grain market of Russia, we use prices observed within the two primary wheat producing regions Black Earth and West Siberia (Ministry of Agriculture of Russia 2016; Figure 5). Since price series for Russia are only available at the 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 10 price pairs for Black Earth and 15 price pairs for West Siberia, each price series comprising 52 biweekly observations in the period July 2014 to August 2016.

We choose West Siberia as it is one of the largest grain production regions in Russia, primarily involved in domestic wheat trade due to its large distances to the world market. However, instead of Black Earth, we would have preferred to analyze price relationships in North Caucasus, which is the primary grain export region with direct access to its ports at the Black Sea. Nonetheless, since the quality of the price data for North Caucasus (Figure 5) does not suffice the data requirements for a rather complex TVECM we choose its neighboring Black Earth region as an alternative.

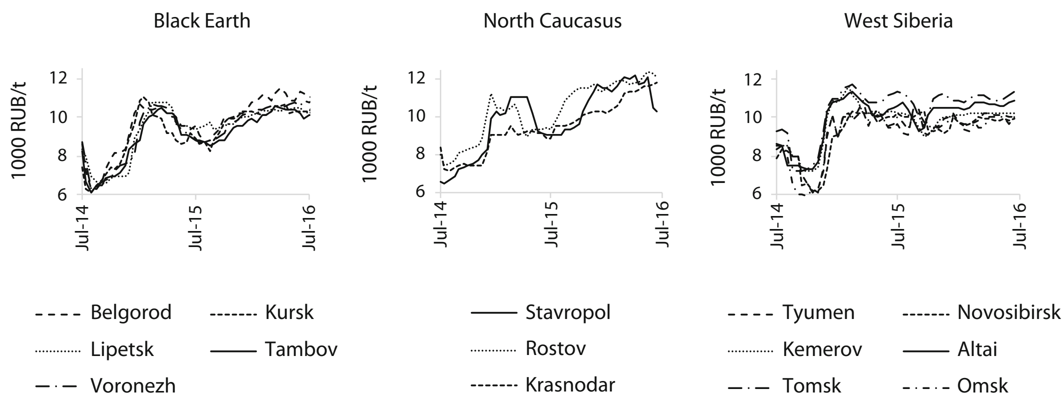


Figure 5 Development of regional wheat prices in Black Earth, North Caucasus and West Siberia during 2014–2016

Source: Ministry of Agriculture of Russia (2016)

Likewise, the intraregional analysis for the USA covers Iowa, 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. The price series for Iowa and North Carolina are supplied by the consultancy company GeoGrain (2016). Thus, we analyze 28 price pairs for Iowa and 15 price pairs for North Carolina, each price series comprising 110 weekly observations (July 2014 to August 2016).

5 \ Empirical results

5.1. | Data properties

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 A1, Appendix).

The tests on cointegration of the price pairs involved in the interregional analysis indicate that linear or threshold cointegration is identified for all 15 price pairs representing the Russian wheat market, and 53 out of 63 price pairs for the corn market in the USA, 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.

Table 2 Summary results of cointegration tests

	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 A2 and A3 in Appendix.

5.2. | Measurement of market integration

In this subsection, we present selected estimation results of the wheat price transmission analysis for Russia and the 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.

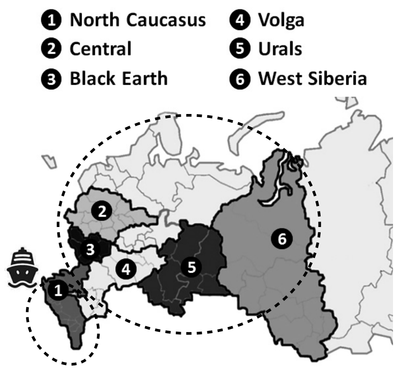
5.2.1 | Long-run price equilibrium

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 integration of wheat markets between regions of Russia is weaker, the higher the distance between those regions.

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**



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

Further, results indicate that North Caucasus is the least integrated with the other grain producing regions of Russia. Price changes are transmitted between markets by 13% to 35% if one of the two regions in question is North Caucasus, whereas prices are transmitted by 36% to 94% between other regions of Russia. Obviously, the export region negatively affects the degree of wheat market integration in Russia.

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 Figure 6 (left). The long-run price transmission parameters estimated within the intraregional analysis for Russia and the USA are shown in Figure 6 (right).

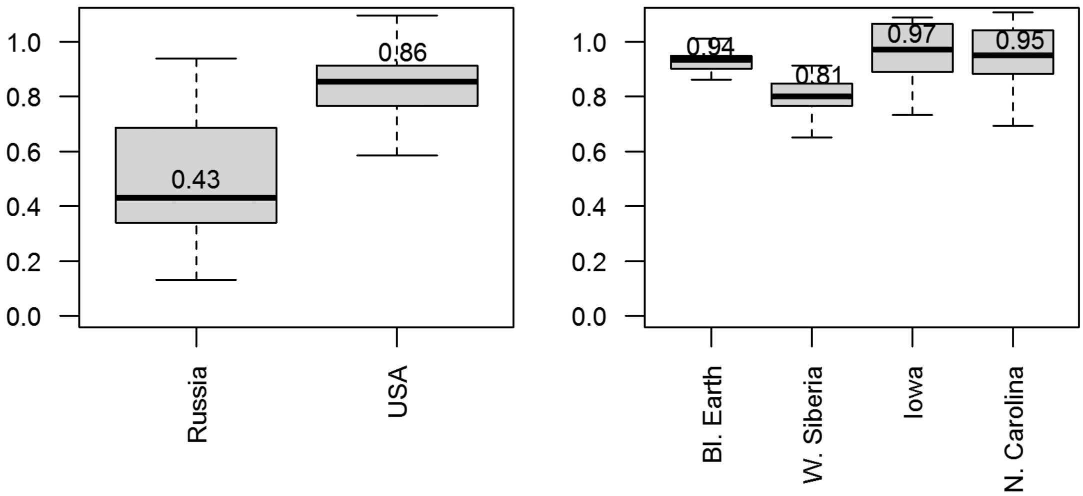


Figure 6 Boxplots of the estimated long-run price transmission elasticity parameters: interregional analysis (left), intraregional analysis (right)

Note: Plots are based on estimated parameters given in Table 3, Table A4 and Table A5.

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

Concerning cross-country comparisons, median long-run price transmission elasticity equals to 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 that 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 Figure 7.

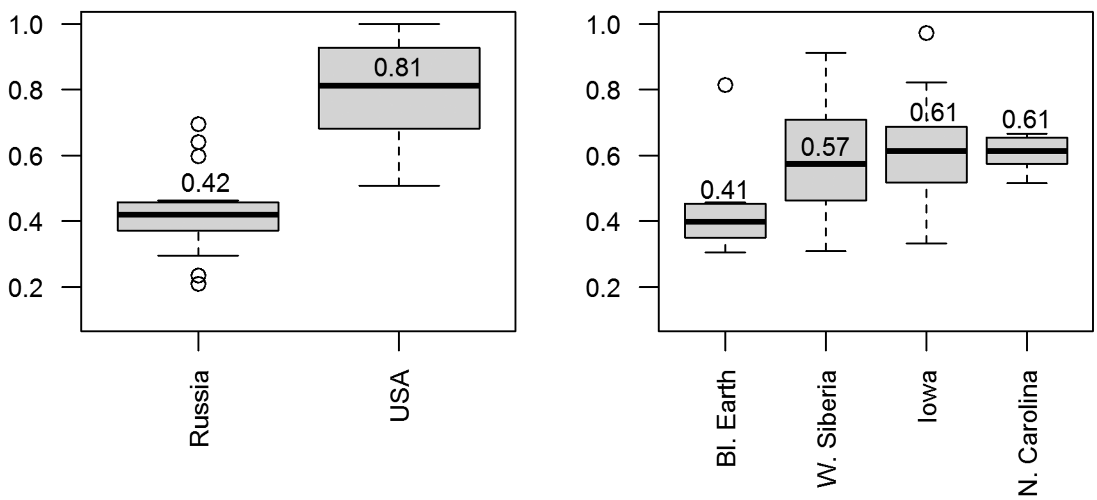


Figure 7 Boxplots of the estimated speed of adjustment parameters: interregional analysis (left), intraregional analysis (right)

Note: Plots are based on estimated parameters given in Table A6 and Table A7 in Appendix. To compare the speed of adjustment parameters of different frequencies we convert parameters from weekly to biweekly frequency by using following formula $|\rho|^{biweekly} = 1 - (1 - |\rho|^{weekly})^2$.

The estimated adjustment parameters (at the bi-weekly frequency) suggest that the price disequilibrium is eliminated at a rate of 0.8 in the corn market of the USA, 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 empirical benchmark at the intraregional level is 0.6, which is by 40% lower compared to the theoretically obtainable speed of price adjustment parameter.

Results indicate that the median speed of adjustment is by nearly 40% lower for Russia (0.42) compared to the USA (0.81) at the interregional level (Figure 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 by 30% and 5% lower in Black Earth (0.41) and West Siberia (0.57), respectively (Figure 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 Figure 8.

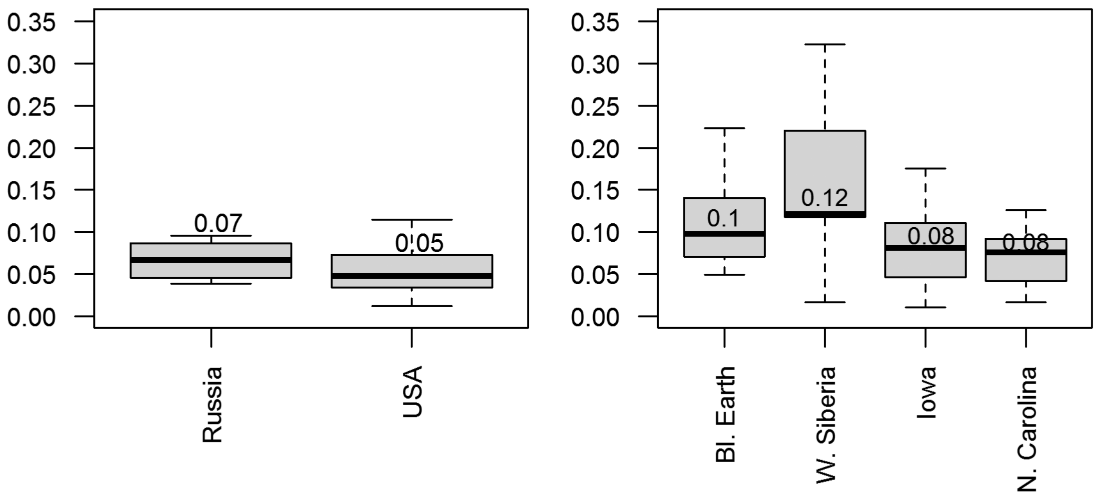


Figure 8 Boxplots of the estimated band of inaction parameters: interregional analysis (left), intraregional analysis (right)

Note: Plots are based on estimated parameters given in Table A6 and Table A7 in Appendix.

