Bayesian threshold adjustment in spatially integrated wheat markets in Russia

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Introduction

During the last two decades, the role of Russia in a world grain market rose significantly. In the period 2001/14, Russia became a net exporter of wheat supplying in total more than 174 million tons abroad. In 2014 its share of the total global exports of wheat amounted to 12.7% (USDA, 2015). Given this visible contribution to the world grain trade, global food security becomes increasingly dependent on regular and sufficient wheat supplies from Russia.

Owing to the availability of high-quality land and low levels of fertilization, Russia is able to substantially mobilize its production potential to further increase volumes of exported wheat (Lioubimtseva and Henebry, 2012). However, realization of this potential is constantly challenged by both climatic risks and policies of Russian government to restrict free trade with world markets. As a result, export supplies from Russia are quite often suspended that creates uncertainty in the global grain market and might lead to short-term shortages in countries-importers (Fellmann *et al.*, 2014).

To study the relevance of Russian wheat production for global food security, it is crucial to pay more attention to regional patterns inherent in production and distribution of wheat within the country. In Russia, grain production is scattered across six major areas, which include North Caucasus, Black Earth, Volga, Central, Urals and West Siberia. They cover a spatially protracted territory with diverse climatic conditions and different levels of infrastructural development.

The Southern and Central areas (North Caucasus, Black Earth, Central and Volga) have direct access to sea port facilities and thus world markets and have a developed network of railway tracks and highways. They are highly active in international grain trade and in delivering grain to consumption regions in Russia with deficit stocks. The major grain cultivated in this region is winter wheat. In contrast, Urals and West Siberia are far away from the world market (distance to Black Sea ports is up to 4000 km) and the major consumption areas (distance to Moscow is 2000-3000 km). Due to outdated and insufficient transport infrastructure, both regions are not well connected either with the world market or the consumption areas. The primary grain produced in those regions is spring wheat which is generally characterized by lower yields comparably to winter wheat.

Climatic differences primarily determine levels of wheat crop gathered in various regions. The areas in the South and Center are dominated by moderate continental climate with snowy and mild winters, but hot and dry summers. These conditions generally lead to rich crops of winter wheat, which is sown in late summer and remains under a snow cover throughout winter. However, insufficient precipitation in a summer time may endanger initially strong sowings. By contrast, Urals and West Siberia are located in the zone of continental climate, where winters are much harsher. Therefore, wheat is sown late in spring, while harvests are quite low. At the same time, weather conditions are more stable there and rarely result into harvest failures (Geography of Russia, 2015).

To capture possible effects of regional differentiation, we explore price relations between the six crop growing areas by using the economic model of price transmission. We primarily address two research questions. First, we aim to enlighten how fast price changes are transmitted between the selected regions. Additionally, we also take into account the possible influence of transaction costs. Second, we investigate the influence of export restrictions for grain on domestic wheat markets in Russia. The government has interfered in the grain export market several times. In 2007/8 it imposed an export tax for wheat up to 40%, whereas wheat exports were completely banned during the 2010/11 commodity price peak. In February 2015, an export tax of 15% was implemented for wheat. Export restrictions aim to increase supply on the domestic market inducing price decreasing effects. This paper focuses on the wheat export ban in 2010/11, which was supplemented by a transport subsidy for grain transport between selected regions within Russia. During the wheat export ban, interregional trade within Russia increased substantially. In particular, large amounts of wheat were exported from surplus regions (North Caucasus and West Siberia) to the consumption areas (Central) and regions which were most severely affected by the drought (Urals and Volga). Our research question is: Did the export ban influence price relationships and price transmission between the different regions within Russia? What is the role of the transport subsidy?

To analyze both research questions, we apply threshold vector error-correction model (TVECM) with two thresholds and three regimes (Greb *et al.*, 2013). This model represents a flexible tool to estimate possible asymmetric effects that emerge from a change in trade direction and/or from a difference in transaction costs. As our findings suggest, export restricting policy of Russian government provided necessary circumstances for such effects to spring.

The remainder of this paper is organized as follows. In the next section, we discuss market conditions and the consequences of export ban 2010/11 for wheat trade in Russia. This is followed by the review of major literature sources. The detailed presentation of econometric model is given in the section on methodology and estimation. Data section focuses on the properties and preliminary assessment of time series used in analysis. In the results section, we discuss outcomes of model estimation. In the final section, concluding remarks are given.