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. Especially, all price pairs including 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 size of trade costs in a spatially efficient market is not defined in the literature, estimating thresholds for the corn market of the USA allows evaluating 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 by 40% higher for Russia compared to the USA (Figure 8, left). Results at the intraregional level suggest that the band of inaction for Black Earth and West Siberia is by 25% and 50% higher compared to the USA (Figure 8, right).

6 \ Discussion of results and conclusions

This study has made evident that the integration of regional grain markets mostly in distant grain producing regions 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.

Further, our study has demonstrated that 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 and the size of trade costs. Thus, the comparative approach has enabled a more comprehensive assessment of the spatial market efficiency of the wheat market of 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. Especially, the grain production region in the North Caucasus, which primarily exports grain to the world market, is only 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 are strongly co-moving with prices on the world market (compare Götz et al., 2016), are only to a limited extent transmitted further to grain production regions of Russia. Also, results indicate that trade costs in Russia are high. Especially, trade costs are the highest for the distant grain markets in 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 bear large additional grain production potential, accounting for between 25% to 35% of Russia's additional grain production potential of 25 to 65 million tons (Swinnen et al., 2017). However, under current market conditions with 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 at most 15-45 million tons (for calculations see Table A8, Appendix). 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 export.

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 in 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.

Further, 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.

In general, this study has made evident the importance to distinguish between agricultural production potential and agricultural export potential, especially if production potential is located in regions, which are distant to 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 for future global food security. Therefore, we suggest that a spatial market efficiency should be included in global scenario studies (for an overview see Le Mouël and Forslund, 2017) to assess future global food security.

Also, this study has shown that to foster global food security, it is not sufficient to focus on raising agricultural production potential e.g. by technological progress in plant breeding and agronomic practices, but also to explicitly boost agricultural export potential by enhancing spatial market efficiency in the agricultural sector.

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APPENDIX

Table A1 Augmented Dickey-Fuller test for prices in levels and first differences

price series	determ. component	lags	test-stat.	Δ price series	determ. component	lags	test-stat.
Russia (interregional analysis)							
Central	Constant & trend	3	-2.924	Δ Central	None	0	-3.396***
N. Caucasus	Constant	1	-1.581	Δ N. Caucasus	None	0	-7.305***
Black Earth	None	1	-0.755	Δ Black Earth	None	0	-2.823***
Volga	Constant	4	-2.252	Δ Volga	None	0	-4.086***
Urals	Constant	1	-2.170	Δ Urals	None	0	-2.793***
W. Siberia	Constant	0	-2.211	Δ W. Siberia	None	1	-2.081***
USA (interregional analysis)							
Arkansas	Constant	0	-1.925	Δ Arkansas	None	0	-7.579***
California	Constant	0	-1.893	Δ California	None	0	-7.437***
Colorado	Constant	0	-1.690	Δ Colorado	None	0	-7.157***
Illinois	Constant	0	-2.376	Δ Illinois	None	0	-7.289***
Iowa	Constant	0	-2.448	Δ Iowa	None	0	-9.139***
Kansas	Constant	0	-1.793	Δ Kansas	None	0	-7.218***
Minnesota	Constant	0	-1.799	Δ Minnesota	None	0	-7.570***
Missouri	Constant	0	-1.857	Δ Missouri	None	0	-7.538***
Nebraska	Constant	0	-1.884	Δ Nebraska	None	0	-7.589***
Oklahoma	Constant	0	-1.802	Δ Oklahoma	None	0	-7.248***
Oregon	Constant	0	-1.696	Δ Oregon	None	0	-7.182***
S. Dakota	Constant	0	-2.400	Δ S. Dakota	None	0	-8.358***
Texas	Constant	0	-1.695	Δ Texas	None	0	-7.252***
Virginia	Constant	0	-1.996	Δ Virginia	None	0	-7.312***
Washington	Constant	0	-1.642	Δ Washington	None	0	-6.579***
Wyoming	Constant	0	-0.693	Δ Wyoming	None	0	-7.002***
Black Earth (intraregional analysis)							
Belgorod	None	1	1.314	Δ Adygea	None	0	-4.836***
Kursk	None	1	1.795	Δ Krasnodar	None	0	-5.472***
Lipetsk	None	1	0.517	Δ Rostov	None	0	-4.419***
Tambov	None	3	1.134	Δ Stavropol	None	2	-2.467***
Voronezh	Constant	1	-1.891	Δ Voronezh	None	0	-4.659***
West Siberia (intraregional analysis)							
Altai	Constant	1	-2.237	Δ Altai	None	0	-3.696***
Kemerovo	Constant	1	-2.395	Δ Kemerovo	None	0	-3.926***
Novosibirsk	Constant	0	-1.439	Δ Novosibirsk	None	0	-5.364***
Omsk	Constant	0	-1.431	Δ Omsk	None	1	-4.599***
Tomsk	Constant	1	-2.074	Δ Tomsk	None	1	-3.765***
Tyumen	Constant	0	-1.806	Δ Tyumen	None	1	-5.063***
Iowa (intraregional analysis)							
Cedar Rapids	Constant	0	-2.140	Δ Cedar Rapids	None	0	-10.444***
Clinton	Constant	0	-1.163	Δ Clinton	None	0	-9.478***
Davenport	Constant	0	-2.275	Δ Davenport	None	0	-9.609***
Eddyville	Constant & trend	0	-2.928	Δ Eddyville	None	0	-11.082***
Emmetsburg	Constant	0	-1.895	Δ Emmetsburg	None	0	-10.301***
Keokuk	Constant	0	-2.412	Δ Keokuk	None	0	-9.951***
Muscatine	Constant	0	-2.263	Δ Muscatine	None	0	-9.335***
W. Burlington	Constant	0	-2.118	Δ W. Burlington	None	0	-9.464***
North Carolina (intraregional analysis)							
Candor	Constant	0	-1.667	Δ Candor	None	0	-10.105***
Cofield	Constant	0	-1.763	Δ Cofield	None	0	-9.559***
Creswell	Constant	0	-2.312	Δ Creswell	None	0	-11.270***
Laurinburg	Constant	0	-1.817	Δ Laurinburg	None	0	-9.200***
Roaring River	Constant	0	-1.588	Δ Roaring River	None	0	-10.089***
Statesville	Constant	0	-1.861	Δ Statesville	None	0	-10.143***

Note: Lag length selection is based on Schwarz Information Criterion. * p<0.10, ** p<0.05, *** p<0.01.

Table A2 Tests of cointegration: interregional analysis

price pair	Hansen & Seo test (2002) [†, a]		Larsen test (2012) [†, b]	Johansen test (1988) [c]	
	sup-Wald test statistic	5% cr. value	p-value	trace test statistic	p-value
			Russia		
Central – Black Earth	11.111	18.398	0.06	21.606** / 4.031	0.033 / 0.408
Central – Volga	17.262	18.596	0.07	34.094*** / 5.105	0.001 / 0.272
Central – Urals	20.363***	18.566	0.21	27.700*** / 7.133	0.004 / 0.120
Central – W. Siberia	14.133**	13.109	0.40	22.342** / 6.243	0.026 / 0.173
N. Caucasus – Central	21.037**	19.054	0.02	14.645 / 3.468	0.248 / 0.497
N. Caucasus – Black Earth	13.932*	14.769	0.08	37.811*** / 4.477	0.001 / 0.346
N. Caucasus – Volga	21.666***	18.271	0.04	27.197** / 8.189	0.034 / 0.237
N. Caucasus – Urals	24.227***	19.072	0.01	16.076** / 0.598	0.041 / 0.439
N. Caucasus – W. Siberia	20.543**	19.377	0.02	36.835*** / 4.320	0.001 / 0.367
Black Earth – Volga	24.383*	05.088	0.04	20.484** / 4.454	0.047 / 0.349
Black Earth – Urals	25.332***	24.907	0.01	18.413* / 2.392	0.088 / 0.699
Black Earth – W. Siberia	15.223*	16.237	0.08	26.237*** / 4.579	0.007 / 0.333
Volga – Urals	17.746*	18.451	0.46	35.220*** / 6.298	0.001 / 0.169
Volga – W. Siberia	12.149*	13.296	0.06	25.246*** / 7.248	0.009 / 0.114
Urals – W. Siberia	18.002*	18.528	0.62	17.093 / 6.817	0.129 / 0.136
			USA		
Arkansas – Illinois	11.387	15.980	0.70	9.528 / 4.674	0.685/ 0.321
Arkansas – Iowa	16.040**	15.947	0.05	16.436** / 3.528*	0.036/ 0.060
Arkansas – Kansas	9.476	16.519	0.98	8.789 / 3.297	0.755 / 0.526
Arkansas – Minnesota	12.576	16.233	0.34	11.386 / 3.629	0.505 / 0.470
Arkansas – Missouri	14.236**	16.049	0.58	21.525** / 9.164	0. 033/ 0.543
Arkansas – Nebraska	16.593**	16.349	0.01	9.898 / 0.001	0.123 / 0.972
Arkansas – S. Dakota	7.041	16.557	0.26	10.643* / 0.001	0.094 / 0.997
California – Illinois	12.655*	13.636	0.03	24.530***/ 4.142	0.012 / 0.391
California – Iowa	15.553*	17.087	0.41	31.955***/ 3.468	0.001 / 0.497
California – Kansas	14.403	16.642	0.21	20.587**/ 3.186	0.045 / 0.546
California – Minnesota	17.510**	16.011	0.01	23.688***/ 3.018	0.016/ 0.577
California – Missouri	12.342*	13.603	0.26	30.757***/ 2.906	0.001/0.598
California – Nebraska	20.138**	18.474	0.12	29.767***/3.097	0.001/ 0.562
California – S. Dakota	11.643	14.028	0.01	32.662***/ 3.516	0.001/0.488
Colorado – Illinois	10.432	13.864	0.09	19.105**/ 2.434	0.013/ 0.118
Colorado – Iowa	11.573	13.418	0.28	26.259***/ 2.519	0.001/ 0.112
Colorado – Kansas	9.499	13.660	0.21	15.657**/ 5.172***	0.047/ 0.022
Colorado – Minnesota	12.088	16.271	0.12	8.843/ 2.741*	0.380/ 0.097
Colorado – Missouri	15.229*	15.647	0.22	14.072*/ 3.073*	0.081/ 0.079
Colorado – Nebraska	9.4381	13.448	0.85	6.240/ 1.953	0.667/ 0.162
Colorado – S. Dakota	12.891*	13.665	0.24	21.907***/ 3.841	0.004/ 0.106
Oklahoma – Illinois	12.826*	13.925	0.06	24.428**/ 3.562	0.012/ 0.481
Oklahoma – Iowa	14.715**	13.729	0.05	29.764**/ 3.366	0.002/ 0.514
Oklahoma – Kansas	15.683*	16.575	0.16	16.399**/ 3.434*	0.036/ 0.063
Oklahoma – Minnesota	20.062***	15.917	0.01	12.074/ 3.231*	0.153/ 0.072
Oklahoma – Missouri	17.247**	15.919	0.07	17.505**/ 3.841*	0.024/ 0.071
Oklahoma – Nebraska	14.978	16.306	0.31	8.888/ 3.271*	0.375/ 0.070
Oklahoma – S. Dakota	12.941*	13.593	0.08	17.751**/ 3.186*	0.022/ 0.074
Oregon – Illinois	18.956***	13.741	0.01	25.721***/ 6.552	0.008/ 0.152
Oregon – Iowa	17.515*	18.234	0.10	25.060**/ 3.042	0.010/ 0.572
Oregon – Kansas	16.902***	13.892	0.02	20.637**/ 7.298	0.044/ 0.106
Oregon – Minnesota	18.092**	16.285	0.01	14.581/ 3.248	0.251/ 0.535
Oregon – Missouri	11.520	13.244	0.24	23.816**/ 3.558	0.015/ 0.481
Oregon – Nebraska	10.207	13.271	0.22	10.411*/ 0.008	0.102/ 0.938
Oregon – S. Dakota	17.228***	13.601	0.01	21.960***/ 2.844*	0.004/ 0.091
Texas – Illinois	14.871**	14.115	0.05	16.911**/ 15.494	0.030/ 0.158
Texas – Iowa	12.696*	13.657	0.01	11.080*/ 0.005	0.080/ 0.950
Texas – Kansas	13.235*	14.024	0.26	33.326***/ 2.475	0.001/ 0.115
Texas – Minnesota	10.946	13.589	0.24	10.598*/ 0.051	0.095/ 0.852
Texas – Missouri	17.050**	16.727	0.25	20.667***/ 2.874*	0.007/ 0.090
Texas – Nebraska	15.481**	13.427	0.15	10.140/ 3.006*	0.270/ 0.082
Texas – S. Dakota	11.019	16.406	0.37	19.959***/ 2.704	0.009/ 0.100

(continued)

Table A2. (*continued*)

Virginia – Illinois	11.131	13.629	0.17	19.653*/ 3.633	0.060/ 0.469
Virginia – Iowa	9.079	13.096	0.13	34.631***/ 4.825	0.001/ 0.303
Virginia – Kansas	12.274	16.262	0.43	22.076**/ 5.625	0.027/ 0.221
Virginia – Minnesota	10.385	13.886	0.32	21.934**/ 6.740	0.029/ 0.140
Virginia – Missouri	13.757**	13.116	0.32	31.974***/ 3.957	0.001/ 0.418
Virginia – Nebraska	9.624	13.629	0.37	10.516*/ 0.023	0.098/ 0.899
Virginia – S. Dakota	11.328	13.578	0.01	13.822**/ 0.030	0.027/ 0.885
Washington – Illinois	12.481*	13.412	0.03	27.240***/ 4.474	0.004/ 0.346
Washington – Iowa	14.026*	14.300	0.20	33.120***/ 2.623	0.001/ 0.653
Washington – Kansas	13.458	15.638	0.25	21.222**/ 4.293	0.036/ 0.370
Washington – Minnesota	14.191**	13.198	0.24	14.326/ 2.656	0.267/ 0.646
Washington – Missouri	16.208**	15.956	0.01	31.900***/ 3.038	0.001/ 0.573
Washington – Nebraska	9.983	14.110	0.70	12.671/ 2.669	0.390/ 0.644
Washington – S. Dakota	12.162	13.877	0.27	22.459**/ 2.559	0.024/ 0.665
Wyoming – Illinois	10.723	13.364	0.36	21.784**/ 9.164	0.030/ 0.291
Wyoming – Iowa	9.385	13.961	0.49	22.083**/ 3.140	0.027/ 0.554
Wyoming – Kansas	11.594	14.075	0.22	20.220**/ 7.547	0.050/ 0.100
Wyoming – Minnesota	5.873	8.959	0.92	10.641/ 3.446	0.577/ 0.500
Wyoming – Missouri	15.099**	13.511	0.08	15.860**/ 3.834**	0.044/ 0.050
Wyoming – Nebraska	10.925	13.366	0.46	11.351/ 3.514*	0.190/ 0.060
Wyoming – S. Dakota	12.893	13.762	0.12	26.594***/ 2.971*	0.001/ 0.084

Note: † H_0: linear cointegration | H_1: threshold cointegration. Trimming parameter is 0.05, number of bootstrapping is set to 1000, type of bootstrapping is "fixed Regression". ^{a} two-regime TVECM with one threshold, ^{b} three-regime TVECM with two thresholds. ^{c} the first number in the column refers to the hypothesis H_0: no cointegration | H_1: at least one cointegration equation. The second number in the columns refers to the hypothesis H_0: one cointegration equation | H_1: two cointegration equations. * p<0.10, ** p<0.05, *** p<0.01.

Table A3 Tests of cointegration: intraregional analysis

price pair	Hansen & Seo test (2002) ^{†,a}		Larsen test (2012) ^{†,b}	Johansen test (1988) ^{c}	
	sup-Wald test statistic	5% cr. value	p-value	trace test statistic	p-value
			Black Earth		
Belgorod – Kursk	14.270**	13.568	0.13	14.799**/ 2.892	0.018/ 0.105
Belgorod – Lipetsk	13.630	16.228	0.16	29.167***/ 4.277	0.002/ 0.372
Belgorod – Tambov	20.756***	13.707	0.01	26.637***/ 2.057	0.001/0.178
Belgorod – Voronezh	13.468*	14.112	0.26	25.968***/ 7.886*	0.007/0.086
Kursk – Lipetsk	12.413	19.277	0.41	21.096***/ 12.320*	0.001/ 0.088
Kursk – Tambov	18.881**	17.054	0.01	43.219***/ 7.574*	0.000/ 0.099
Kursk – Voronezh	24.478*	25.016	0.38	44.483/*** 7.635*	0.000/ 0.096
Lipetsk – Tambov	11.915	14.056	0.29	13.617**/ 2.343	0.030/ 0.148
Lipetsk – Voronezh	18.238**	18.120	0.41	10.719*/ 0.551	0.091/0.520
Tambov – Voronezh	20.310***	14.203	0.01	26.475***/ 2.617	0.001/ 0.124
			West Siberia		
Kemerovo – Altai	12.935**	12.939	0.18	18.767* / 5.482	0.079 / 0.135
Kemerovo – Novosibirsk	19.089***	13.139	0.03	30.322*** / 6.506	0.002 / 0.155
Kemerovo – Omsk	9.957	12.789	0.56	21.270** / 4.098	0.036 / 0.398
Kemerovo – Tomsk	9.368	13.356	0.09	22.650** / 4.798	0.023 / 0.306
Novosibirsk – Altai	15.724**	13.972	0.32	26.038*** / 5.217	0.007 / 0.261
Novosibirsk – Omsk	23.676***	17.139	0.01	38.701*** / 3.545	0.001 / 0.484
Tomsk – Novosibirsk	16.473*	17.202	0.35	53.816*** / 3.928	0.001 / 0.423
Tomsk – Altai	21.845**	21.089	0.32	25.430*** / 6.325	0.009 / 0.167
Tomsk – Omsk	15.671**	13.328	0.15	21.658** / 3.772	0.032 / 0.447
Altai – Omsk	13.971**	13.345	0.04	23.557** / 5.001	0.017 / 0.283
Tyumen – Altai	10.489	12.914	0.09	25.297*** / 5.671	0.009 / 0.218
Tyumen – Kemerovo	14.738*	15.638	0.02	18.526* / 6.927	0.085 / 0.130
Tyumen – Novosibirsk	17.544***	13.067	0.16	28.365*** / 2.805	0.003 / 0.618
Tyumen – Omsk	15.521***	13.185	0.06	33.161*** / 3.703	0.001 / 0.458
Tyumen – Tomsk	13.238*	13.432	0.13	33.269*** / 4.064	0.001 / 0.403

(continued)