Market environment and the export ban 2010/11

Geographical clustering of wheat production

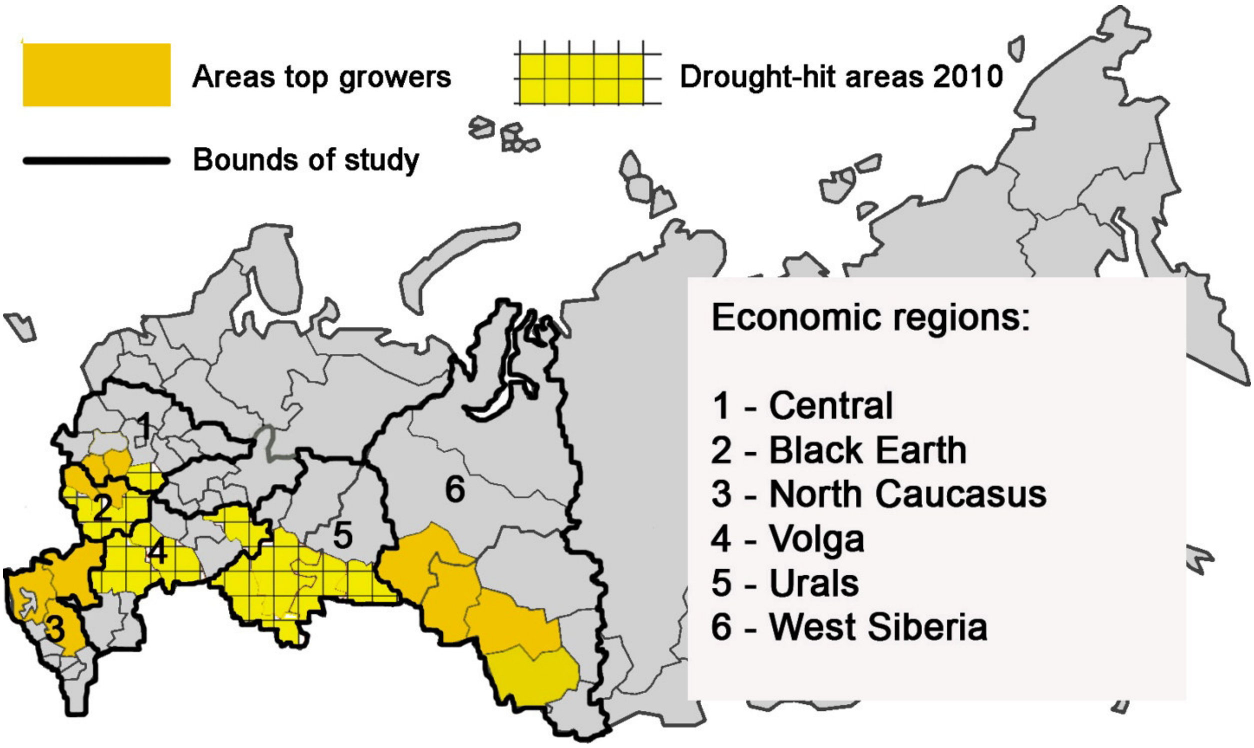
Wheat production in Russia is concentrated on a limited, yet spatially protracted area. Biggest crops are traditionally harvested in the south of European part (North Caucasus, Black Earth and Volga) as well as in Urals and West Siberia. These regions together form so-called "wheat belt" spreading over about 4000 kilometers along the border with Ukraine, Georgia and Kazakhstan. Two large regional production clusters emerge depending on both the type of culture and the area of cultivation. Winter wheat cluster covers Southwest Russia between Black Sea and Volga. Yields in this area amounted averagely to 3 tons/hectare in 2006-2010. Spring wheat cluster spans over Urals and West Siberia. In contrast to winter wheat, spring wheat is much less productive as only 1.7 ton/hectare were reaped there in 2006-2010 (Rosstat, 2015, 1). Both production clusters are essentially surplus areas that supply wheat to primarily consuming markets situated in Central as well as in North West and Far East. Additionally, a large portion of annual harvest is also being exported abroad. For instance, in the 2011-2012 marketing year Russia exported 22.5 million tons of wheat or 40% of the total wheat harvest (USDA, 2015).

As production areas cover large territory, the influence of transport infrastructure is crucial for distribution of wheat. Some regions have much better infrastructure than others. For instance, density of railway network is highest in the European part of Russia, whereas it is much lower in Urals and West Siberia. It is reported that 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 (Gonenko, 2011).