Table A3. *(continued)*

price pair	Hansen & Seo test (2002) †, a		Larsen test (2012) †, b	Johansen test (1988) c	
	sup-Wald test statistic	5% cr. value	p-value	trace test statistic	p-value
			Iowa		
Cedar Rapids – Emmetsburg	15.803**	15.107	0.02	16.035/ 20.261	0.172/ 0.177
Clinton – Cedar Rapids	16.616**	15.122	0.03	24.361**/ 4.720	0.012/ 0.315
Clinton – Davenport	12.583	15.138	0.11	28.464**/ 6.592	0.023/ 0.388
Clinton – Emmetsburg	18.130***	14.897	0.01	21.362**/ 5.334	0.035/ 0.248
Eddyville – Cedar Rapids	19.128***	15.515	0.02	19.644*/ 4.475	0.060/ 0.345
Clinton – Muscatine	11.728	15.158	0.38	36.069***/ 3.637	0.001/ 0.468
Davenport – Cedar Rapids	11.988	14.900	0.09	10.243/ 2.104	0.615/ 0.756
Davenport – Emmetsburg	14.038*	15.428	0.28	28.627**/ 9.429	0.022/ 0.155
Eddyville – Clinton	13.870*	15.136	0.08	24.082**/ 5.418	0.014/ 0.240
Eddyville – Davenport	14.210*	14.514	0.33	14.996/ 5.115	0.226/ 0.271
Eddyville – Emmetsburg	14.515	17.805	0.06	18.428*/ 2.966	0.0876/ 0.587
Eddyville – Keokuk	31.678*	32.574	0.13	14.545**/ 0.425	0.020/ 0.577
Eddyville – Muscatine	13.144	15.105	0.09	20.042*/ 5.567	0.053/ 0.226
Keokuk – Cedar Rapids	13.884	15.448	0.32	13.176/ 4.144	0.349/ 0.391
Keokuk – Clinton	15.017**	14.855	0.09	12.640/ 4.020	0.393/ 0.409
Keokuk – Davenport	15.058	18.674	0.35	24.048**/ 7.208	0.014/ 0.115
Keokuk – Emmetsburg	10.561	15.130	0.09	15.995/ 5.114	0.174/ 0.271
Keokuk – Muscatine	17.933*	18.504	0.27	23.704**/ 7.129	0.016/ 0.119
Muscatine – Cedar Rapids	16.707**	14.648	0.01	19.604*/ 9.164	0.061/ 0.340
Muscatine – Davenport	14.732*	14.835	0.70	7.034/ 0.705	0.321/ 0.460
Muscatine – Emmetsburg	10.496	14.547	0.23	18.233*/ 7.287	0.092/ 0.112
W. Burlington – Cedar Rapids	18.285*	18.799	0.54	10.347/ 1.997	0.605/ 0.778
W. Burlington – Clinton	12.711	14.691	0.12	12.578/ 3.912	0.398/ 0.425
W. Burlington – Davenport	14.944	18.461	0.11	26.991***/ 6.291	0.005/ 0.169
W. Burlington – Eddyville	15.427**	14.625	0.01	20.565**/ 6.149	0.045/ 0.179
W. Burlington – Emmetsburg	21.514***	14.811	0.01	26.240**/ 6.535	0.045/ 0.395
W. Burlington – Keokuk	16.866	18.003	0.01	19.107*/ 6.093	0.071/ 0.183
W. Burlington Muscatine	20.126**	19.244	0.23	21.819**/ 6.776	0.030/ 0.138
			North Carolina		
Candor – Creswell	18.470***	14.107	0.03	19.048*/ 3.416	0.072/ 0.505
Cofield – Candor	19.469**	17.478	0.07	10.149/ 3.674	0.625/ 0.462
Cofield – Creswell	12.048	14.379	0.18	21.288**/ 4.576	0.036/ 0.333
Laurinburg – Candor	15.472**	14.902	0.14	16.517/ 3.727	0.151/ 0.454
Laurinburg – Cofield	11.681	17.164	0.25	8.813/ 3.467	0.753/ 0.497
Laurinburg – Creswell	15.206**	14.573	0.10	22.975**/ 4.832	0.020/ 0.302
Laurinburg – Roaring River	18.305***	14.860	0.03	15.741/ 2.987	0.186/ 0.582
Laurinburg – Statesville	20.286	14.865	0.01	14.781/ 3.979	0.239/ 0.415
Roaring River – Candor	12.362	15.349	0.06	24.230**/ 2.991	0.013/ 0.582
Roaring River – Cofield	13.446*	13.669	0.16	13.100/ 3.062	0.355/ 0.569
Roaring River – Creswell	10.038	14.862	0.34	26.770***/ 3.523	0.005/ 0.487
Roaring River – Statesville	16.402	17.659	0.09	14.970/2.862	0.228/ 0.606
Statesville – Candor	13.726*	14.354	0.19	12.392/ 3.310	0.414/ 0.524
Statesville – Cofield	15.691	17.822	0.07	11.612/ 3.862	0.484/ 0.433
Statesville – Creswell	12.661	14.357	0.18	18.602*/ 3.773	0.083/ 0.446

Note: † H_0: linear cointegration | H_1: threshold cointegration. Trimming parameter is 0.05, number of bootstrapping is set to 1000, type of bootstrapping is 'fixed Regression'. a two-regime TVECM with one threshold, b three-regime TVECM with two thresholds. c the first number in the column refers to the hypothesis H_0: no cointegration | H_1: at least one cointegration equation. The second number in the columns refers to the hypothesis H_0: one cointegration equation | H_1: two cointegration equations. * p<0.10, ** p<0.05, *** p<0.01.

Table A4 Parameters of long-run price equilibrium regression: USA, interregional analysis

price pair	distance (km)	long-run price transmission elasticities (β)	intercept parameter (α)
Arkansas – Illinois	595	-	-
Arkansas – Iowa	475	1.020	-0.054
Arkansas – Kansas	993	-	-
Arkansas – Minnesota	531	-	-
Arkansas – Missouri	393	0.888	0.593
Arkansas – Nebraska	581	0.912	0.468
Arkansas – S. Dakota	1144	0.895	0.635
California – Illinois	3288	0.948	1.151
California – Iowa	3084	0.957	-0.685
California – Kansas	2356	1.201	-2.134
California – Minnesota	3224	0.715	2.336
California – Missouri	2945	0.724	2.282
California – Nebraska	2675	0.767	2.064
California – S. Dakota	2548	0.760	2.170
Colorado – Illinois	1720	0.644	1.786
Colorado – Iowa	1273	0.752	1.230
Colorado – Kansas	494	-	-
Colorado – Minnesota	1482	-	-
Colorado – Missouri	974	0.856	0.715
Colorado – Nebraska	866	-	-
Colorado – S. Dakota	901	0.826	0.781
Oklahoma – Illinois	1315	0.613	1.935
Oklahoma – Iowa	1289	0.705	1.456
Oklahoma – Kansas	220	0.890	0.528
Oklahoma – Minnesota	1498	0.867	0.648
Oklahoma – Missouri	789	0.810	0.939
Oklahoma – Nebraska	874	-	-
Oklahoma – S. Dakota	1073	0.752	1.140
Oregon – Illinois	3642	0.843	0.593
Oregon – Iowa	2836	0.900	0.720
Oregon – Kansas	2472	0.755	1.454
Oregon – Minnesota	2926	0.765	1.401
Oregon – Missouri	2895	0.773	1.350
Oregon – Nebraska	2660	0.820	1.110
Oregon – S. Dakota	2245	0.806	1.253
Texas – Illinois	1226	0.674	1.575
Texas – Iowa	1487	0.787	0.985
Texas – Kansas	380	0.990	-0.050
Texas – Minnesota	1695	0.986	-0.022
Texas – Missouri	985	0.913	0.356
Texas – Nebraska	1032	0.903	0.414
Texas – S. Dakota	1262	0.848	0.595
Virginia – Illinois	1349	1.299	-1.412
Virginia – Iowa	1897	1.097	-0.387
Virginia – Kansas	2356	0.911	0.549
Virginia – Minnesota	1833	0.869	0.745
Virginia – Missouri	1754	0.946	0.358
Virginia – Nebraska	2037	0.895	0.598
Virginia – S. Dakota	2565	0.902	0.646
Washington – Illinois	3375	0.687	0.784
Washington – Iowa	2393	0.799	0.080
Washington – Kansas	2351	0.956	1.366
Washington – Minnesota	2482	0.956	1.359
Washington – Missouri	2628	0.985	1.202
Washington – Nebraska	2342	-	-
Washington – S. Dakota	1801	1.008	1.173
Wyoming – Illinois	1782	0.585	2.208
Wyoming – Iowa	1221	0.690	1.692
Wyoming – Kansas	721	0.879	0.789
Wyoming – Minnesota	1310	-	-
Wyoming – Missouri	1033	0.788	1.232
Wyoming – Nebraska	800	-	-
Wyoming – S. Dakota	653	0.780	1.189

Note: The hyphen (-) = not applicable, because the existence of long-run equilibrium is not confirmed.

Table A5 Parameters of long-run price equilibrium regression: intraregional analysis

price pair	distance (km)	long-run price transmission elasticities (β)	intercept parameter (α)
		Black Earth	
Belgorod – Kursk	142	0.932	0.666
Belgorod – Lipetsk	317	0.890	1.045
Belgorod – Tambov	477	0.944	0.442
Belgorod – Voronezh	255	0.919	0.773
Kursk – Lipetsk	323	0.861	1.262
Kursk – Tambov	451	0.949	0.478
Kursk – Voronezh	228	0.902	0.885
Lipetsk – Tambov	134	0.938	0.534
Lipetsk – Voronezh	133	0.987	0.120
Tambov – Voronezh	220	1.010	-0.071
		West Siberia	
Kemerovo – Altai	411	0.856	1.300
Kemerovo – Novosibirsk	267	0.672	3.043
Kemerovo – Omsk	906	0.652	3.234
Kemerovo – Tomsk	218	0.808	1.710
Novosibirsk – Altai	226	0.906	0.786
Novosibirsk – Omsk	654	0.797	1.852
Tomsk – Novosibirsk	268	0.776	2.160
Tomsk – Altai	490	0.913	0.759
Tomsk – Omsk	911	0.799	1.951
Altai – Omsk	880	0.728	2.560
Tyumen – Altai	1504	0.855	1.259
Tyumen – Kemerovo	1548	0.788	1.981
Tyumen – Novosibirsk	1280	0.838	1.485
Tyumen – Omsk	624	0.757	2.223
Tyumen – Tomsk	1538	0.826	1.492
		Iowa	
Cedar Rapids – Emmetsburg	354	0.780	1.143
Clinton – Cedar Rapids	138	0.979	0.110
Clinton – Davenport	66	0.733	1.367
Clinton – Emmetsburg	489	1.084	-0.494
Clinton – Muscatine	114	0.950	0.264
Davenport – Cedar Rapids	129	1.048	-0.278
Davenport – Emmetsburg	483	0.823	0.891
Eddyville – Cedar Rapids	174	1.066	-0.374
Eddyville – Clinton	290	1.083	-0.468
Eddyville – Davenport	240	0.928	0.359
Eddyville – Emmetsburg	367	0.856	0.726
Eddyville – Keokuk	182	0.891	0.523
Eddyville – Muscatine	166	1.088	-0.474
Keokuk – Cedar Rapids	188	-	-
Keokuk – Clinton	253	1.083	-0.451
Keokuk – Davenport	190	0.896	0.527
Keokuk – Emmetsburg	542	0.779	1.125
Keokuk – Muscatine	140	1.082	-0.428
Muscatine – Cedar Rapids	105	0.973	0.122
Muscatine – Davenport	47	0.766	1.184
Muscatine – Emmetsburg	462	1.065	-0.379
W. Burlington – Cedar Rapids	159	1.043	-0.239
W. Burlington – Clinton	193	-	-
W. Burlington – Davenport	126	1.020	-0.113
W. Burlington – Eddyville	151	0.970	0.129
W. Burlington – Emmetsburg	512	0.890	0.506
W. Burlington – Keokuk	66	0.921	0.389
W. Burlington – Muscatine	76	1.085	-0.440

(continued)

Table A5. *(continued)*

price pair	distance (km)	long-run price transmission elasticities (β)	intercept parameter (α)
		North Carolina	
Candor – Creswell	360	0.747	1.402
Cofield – Candor	333	1.043	-0.286
Cofield – Creswell	97	0.883	0.656
Laurinburg – Candor	71	1.010	-0.071
Laurinburg – Cofield	343	-	-
Laurinburg – Creswell	370	1.048	-0.367
Laurinburg – Roaring River	261	0.966	0.152
Laurinburg – Statesville	211	0.921	0.356
Roaring River – Candor	192	0.988	0.065
Roaring River – Cofield	286	0.693	1.630
Roaring River – Creswell	475	0.752	1.382
Roaring River – Statesville	65	0.933	0.404
Statesville – Candor	157	0.934	0.392
Statesville – Cofield	439	1.059	-0.304
Statesville – Creswell	470	1.108	-0.627

Note: The hyphen (-) = not applicable, because the existence of long-run equilibrium is not confirmed.

Table A6 Results of TVECM and VECM: interregional analysis[†]

price pair	lower regime			middle regime / VECM parameters [a]			upper regime		total adjustment [b]			
	sp. adj. (ρ_1)	p-value	threshold (τ_1)	sp. adj. (ρ_2)	p-value	threshold (τ_2)	sp. adj. (ρ_3)	p-value	lower	middle	upper	band of inaction [c]
					Russia							
Central – Black Earth	-0.379	0.360	*-0.021*	-0.373	0.336	*0.018*	-0.581*	0.089	0.564	0.596	0.929	*0.039*
Black Earth – Central	0.564*	0.072		0.596**	0.035		0.616**	0.015				
Central – Volga	-	-	-	-0.438***	0.001	-	-	-	-	0.641	-	-
Volga – Central	-	-		0.279**	0.047		-	-				
Central –Urals	-0.057	0.757	*-0.047*	-0.276	0.259	*0.029*	-0.316**	0.030	0.524	-	0.316	*0.076*
Urals – Central	0.524***	0.004		0.326	0.214		0.190	0.233				
Central – W. Siberia	-0.076	0.646	*-0.062*	-0.194	0.311	*0.021*	-0.304**	0.014	0.452	-	0.304	*0.083*
W. Siberia – Central	0.454**	0.041		0.157	0.574		-0.010	0.955				
N. Caucasus – Black Earth	-0.371**	0.041	*-0.021*	-0.371**	0.041	*0.020*	-0.371**	0.041	0.371	0.371	0.371	*0.041*
Black Earth – N. Caucasus	-0.036	0.809		-0.036	0.809		-0.036	0.809				
N. Caucasus – Central	-0.510***	0.025	*-0.030*	-0.386*	0.088	*0.020*	-0.308	0.136	0.510	0.385	-	*0.050*
Central – N. Caucasus	-0.281	0.187		0.215	0.299		-0.061	0.744				
N. Caucasus – Volga	-0.306*	0.078	*-0.038*	-0.323	0.136	*0.012*	-0.283*	0.060	0.306	-	0.283	*0.050*
Volga – N. Caucasus	-0.203	0.276		-0.143	0.569		-0.174	0.328				
N. Caucasus – Urals	-	-	-	0.045	0.774	-	-	-	-	0.464	-	-
Urals – N. Caucasus	-	-		0.464***	0.000		-	-				
N. Caucasus – W. Siberia	-0.219	0.146	*-0.049*	-0.234**	0.036	*0.029*	-0.234**	0.036	-	0.234	0.234	*0.078*
W. Siberia – N. Caucasus	-0.020	0.926		0.111	0.573		0.111	0.573				
Black Earth – Volga	-0.179*	0.086	*-0.046*	-0.271*	0.052	*0.011*	-0.179*	0.086	0.179	0.271	0.179	*0.057*
Volga – Black Earth	0.044	0.781		-0.006	0.979		0.044	0.781				
Black Earth – Urals	0.122	0.318	*-0.059*	0.122	0.318	*0.031*	0.010	0.928	0.503	0.503	0.349	*0.090*
Urals – Black Earth	0.503***	0.000		0.503***	0.000		0.349**	0.016				
Black Earth – W. Siberia	-	-	-	0.051	0.659	-	-	-	-	0.598	-	-
W. Siberia – Black Earth	-	-		0.598***	0.000		-	-				
Volga – Urals	-0.294	0.203	*-0.058*	-0.038	0.858	*0.038*	-0.506**	0.014	0.376	0.360	0.506	*0.096*
Urals – Volga	0.376*	0.067		0.360**	0.043		0.226	0.245				

(continued)

Table A6. *(continued)*

price pair	lower regime			middle regime / VECM parameters [a]			upper regime		total adjustment [b]			
	sp. adj. (ρ_1)	p-value	threshold (τ_1)	sp. adj. (ρ_2)	p-value	threshold (τ_2)	sp. adj. (ρ_3)	p-value	lower	middle	upper	band of inaction [c]
Volga – W. Siberia	-0.262	0.274	*-0.056*	-0.362**	0.035	*0.035*	-0.493***	0.004	-	0.362	0.493	*0.091*
W. Siberia – Volga	0.385	0.125		0.186	0.228		-0.051	0.763				
Urals – W. Siberia	-0.370*	0.072	*-0.027*	-0.337	0.183	*0.012*	-0.370	0.141	0.370	-	-	*0.039*
W. Siberia – Urals	0.381	0.157		0.306	0.324		0.022	0.951				
					USA							
Arkansas – Iowa	-0.303	0.468	*-0.090*	-0.481	0.249	*0.008*	-0.389	0.378	-	-	-	*0.098*
Iowa – Arkansas	0.421	0.334		-0.010	0.984		-0.006	0.991				
Arkansas – Missouri	-0.767*	0.059	*-0.025*	-0.767*	0.059	*0.024*	-0.312	0.488	0.767	0.767	-	*0.049*
Missouri – Arkansas	-0.076	0.898		-0.076	0.898		0.671	0.120				
Arkansas – Nebraska	-0.835**	0.020	*-0.034*	-0.726*	0.059	*0.012*	-0.835**	0.020	0.835	0.726	0.835	*0.047*
Nebraska – Arkansas	-0.351	0.520		-0.118	0.817		-0.351	0.520				
Arkansas – S. Dakota	-	-	-	-0.020	0.951	-	-	-	-	0.581	-	-
S. Dakota – Arkansas	-	-		0.581*	0.082		-	-				
California – Illinois	0.012	0.974	*-0.044*	0.065	0.859	*0.016*	-0.010	0.978	0.640	0.680	0.613	*0.060*
Illinois – California	0.640*	0.059		0.680**	0.037		0.613*	0.071				
California – Iowa	0.105	0.816	*-0.032*	-0.118	0.831	*0.010*	-0.576	0.175	0.813	-	-	*0.042*
Iowa – California	0.813**	0.051		0.510	0.383		-0.021	0.975				
California – Kansas	-	-	-	-0.250	0.424	-	-	-	-	0.681	-	-
Kansas – California	-	-		0.681*	0.057		-	-				
California – Minnesota	-0.783*	0.061	*-0.022*	-0.818*	0.081	*0.012*	-0.815**	0.050	0.783	0.818	-	*0.034*
Minnesota – California	-0.307	0.700		-0.237	0.780		-0.531	0.526				
California – Missouri	-0.131	0.730	*-0.037*	-0.131	0.730	*0.035*	-0.291	0.580	0.959	0.959	0.808	*0.073*
Missouri – California	0.959***	0.002		0.959***	0.002		0.808*	0.097				
California – Nebraska	-0.527	0.327	*-0.028*	-0.791**	0.047	*0.020*	-0.795*	0.080	-	0.791	0.795	*0.047*
Nebraska – California	0.537	0.401		0.406	0.507		0.304	0.659				
California – S. Dakota	-0.298	0.471	*-0.035*	-0.343	0.431	*0.005*	-0.298	0.471	-	-	-	*0.041*
S. Dakota – California	0.719	0.152		0.741	0.146		0.719	0.152				
Colorado – Illinois	1.036**	0.048	*-0.028*	1.036**	0.048	*0.025*	1.036**	0.048	0.736	0.736	0.736	*0.053*
Illinois – Colorado	0.736**	0.015		0.736**	0.015		0.736**	0.015				
Colorado – Iowa	-	-	-	1.421***	0.007	-	-	-	-	0.991	-	-
Iowa – Colorado	-	-		0.991***	0.001		-	-				
Colorado – Missouri	0.254	0.589	*-0.042*	0.223	0.587	*0.032*	0.254	0.589	0.632	0.556	0.632	*0.074*

(continued)