Trade effects of export ban

Whether conditions are a key determinant of wheat harvest in Russia. In recent years, Russian market experienced several weather shocks that dramatically affected wheat harvest. For instance, in 2010 severe drought destroyed half of projected harvest in Urals and Black Earth and 30% of projected harvest in Volga. At the same time, North Caucasus stayed completely unaffected and even produced more wheat than year before (Rosstat, 2015, 1). Apart from being a key grower, North Caucasus serves as a gate-region to the world grain market. By estimates of 2013, on its territory there were several sea terminals with a total annual throughput capacity of 24 million tons of grain (90% of all terminal capacity in Russia). As wheat harvest in Russia increased, so did export volumes that achieved 22.5 million tons in the marketing year before the drought (USDA, 2015).

Figure 1. Map of crop-growing regions affected by drought in 2010



As the drought was unfolding, Russian government intervened to contain the outflow of grains abroad. Authorities officially motivated their decision by the intention to inhibit bread inflation and protect low-income households. In particular, on August 15 of 2010 authorities imposed export ban on a wide range of products, such as wheat and flour, maize, rye and flour. Initially, the ban was introduced until the end of the year, but was subsequently prolonged until July 2011. This measure was effective enough to redraw the map of internal wheat trade. Prior to the ban, North Caucasus routinely supplied wheat abroad, but rarely realized it inside the country, while other domestic markets shipped primarily to internal consumption areas. During the export ban, usual trade flows were reversed, and wheat was directed from North Caucasus to the regions suffered from the consequences of drought. According to Russian railways, more than 2 million tons of wheat were supplied to the regions of Center, Black Earth and Volga. Since around 80% of wheat was transported during that time by means of railways, these figures quite accurately reflect the magnitude of domestic trade in this production cluster (Gonenko, 2011).

Railway transport subsidies

Railways and trucks are two primary ways of wheat transportation in Russia. Railways are mostly used when distance between remote areas exceeds 1000 kilometers, while trucks are often preferred on shorter hauls. During the export ban 2010-2011, availability of trucks to use in grain transportation was limited as main fleet was involved in construction of sport facilities for winter Olympic games in Sochi . Moreover, the volume of grains to deliver from North Caucasus to other domestic regions was very high and trucks could not transport it alone (Gonenko, 2011). Therefore, on September 20 of 2010 Russian government introduced transport subsidy for grain producers located in North Caucasus. Specifically, state railway monopoly (Russian Railways) cut delivery fees[1] by half for dispatches heading from North Caucasus towards the regions of Volga, North West and Center. The given subsidy was valid for all grain supplies exceeding 300 kilometers and expired together with the export ban in July 2011. By our own estimates, the reduction of delivery fee resulted into 20% discount on a ton of wheat delivered from North Caucasus (Kavkazskaya station) to Black Earth (Voronezh) as an example of a supply operation that takes 870 kilometers.

[1] Delivery fee is recognized as a charge due to be paid for the rent of one wagon.

Literature review

This paper adds to the strand of literature focusing on spatial price relations between regional agricultural markets. According to the Law of One Price (Fackler and Goodwin, 2001), the prices of two regions are in an equilibrium if the price difference is at most equal to transaction costs of trade between them. Goodwin and Piggott (2001) first introduced threshold cointegration in the spatial price transmission literature. They analyze spatial price links between regional corn and soybean markets in North Carolina using a two-regime threshold autoregressive (TAR) model. They find that thresholds are proportionally related to transaction costs, which increase with distance between the markets. Their study confirms the presence of non-linear adjustment of prices to deviations from the long-run price equilibrium between two regions. In particular, price adjustment is hardly confirmed if regional price differences are smaller than transaction costs. On the contrary, large price differentials induce adjustment of regional prices to their price equilibrium, which increases with proximity of the markets. Additionally, the authors utilize a three-regime threshold vector error-correction model (TVECM) to account for the change in direction of trade flows. Model results do not find evidence that a shift in trade direction changes the speed of price adjustments.

Brosig *et al.* (2010) investigate wheat trade between 28 provinces in Turkey. They emphasize increasing regional segregation that originates from climatic, geographic and infrastructural variations within the country. They show that centrally-located markets are integrated quite well, while integration is rather poor between a centre and a periphery of the country. At the same time, peripheral markets tend to cluster around large production areas. Authors apply TVECM with two regimes to explore effects of transaction costs. In accordance with expectations, they find very slow adjustment to equilibrium between distantly located markets, which accelerates for markets-neighbours.

Trade relations between spatially heterogeneous territories are expected to result into non-linear price transmission. To capture non-linearity in price transmission, it is important to correctly identify the optimal threshold parameter. Chan (1993) offers the method of threshold selection that gained recognition in the context of TAR model. According to this approach, the optimal threshold is to be chosen from the set of residuals retrieved from a long-run regression. Hansen and Seo (2002) use values of error-correction terms (ECTs) to determine possible threshold adjustment in two-regime TVECM. They pair ECTs with corresponding values of cointegrating vector to construct a two-dimensional grid and then estimate it with maximum likelihood. These procedures are criticized for their increasing reliance on a trimming parameter which is used to ensure the correct model estimation across regimes. According to Greb *et al.* (2014), the choice of the given parameter is purely arbitrary and might lead to spurious estimates.

Greb *et al.* (2014) develop an alternative framework to estimate the value of threshold on the basis of empirical Bayesian theory. In contrast to the conventional methods, this approach does not require to trim the parameter space to achieve the desired model outcome. Greb *et al.* (2013) exploit the new approach and compare it to the maximum likelihood procedure to revisit the study of Goodwin and Piggott (2001). Applying three-regime TVECM, they conclude that the Bayesian estimator identifies larger thresholds and wider inaction bands compared to the maximum likelihood counterpart. Moreover, they also find more evidence in support of asymmetric adjustment that takes place, potentially, due to changes in the direction of trade. Drawing upon these findings, we try to explicitly model the non-linear adjustment[2] as a consequence of export restrictions implemented in Russian domestic wheat market. Additionally, we attempt to capture the non-linearity in thresholds as we observe that transaction costs also differ for trade flows in opposite directions.

[2] We use the expression "non-linear adjustment" together with "(a)symmetric adjustment". The former simply implies presence of several regimes separated by thresholds. The latter specifically refers to (in) equality in the speed of transmission between these regimes. As noted in von-Cramon and Meyer (2004), the term "asymmetry" can be also applied to describe the difference in magnitudes of threshold parameters.

Therefore, our study also contributes to the growing price transmission literature on the domestic price effects of export controls. Serebrennikov *et al.* (2014) recently explored the impact of export ban 2010/11 on integration of regional wheat markets in Russia. Adopting approach of Goodwin and Piggot (2001), they estimate two-regime TAR model. They identify strong economic linkages between North Caucasus and its close neighbors - Black Earth, Central and Volga - that persist either in the time of export ban or free trade afterwards. However, they found mixed evidence in support of asymmetric effects conditioned by a change in trade scenario. For instance, for Central-North Caucasus asymmetric adjustment only holds when trade is free, but statistics suggests the absence of wheat transfer between Central and North Caucasus following ban lift. It should be noted that two-regime TAR explores different trade regimes separately. In the current paper, we take this restriction into account by analyzing both regimes together within a more flexible model.

Götz *et al.* (2014) use a regime-switching long-run price equilibrium model to investigate the effects of export restrictions on the relationship between the wheat world market price and regional wheat producer prices in Kazakhstan, Ukraine and Russia. With respect to Russian market, they find evidence for strong regional variation of the price effects of the export ban 2010/11. In particular, the strongest price damping and price insulating effects are identified for North Caucasus, which is close to the Black Sea harbors, whereas those effects are smaller in regions which are more distant to the world market. Similarly, Götz *et al.* (2013) use Markov-switching vector error correction (MSVECM) model to explore the influence of export quotas in Ukraine and export tax in Russia on price relations between the domestic (export) markets and the world market of wheat. For Russia, their analysis shows that the imposition of export tax leads to the emergence of several regimes with different short-run dynamics. It is demonstrated that the speed of adjustment rises as the price difference between the world and domestic market increases.

Djuric *et al.* (2014) study the domestic price effects of an export ban for wheat market in Serbia. They implement MSVECM that clearly separates regimes of restricted trade and free trade. Their results suggest that the export ban had a limited price damping impact on the domestic wheat market due to conflicting effects of auxiliary policy measures.