Table A6. *(continued)*

price pair	lower regime			middle regime / VECM parameters [a]			upper regime		total adjustment [b]			
	sp. adj. (ρ_1)	p-value	threshold (τ_1)	sp. adj. (ρ_2)	p-value	threshold (τ_2)	sp. adj. (ρ_3)	p-value	lower	middle	upper	band of inaction [c]
Missouri – Colorado	0.632*	0.075		0.556*	0.088		0.632*	0.075				
Colorado – S. Dakota	-0.003	0.995	*-0.019*	-0.099	0.856	*0.025*	-0.003	0.995	-	-	-	*0.044*
S. Dakota – Colorado	0.586	0.177		0.531	0.298		0.586	0.177				
Oklahoma – Illinois	1.347**	0.047	*-0.024*	1.347**	0.047	*0.024*	1.347**	0.047	0.875	0.875	0.875	*0.048*
Illinois – Oklahoma	0.875***	0.003		0.875***	0.003		0.875***	0.003				
Oklahoma – Iowa	0.099	0.859	*-0.091*	0.099	0.859	*0.023*	0.099	0.859	0.895	0.895	0.895	*0.114*
Iowa – Oklahoma	0.895***	0.008		0.895***	0.008		0.895***	0.008				
Oklahoma – Kansas	-0.225	0.787	*-0.012*	-0.225	0.787	*0.023*	-0.225	0.787	-	-	-	*0.035*
Kansas – Oklahoma	0.446	0.513		0.446	0.513		0.446	0.513				
Oklahoma – Minnesota	-0.503	0.290	*-0.040*	-0.503	0.290	*0.014*	-0.239	0.641	-	-	-	*0.054*
Minnesota – Oklahoma	-0.243	0.636		-0.243	0.636		0.333	0.450				
Oklahoma – Missouri	0.043	0.932	*-0.053*	-0.006	0.990	*0.028*	0.043	0.932	-	-	-	*0.081*
Missouri – Oklahoma	0.561	0.117		0.480	0.174		0.561	0.117				
Oklahoma – S. Dakota	-0.138	0.709	*-0.029*	-0.063	0.874	*0.033*	-0.063	0.874	-	-	-	*0.062*
S. Dakota – Oklahoma	0.446	0.182		0.483	0.158		0.483	0.158				
Oregon – Illinois	0.394	0.333	*-0.020*	0.622	0.217	*0.014*	1.408**	0.026	0.693	0.773	0.961	*0.034*
Illinois – Oregon	0.693*	0.059		0.773**	0.048		0.961***	0.008				
Oregon – Iowa	0.901	0.165	*-0.102*	0.463	0.466	*0.009*	0.944	0.155	0.999	-	0.999	*0.110*
Iowa – Oregon	0.999***	0.005		0.807	0.123		0.999***	0.006				
Oregon – Kansas	0.348	0.565	*-0.016*	0.579	0.402	*0.010*	0.593	0.392	-	-	-	*0.026*
Kansas – Oregon	0.691	0.250		0.785	0.190		0.791	0.186				
Oregon – Minnesota	-0.082	0.927	*-0.004*	0.015	0.987	*0.008*	0.255	0.797	-	-	-	*0.012*
Minnesota – Oregon	0.680	0.465		0.739	0.411		0.814	0.348				
Oregon – Missouri	-	-	-	0.469	0.303	-	-	-	-	0.985	-	-
Missouri – Oregon	-	-		0.985***	0.001		-	-				
Oregon – Nebraska	-	-	-	1.373***	0.008	-	-	-	-	0.970	-	-
Nebraska – Oregon	-	-		0.970***	0.001		-	-				
Oregon – S. Dakota	0.031	0.945	*-0.024*	0.031	0.945	*0.019*	0.018	0.966	-	-	-	*0.043*
S. Dakota – Oregon	0.748	0.132		0.748	0.132		0.741	0.134				
Texas – Illinois	-0.999***	0.004	*-0.009*	-0.999***	0.004	*0.009*	-0.999***	0.004	0.999	0.999	0.999	*0.018*
Illinois – Texas	-3.653***	0.000		-3.629***	0.000		-3.653***	0.000				
Texas – Iowa	1.030	0.195	*-0.100*	1.030	0.195	*0.014*	1.030	0.195	0.996	0.996	0.996	*0.113*
Iowa – Texas	0.996***	0.007		0.996***	0.007		0.996***	0.007				
Texas – Kansas	0.404	0.783	*-0.014*	0.404	0.783	*0.008*	0.438	0.767	-	-	-	*0.021*

(continued)

Table A6. *(continued)*

price pair	lower regime			middle regime / VECM parameters [a]			upper regime		total adjustment [b]			
	sp. adj. (ρ_1)	p-value	threshold (τ_1)	sp. adj. (ρ_2)	p-value	threshold (τ_2)	sp. adj. (ρ_3)	p-value	lower	middle	upper	band of inaction [c]
Kansas – Texas	0.743	0.485		0.743	0.485		0.753	0.475				
Texas – Minnesota	-	-	-	-0.735	0.339	-	-	-		-		
Minnesota – Texas	-	-		-0.404	0.735		-	-				
Texas – Missouri	0.316	0.567	*-0.033*	-0.170	0.754	*0.020*	0.316	0.567	0.791	-	0.791	*0.053*
Missouri – Texas	0.791**	0.044		0.529	0.299		0.791**	0.044				
Texas – Nebraska	-0.428	0.328	*-0.003*	-0.256	0.726	*0.011*	-0.428	0.328	-	-	-	*0.015*
Nebraska – Texas	-0.010	0.984		0.224	0.761		-0.010	0.984				
Texas – S. Dakota	-	-	-	0.213	0.550	-	-	-	-	0.766	-	-
S. Dakota – Texas	-	-		0.766**	0.011		-	-				
Virginia – Illinois	-	-	-	-0.050	0.910	-	-	-	-	0.617	-	-
Illinois – Virginia	-	-		0.617*	0.053		-	-				
Virginia – Iowa	-	-	-	-0.643**	0.023	-	-	-	-	0.643	-	-
Iowa – Virginia	-	-		0.384	0.247		-	-				
Virginia – Kansas	-	-	-	-0.924***	0.001	-	-	-	-	0.924	-	-
Kansas – Virginia	-	-		-1.063***	0.009		-	-				
Virginia – Minnesota	-	-	-	-0.778***	0.001	-	-	-	-	0.778	-	-
Minnesota – Virginia	-	-		-0.639*	0.078		-	-				
Virginia – Missouri	-0.886	0.017	*-0.009*	-0.774**	0.036	*0.023*	-0.774**	0.036	0.886	0.774	0.774	*0.032*
Missouri – Virginia	-0.316	0.599		-0.308	0.575		-0.308	0.575				
Virginia – Nebraska	-	-	-	-0.600***	0.009	-	-	-	-	0.600	-	-
Nebraska – Virginia	-	-		-0.308	0.281		-	-				
Virginia – S. Dakota	-0.509	0.052	*-0.049*	-0.254	0.462	*0.041*	-0.253	0.463	0.509	-	-	*0.090*
S. Dakota – Virginia	-0.185	0.611		0.235	0.545		0.238	0.539				
Washington – Illinois	0.668	0.190	*-0.061*	1.466**	0.026	*0.020*	1.466***	0.026	0.800	0.959	0.959	*0.081*
Illinois – Washington	0.800	0.013		0.959***	0.002		0.959***	0.002				
Washington – Iowa	-0.157	0.799	*-0.011*	0.589	0.500	*0.015*	0.589	0.500	-	-	-	*0.026*
Iowa – Washington	0.479	0.391		0.852	0.115		0.852	0.115				
Washington – Kansas	-	-	-	1.200*	0.071	-	-	-	-	0.980	-	-
Kansas – Washington	-	-		0.980***	0.007		-	-				
Washington – Minnesota	-0.862	0.118	*-0.024*	-0.862	0.118	*0.005*	-0.521	0.466	-	-	-	*0.029*
Minnesota – Washington	-0.621	0.553		-0.621	0.553		0.105	0.911				
Washington – Missouri	0.063	0.918	*-0.035*	0.081	0.896	*0.020*	0.095	0.879	0.900	0.903	0.905	*0.055*
Missouri – Washington	0.900	0.038		0.903**	0.037		0.905**	0.036				
Washington – S. Dakota	-	-	-	0.546	0.135	-	-	-	-	0.929	-	-

(continued)

Table A6. *(continued)*

price pair	lower regime			middle regime / VECM parameters [a]			upper regime		total adjustment [b]			
	sp. adj. (ρ_1)	p-value	threshold (τ_1)	sp. adj. (ρ_2)	p-value	threshold (τ_2)	sp. adj. (ρ_3)	p-value	lower	middle	upper	band of inaction [c]
S. Dakota – Washington	-	-		0.929^{***}	0.001		-	-				
Wyoming – Illinois	-	-	-	0.970^{***}	0.001	-	-	-	-	0.581	-	-
Illinois – Wyoming	-	-		0.581^{***}	0.001		-	-				
Wyoming – Iowa	-	-	-	1.036^{***}	0.008	-	-	-	-	0.851	-	-
Iowa – Wyoming	-	-		0.851^{***}	0.001		-	-				
Wyoming – Kansas	-	-	-	1.595^{**}	0.021	-	-	-	-	0.927	-	-
Kansas – Wyoming	-	-		0.927^{***}	0.001		-	-				
Wyoming – Missouri	0.276	0.622	*-0.060*	-0.431	0.135	*0.045*	1.029^{*}	0.070	0.681	-	0.681	*0.105*
Missouri – Wyoming	0.681	0.097		0.064	0.841		0.874^{***}	0.005				
Wyoming – S. Dakota	-	-	-	0.819^{**}	0.031	-	-	-	-	0.959	-	-
S. Dakota – Wyoming	-	-		0.959^{***}	0.001		-	-				

Note: [†]to make speed of adjustment parameters of different frequencies comparable we convert them from weekly to biweekly frequency by using following formula $|\rho|^{\text{biweekly}} = 1 - (1 - |\rho|^{\text{weekly}})^2$ for Russia and the USA. [a] parameters from the linear VECM are not regime-specific and thresholds are not estimated. Thus, linear VECM estimates are presented in the middle regime column. [b] total adjustment in one regime is calculated as the sum of the absolute value of the respective regime-specific speed of adjustment parameters of the TVECM significant at least 10% level. [c] the band of inaction is given as the difference between the absolute value of the upper and lower threshold. The hyphen (-) = not applicable. * p<0.10, ** p<0.05, *** p<0.01.