Baylis *et al.* (2014) investigate rice and wheat markets in India in the context of export ban. They take into account integration between the world and domestic markets, but also explicitly focus upon interregional relations inside India. Indian domestic markets are classified into supply (producing), export and consumption areas. Results of the VECM analysis identify strong integration during the export ban between domestic wheat markets. The application of two-regime TVECM provides additional insights about transaction costs associated with domestic grain trading. It is shown that trade restrictions favor wheat trade that becomes cheaper to organize between producing and consuming areas. In our study of regional integration in Russia, we move further to show that such a trade might involve different transaction costs if organized in both directions.

Methodology and estimation

Econometric model

We apply TVECM with three regimes and two thresholds as in Greb *et al.* (2013) that takes an innovative Bayesian approach to estimation of threshold parameters. We are going to use this method together with the conventional maximum likelihood approach and then choose those results which are better coherent with economic theory.

Model formulation proposed by Greb *et al.* (2013) is given in (1). The dependent variable $\Delta P_t = (\Delta P_t^{Market\,1}, \Delta P_t^{Market\,2})$ denotes the difference between prices in periods t and $t-1$ for both markets in question. As the independent variables, $\gamma' P_t = (P_{t-1}^{Market\,1} - P_{t-1}^{Market\,2})$ measures the error-correction term (ECT) which represents the price differential between two markets lagged by one period, assuming that the connecting vector is equal to (1, -1). Additionally, $\sum_{m=1}^{M} \Delta P_{t-m}$ is the sum of price differences lagged by period *m* to correct residual correlation, and ε_t denotes a white-noise process with expected value $E\,(\varepsilon_t) = 0$ and covariance matrix $Cov\,(\varepsilon_t) = \Omega\ \in (\mathbb{R}^{+})^{2\times 2}$.

$$\Delta P_t = \begin{cases} \rho_1\gamma' P_{t-1} + \theta_1 + \sum_{m=1}^{M}\Theta_{1m}\Delta P_{t-m} + \varepsilon_t\,, & if\gamma' P_{t-1} \le \tau_1\ (Lower) \\ \rho_2\gamma' P_{t-1} + \theta_2 + \sum_{m=1}^{M}\Theta_{2m}\Delta P_{t-m} + \varepsilon_t, & if\tau_1 < \gamma' P_{t-1} \le \tau_2\ (Middle\,) \\ \rho_3\gamma' P_{t-1} + \theta_3 + \sum_{m=1}^{M}\Theta_{3m}\Delta P_{t-m} + \varepsilon_t\,, & if\tau_2 < \gamma' P_{t-1}\ (Upper) \end{cases} \quad (1)$$

The short-run dynamics is characterized by the speed of adjustment parameter (ρ_k) and the coefficients of the price differences (Θ_{km}) lagged by *m*-periods with *k* referring to a regime. θ_k denotes the intercept in the mean equation. All parameters may vary by regime with *k=1 … 3*. Price observations are attributed to a certain regime depending on the size of the ECT. Price observations for which the ECT is smaller than thresholdτ_1 are attributed to Lower regime, whereas price observations with an ECT larger than threshold τ_2 are assigned to Upper regime 3. If the ECT is of the size smaller than threshold τ_2 but larger than threshold τ_1 , the observations are allocated to Middle regime, which is often referred to as "band of inaction". Within this regime, the difference between the prices of two regions are smaller than transaction costs of trade and price adjustments will not occur. However, prices in the two regions might react to a price change in the other region due to information flows (Stephens *et al.*, 2012).

There are several conditions that should be satisfied to ensure the stability of the system in (1). First of all, parameters of adjustment in each regime should be of opposite signs to make sure that in the long-run markets return to their equlibrium path. From (1) it follows that both markets can be treated as dependent simultaneously such that in each regime $\Delta P_{1,t} = \rho_{k1}\gamma' P_{t-1}$ and $\Delta P_{2,t} = \rho_{k2}\gamma' P_{t-1}$. Convergence is achieved if $\rho_{k1} \le 0$ and $\rho_{k2} \ge 0$. Given this restriction, it is considered sufficient that at least one variable does entire correction. Secondly, in outer regimes, the difference between two adjustment prameters should fall in the following interval $0 < \rho_{k2} - \rho_{k1} < 1$. The last restriction is important to guarantee that price fluctuations decay gradually (Greb *et al.*, 2013).

Model estimation

The presented model is estimated in two steps. First, the threshold parameter is selected from the set of ECTs by using both regularized Bayesian (RB) technique and profile likelihood (PL)[3] approach. Second, model parameters are evaluated by implementing restricted maximum likelihood method.