Table A7 Results of TVECM and VECM: intraregional analysis†

price pair	lower regime			middle regime / VECM parameters [a]			upper regime		total adjustment [b]			
	sp. adj. (ρ_1)	p-value	threshold (τ_1)	sp. adj. (ρ_2)	p-value	threshold (τ_2)	sp. adj. (ρ_3)	p-value	lower	middle	upper	band of inaction [c]
					Black Earth							
Belgorod – Kursk	-0.350***	0.004	*-0.048*	-0.349***	0.004	*0.032*	-0.350***	0.004	0.350	0.349	0.350	*0.080*
Kursk – Belgorod	0.109	0.479		0.105	0.501		0.025	0.479				
Belgorod – Lipetsk	-	-	-	-0.357***	0.001	-	-	-	-	0.357	-	-
Lipetsk – Belgorod	-	-		-0.209**	0.034		-	-				
Belgorod – Tambov	-0.445***	0.001	*-0.009*	-0.263***	0.066	*0.040*	-0.445***	0.000	0.445	-	0.445	*0.049*
Tambov – Belgorod	0.053	0.602		0.170	0.268		0.053	0.602				
Belgorod – Voronezh	-0.228	0.353	*-0.068*	-0.088	0.594	*0.109*	0.228	0.353	0.581	0.162	0.581	*0.177*
Voronezh – Belgorod	0.581***	0.002		0.162*	0.091		0.581***	0.002				
Kursk – Lipetsk	-	-	-	-0.337***	0.001	-	-	-	-	0.337	-	-
Lipetsk – Kursk	-	-		-0.017	0.956		-	-				
Kursk – Tambov	0.024	0.855	*-0.013*	-0.008	0.963	*0.085*	-0.042	0.791	0.400	0.468	0.504	*0.098*
Tambov – Kursk	0.400***	0.001		0.468***	0.001		0.504***	0.001				
Kursk – Voronezh	-0.165	0.457	*-0.087*	-0.264	0.186	*0.136*	0.028	0.931	0.326	0.311	0.721	*0.223*
Voronezh – Kursk	0.326**	0.039		0.311***	0.004		0.721**	0.014				
Lipetsk – Tambov	-	-	-	-0.004	0.967	-	-	-	-	0.306	-	-
Tambov – Lipetsk	-	-		0.306**	0.027		-	-				
Lipetsk – Voronezh	-0.039	0.786	*-0.102*	-0.205**	0.034	*0.002*	0.206**	0.045	0.339	0.205	0.506	*0.104*
Voronezh – Lipetsk	0.399*	0.067		0.041	0.810		0.506***	0.004				
Tambov – Voronezh	-0.726***	0.001	*-0.008*	0.179	0.316	*0.053*	-0.548	0.111	0.961	0.920	0.564	*0.061*
Voronezh – Tambov	0.235***	0.006		0.920***	0.006		0.564	0.104				
					West Siberia							
Kemerovo – Altai	-0.485***	0.002	*-0.059*	-0.402***	0.005	*0.039*	-0.402***	0.005	0.485	0.402	0.402	*0.098*
Altai – Kemerovo	-0.074	0.685		0.063	0.738		0.063	0.738				
Kemerovo – Novosibirsk	0.012	0.979	*-0.097*	-0.236	0.309	*0.123*	-0.145	0.630	-	0.367	0.608	*0.220*
Novosibirsk – Kemerovo	0.653	0.140		0.367***	0.008		0.608***	0.015				
Kemerovo – Omsk	-	-	-	-0.309**	0.027	-	-	-	-	0.309	-	-
Omsk – Kemerovo	-	-		0.304	0.170		-	-				
Kemerovo – Tomsk	-0.411*	0.073	*-0.057*	-0.149	0.249	*0.062*	-0.486*	0.086	0.411	-	0.468	*0.119*
Tomsk – Kemerovo	0.087	0.776		0.269	0.312		0.275	0.483				

(continued)

Table A7. *(continued)*

price pair	lower regime			middle regime / VECM parameters [a]			upper regime		total adjustment [b]			
	sp. adj. (ρ_1)	p-value	threshold (τ_1)	sp. adj. (ρ_2)	p-value	threshold (τ_2)	sp. adj. (ρ_3)	p-value	lower	middle	upper	band of inaction [c]
Novosibirsk – Altai	-0.401**	0.047	*-0.168*	-0.089	0.468	*0.066*	-0.295	0.195	0.401	-	-	*0.234*
Altai – Novosibirsk	-0.289	0.151		-0.137	0.289		-0.074	0.737				
Novosibirsk – Omsk	-1.151***	0.001	*-0.194*	-0.386**	0.057	*0.132*	-0.986***	0.001	-	0.386	0.986	*0.326*
Omsk – Novosibirsk	-0.113	0.719		0.093	0.644		-0.026	0.938				
Tomsk – Novosibirsk	-0.229	0.407	*-0.115*	0.112	0.651	*0.082*	0.008	0.980	0.507	0.485	0.773	*0.197*
Novosibirsk – Tomsk	0.507**	0.013		0.485***	0.001		0.773***	0.002				
Tomsk – Altai	-0.074	0.751	*-0.062*	-0.517*	0.056	*0.008*	-0.344	0.129	0.606	0.517	-	0.070
Altai – Tomsk	0.606***	0.005		0.011	0.967		0.197	0.385				
Tomsk – Omsk	-0.277**	0.041	*-0.015*	-0.084	0.956	*0.002*	-0.114	0.489	0.708	-	0.646	*0.017*
Omsk – Tomsk	0.431**	0.031		0.870	0.574		0.646***	0.006				
Altai – Omsk	-0.590**	0.020	*-0.147*	-0.047	0.723	*0.042*	-0.386	0.113	0.590	0.557	-	*0.189*
Omsk – Altai	0.116	0.692		0.557***	0.002		0.270	0.377				
Tyumen – Altai	-0.836***	0.001	*-0.117*	-0.710***	0.003	*0.007*	-0.714***	0.001	0.836	1.00	0.902	*0.124*
Altai – Tyumen	-0.356***	0.001		0.303**	0.021		0.188*	0.052				
Tyumen – Kemerovo	0.069	0.585	*-0.063*	0.064	0.626	*0.056*	0.064	0.626	0.508	0.531	0.531	*0.119*
Kemerovo – Tyumen	0.508***	0.006		0.531***	0.007		0.531***	0.007				
Tyumen – Novosibirsk	-0.838**	0.017	*-0.057*	-0.620**	0.023	*0.063*	-0.734*	0.081	0.838	0.620	0.734	*0.120*
Novosibirsk – Tyumen	0.040	0.879		0.281	0.135		0.258	0.466				
Tyumen – Omsk	-1.068***	0.001	*-0.089*	-0.869***	0.001	*0.069*	-0.869***	0.001	0.483	0.869	0.869	*0.158*
Omsk – Tyumen	-0.585**	0.053		-0.222	0.341		-0.221	0.341				
Tyumen – Tomsk	-0.995***	0.001	*-0.037*	-0.748***	0.001	*0.081*	0.779***	0.001	0.995	0.748	0.779	*0.112*
Tomsk – Tyumen	-0.255	0.202		0.097	0.683		0.077	0.752				
					Iowa							
Cedar Rapids – Emmetsburg	0.638	0.023	*-0.028*	0.638	0.023	*0.038*	0.638	0.023	-	-	-	*0.066*
Emmetsburg – Cedar Rapids	0.135	0.637		0.135	0.637		0.135	0.637				
Clinton – Cedar Rapids	-0.197	0.759	*-0.008*	-0.005	0.994	*0.018*	-0.197	0.759	-	0.812	-	*0.026*
Cedar Rapids – Clinton	0.705	0.191		0.812	0.108		0.705	0.191				
Clinton – Davenport	-	-	-	-0.195	0.528	-	-	-	-	0.429	-	-
Davenport – Clinton	-	-		0.429	0.057		-	-				
Clinton – Emmetsburg	0.117	0.709	*-0.038*	0.012	0.963	*0.044*	0.117	0.709	0.437	-	0.437	*0.081*
Emmetsburg – Clinton	0.437	0.049		0.287	0.150		0.437	0.049				
Eddyville – Cedar Rapids	-0.522	0.075	*-0.064*	-0.559	0.032	*0.032*	-0.522	0.075	0.522	0.559	0.522	*0.096*
Cedar Rapids – Eddyville	0.218	0.449		0.104	0.693		0.218	0.449				

(continued)

Table A7. *(continued)*

price pair	lower regime			middle regime / VECM parameters [a]			upper regime		total adjustment [b]			
	sp. adj. (ρ_1)	p-value	threshold (τ_1)	sp. adj. (ρ_2)	p-value	threshold (τ_2)	sp. adj. (ρ_3)	p-value	lower	middle	upper	band of inaction [c]
Clinton – Muscatine	-	-	-	0.138	0.843	-	-	-	-	0.787	-	-
Muscatine – Clinton	-	-		0.787	0.003		-	-				
Davenport – Cedar Rapids	0.332	0.374	*-0.123*	-0.421	0.031	*0.052*	0.332	0.374	0.726	-	0.726	*0.175*
Cedar Rapids – Davenport	0.726	0.002		-0.368	0.071		0.726	0.002				
Davenport – Emmetsburg	-0.306	0.047	*-0.077*	-0.394	0.039	*0.027*	-0.332	0.042	0.306	0.394	0.332	*0.104*
Emmetsburg – Davenport	-0.245	0.197		-0.360	0.134		-0.276	0.171				
Eddyville – Clinton	-0.634	0.014	*-0.051*	-0.634	0.014	*0.024*	-0.634	0.014	0.634	0.634	0.634	*0.075*
Clinton – Eddyville	0.130	0.603		0.130	0.603		0.130	0.603				
Eddyville – Davenport	0.194	0.540	*-0.079*	-0.671	0.005	*0.036*	-0.683	0.004	0.715	0.671	0.683	*0.115*
Davenport – Eddyville	0.715	0.004		-0.123	0.707		-0.195	0.555				
Eddyville – Emmetsburg	-0.669	0.001	*-0.076*	-0.627	0.006	*0.028*	-0.578	0.012	0.669	0.627	0.578	*0.103*
Emmetsburg – Eddyville	-0.298	0.305		-0.337	0.275		-0.259	0.386				
Eddyville – Keokuk	0.066	0.847	*-0.052*	-0.031	0.927	*0.027*	0.065	0.846	0.631	0.660	0.618	*0.078*
Keokuk – Eddyville	0.631	0.025		0.660	0.017		0.618	0.025				
Eddyville – Muscatine	-0.531	0.104	*-0.024*	-0.729	0.056	*0.003*	-0.546	0.097	0.531	0.729	0.546	*0.027*
Muscatine – Eddyville	0.447	0.126		0.243	0.566		0.437	0.145				
Keokuk – Clinton	-0.931	0.022	*-0.104*	-0.531	0.009	*0.044*	-0.045	0.001	0.931	0.531	0.045	*0.148*
Clinton – Keokuk	-0.755	0.290		-0.178	0.403		-2.393	0.141				
Keokuk – Davenport	-	-	-	-0.637	0.017	-	-	-	-	0.637	-	-
Davenport – Keokuk	-	-		0.059	0.743		-	-				
Keokuk – Emmetsburg	-0.585	0.008	*-0.144*	-0.401	0.023	*0.030*	-0.426	0.012	0.585	0.401	0.426	*0.174*
Emmetsburg – Keokuk	-0.680	0.019		-0.233	0.215		-0.270	0.142				
Keokuk – Muscatine	-0.823	0.006	*-0.070*	-0.282	0.294	*0.041*	0.370	0.002	0.823	-	-	*0.111*
Muscatine – Keokuk	-0.314	0.445		0.010	0.969		-2.488	0.188				
Muscatine – Cedar Rapids	-0.554	0.157	*-0.014*	-0.973	0.006	*0.019*	-0.554	0.157	-	0.973	-	*0.033*
Cedar Rapids – Muscatine	0.309	0.467		-1.316	0.080		0.309	0.467				
Muscatine – Davenport	0.335	0.461	*-0.094*	-0.600	0.008	*0.018*	-0.600	0.008	0.570	0.600	0.600	*0.113*
Davenport – Muscatine	0.570	0.091		-0.119	0.645		-0.119	0.645				
Muscatine – Emmetsburg	-	-	-	-0.686	0.004	-	-	-	-	0.686	-	-
Emmetsburg – Muscatine	-	-		-1.048	0.012		-	-				
W. Burlington – Cedar Rapids	-0.532	0.036	*-0.014*	-0.676	0.048	*0.032*	-0.532	0.036	0.532	0.676	0.532	*0.046*
Cedar Rapids – W. Burlington	-0.023	0.931		-0.730	0.108		-0.023	0.931				
W. Burlington – Davenport	-	-	-	-0.577	0.014	-	-	-	-	0.577	-	-
Davenport – W. Burlington	-	-		-0.006	0.968		-	-				
W. Burlington – Eddyville	-0.191	0.576	*-0.008*	-0.473	0.171	*0.003*	-0.191	0.576	0.626	-	0.626	*0.011*

(continued)

Table A7. *(continued)*

price pair	lower regime		threshold (τ_1)	middle regime / VECM parameters [a]		threshold (τ_2)	upper regime		total adjustment [b]			
	sp. adj. (ρ_1)	p-value		sp. adj. (ρ_2)	p-value		sp. adj. (ρ_3)	p-value	lower	middle	upper	band of inaction [c]
Eddyville – W. Burlington	0.626	0.031		0.429	0.209		0.626	0.031				
W. Burlington – Emmetsburg	0.146	0.499	*-0.044*	0.170	0.410	*0.049*	0.146	0.499	0.331	0.335	0.331	*0.094*
Emmetsburg – W. Burlington	0.331	0.068		0.335	0.052		0.331	0.068				
W. Burlington – Keokuk	5.509	0.065	*-0.051*	-0.111	0.796	*0.025*	-0.070	0.872	-	-	-	*0.076*
Keokuk – W. Burlington	-0.359	0.012		0.575	0.141		0.610	0.111				
W. Burlington – Muscatine	-0.593	0.102	*-0.032*	-0.595	0.100	*0.013*	-0.593	0.102	0.593	0.595	0.593	*0.045*
Muscatine – W. Burlington	-0.108	0.789		-0.116	0.774		-0.108	0.789				
North Carolina												
Candor – Creswell	-0.143	0.729	*-0.081*	-0.276	0.339	*0.032*	-0.214	0.492	0.655	-	-	*0.112*
Creswell – Candor	0.655	0.107		0.312	0.383		0.357	0.331				
Cofield – Candor	-0.244	0.221	*-0.097*	-0.047	0.799	*0.029*	-0.244	0.221	-	-	-	*0.126*
Candor – Cofield	-0.062	0.743		0.128	0.422		-0.062	0.743				
Cofield – Creswell	-	-	-	0.003	0.998	-	-	-	-	0.574	-	-
Creswell – Cofield	-	-		0.574	0.003		-	-				
Laurinburg – Candor	-0.097	0.762	*-0.038*	-0.097	0.762	*0.006*	-0.316	0.279	-	-	-	*0.045*
Candor – Laurinburg	0.348	0.230		0.348	0.230		0.072	0.813				
Laurinburg – Creswell	-0.647	0.010	*-0.050*	0.082	0.841	*0.036*	-0.685	0.015	0.647	-	0.685	*0.086*
Creswell – Laurinburg	-0.211	0.455		0.416	0.183		-0.138	0.674				
Laurinburg – Roaring River	-0.238	0.337	*-0.075*	-0.252	0.324	*0.003*	-0.515	0.039	-	-	0.515	*0.079*
Roaring River – Laurinburg	0.204	0.377		0.150	0.540		-0.048	0.861				
Laurinburg – Statesville	0.126	0.717	*-0.021*	3.804	0.002	*0.002*	0.126	0.717	-	-	-	*0.023*
Statesville – Laurinburg	0.254	0.397		0.972	0.002		0.254	0.397				
Roaring River – Candor	-0.284	0.448	*-0.029*	-0.284	0.448	*0.026*	-0.284	0.448	-	-	-	*0.055*
Candor – Roaring River	0.469	0.205		0.469	0.205		0.469	0.205				
Roaring River – Cofield	0.111	0.464	*-0.070*	0.183	0.296	*0.028*	0.111	0.464	-	-	-	*0.098*
Cofield – Roaring River	-0.289	0.133		-0.206	0.316		-0.289	0.133				
Roaring River – Creswell	-	-	-	-0.066	0.997	-	-	-	-	0.630	-	-
Creswell – Roaring River	-	-		0.630	0.007		-	-				
Roaring River – Statesville	-0.194	0.484	*-0.014*	-0.212	0.441	*0.003*	-0.194	0.484	-	-	-	*0.017*
Statesville – Roaring River	0.306	0.307		0.275	0.363		0.306	0.307				
Statesville – Candor	-0.260	0.510	*-0.024*	-0.232	0.553	*0.015*	-0.260	0.510	-	-	-	*0.039*
Candor – Statesville	0.120	0.755		0.139	0.710		0.120	0.755				

(continued)

Table A7. *(continued)*

price pair	lower regime			middle regime / VECM parameters [a]			upper regime		total adjustment [b]			
	sp. adj. (ρ_1)	p-value	threshold (τ_1)	sp. adj. (ρ_2)	p-value	threshold (τ_2)	sp. adj. (ρ_3)	p-value	lower	middle	upper	band of inaction [c]
Statesville – Cofield	-0.161	0.409	*-0.057*	-0.161	0.409	*0.018*	-0.161	0.409	-	-	-	*0.076*
Cofield – Statesville	0.052	0.775		0.052	0.775		0.052	0.775				
Statesville – Creswell	-	-	-	-0.021	0.978	-	-	-	-	0.596	-	-
Creswell – Statesville	-	-		0.596	0.016		-	-				

Note: † to make speed of adjustment parameters of different frequencies comparable we convert them from weekly to biweekly frequency by using following formula $|\rho|^{\text{biweekly}} = 1 - (1 - |\rho|^{\text{weekly}})^2$ for Iowa and North Carolina. Parameters for North Caucasus and West Siberia are by itself estimated on biweekly level. [a] parameters from the linear VECM are not regime-specific and thresholds are not estimated. Thus, linear VECM estimates are presented in the middle regime column. [b] total adjustment in one regime is calculated as the sum of the absolute value of the respective regime-specific speed of adjustment parameters of the TVECM significant at least 10% level. [c] the band of inaction is given as the difference between the absolute value of the upper and lower threshold. The hyphen (-) = not applicable. * p<0.10, ** p<0.05, *** p<0.01.

Table A8 Additional production potential in Russia at the regional level

Economic region	Sown area	Observed yield	Yield gap	Abandoned land	Intensification 80%	Recultivation 15%	Intensification 80% & recultivation 15%
Measurement unit	Mio ha	t/ha	t/ha	Mio ha	Mio t (% of total)	Mio t (% of total)	Mio t (% of total)
Column	A	B	D	E	F = (A x D) x 0.8	G = (B x E) x 0.15	H = F + G
Source	Swinnen *et al.* (2017)	Swinnen *et al.* (2017)	Swinnen *et al.* (2017)	Lesiv *et al.* (2018)	own calculation	own calculation	own calculation
Black Earth	2.21	2.95	1.99	2.19	8.69 (13%)	0.96 (7%)	4.10 (9%)
Central	1.37	2.14	3.04	9.53	5.51 (8%)	3.00 (21%)	6.20 (14%)
North Caucasus	5.13	2.52	2.75	4.39	17.25 (26%)	1.70 (12%)	6.75 (15%)
Ural	4.54	1.33	2.56	10.47	12.21 (18%)	2.01 (14%)	10.66 (24%)
Volga	3.75	1.78	1.56	8.76	10.99 (16%)	2.29 (16%)	7.02 (16%)
West Siberia	3.76	1.49	2.13	7.73	5.98 (9%)	1.13 (8%)	5.02 (11%)
Other regions	1.66	1.90	2.56	13.08	5.97 (9%)	3.37 (23%)	4.71 (11%)
Ural & West Siberia	**8.30**	**1.41**	**2.35**	**18.20**	**18.19 (27%)**	**3.14 (22%)**	**15.68 (35%)**
Total Russia	22.43	1.99	2.47	56.14	66.60 (100%)	14.46 (100%)	44.47 (100%)

Note: Data shown in columns A–E is provided by Florian Schierhorn.

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