To estimate thresholds with PL, we are going to use the trimming parameter that adjusts automatically to the number of parameters in a system of equations. For example, for a model with 1 lag, the number of parameters to estimate in each regime equals 8 (using formula for the length of each equation $2M + 2$, where M stands for lag length). Therefore, the number of observations to be allocated into a particular regime should not be less than 8. The two thresholds ($\tau_1$and τ_2) are selected from the values of ECTs by constructing a complete two-dimensional grid and estimating (1) for each pair of positive and negative ECTs with PL. A pair of ECTs that maximizes profile likelihood function is considered to yield optimal thresholds. For a more detailed exposition of PL estimator, one should consult Greb *et al.* (2013) and Greb *et al.* (2014).

Compared to PL method that utilizes maximization, selection of thresholds on the basis of RB estimator is done using integral calculus. According to Greb *et al.* (2014), integration might be more natural to use in TVECM as it provides a means to account for inherent variability of estimates. A function to choose optimal threshold values over the grid of ECTs is called posterior median and constructed as follows:

[3] Profile likelihood is another name for maximum likelihood that underlies the technical side of the given procedure.

$$\int_{\min(\gamma' P_t)}^{\hat{\tau}_{iRB}} P_{RB}(\tau_i|\Delta P, X) d\tau_i = 0.5\,,\ for i = 1,2 \quad (2)$$

Where X is a $n \times d$ matrix that compactly stacks together columns of ECTs, intercepts and values of lagged terms.$P_{RB}(\tau|\Delta P, X)$ is well defined across the space of all possible threshold parameters $\mathrm{T} = \{\tau_1, \tau_2 | \min(\gamma' P_t) < \tau_1 < \tau_2 < \max(\gamma' P_t)\}$. In the previous expression, τ_1 and τ_2 are optimal thresholds that separate the space into three regimes. Additionally, they also satisfy $\tau_1 < 0 < \tau_2$. Computation is based on a prior $P_{RB}(\tau|X) \propto I(\tau \in T)$ for τ, where $I(\cdot)$ is an indicator function providing switching between regimes.

After optimal thresholds are found, we proceed further to estimate parameters in TVECM. We use restricted maximum likelihood framework implemented as a part of mixed-effects modeling in R. Each regime is estimated independently, given the values of thresholds (Gałecki and Burzykowski, 2013).

Preliminary data analysis

Analysis of a long sample

We use weekly prices for wheat of 3d class. This is the most tradable type of wheat in Russian domestic market used primarily for human consumption. Prices are charged per metric ton of commodity either by a farmer or trader operating in a specific location (Ex Works contracts). Prices are collected and reported by Rosstat for six economic regions, namely North Caucasus, Black Earth, Central, Volga, Urals and West Siberia. Altogether, each long price sample contains 468 observations from January 2005 until December 2013.

We begin our analysis of a long sample by applying augmented Dickey-Fuller (ADF) test for a unit root. Results from Table 1 suggest that the six price series are integrated of order 1. Further, in order to perform bivariate analysis, we construct 15 market pairs by combining each market with other five. We apply Johansen trace test to understand whether the prices are connected in the long-run through a common vector. Results show that for 14 pairs the hypothesis of zero cointegration can be rejected at least at 10% level (selected pairs are available in Table 2). As a final step, we estimate all 14 pairs of cointegrated markets with TVECM. As can be seen from Table 3 (a), we obtained results for 8 pairs, while for other pairs the estimation procedure achieved no convergence. The results of estimation will be discussed in a separate section.

Table 1. Augmented Dickey-Fuller test for prices in levels and first differences

Variable	Determ. component	Lags	Test-stat
	Test for a long sample		
Caucasus	None	1	0.6473
Δ Caucasus	None	0	-9.5487
Central	None	1	0.4523
Δ Central	None	0	-8.4245
Volga	None	1	0.5512
Δ Volga	None	1	-7.7724
Black Earth	None	1	0.4409
Δ Black Earth	None	0	-8.2434
Siberia	None	1	0.3666
Δ Siberia	None	1	-7.7271
Urals	None	1	0.4894
Δ Urals	None	1	-7.7211
	Test for a short sample		
Caucasus	None	1	0.07
Δ Caucasus	None	0	-4.6871
Central	None	1	0.4096

Δ Central	None	0	-2.9933
Volga	None	1	0.3651
Δ Volga	None	1	-2.9931
Black Earth	None	1	0.3009
Δ Black Earth	None	0	-3.0047

Notes: Critical values of the test statistic for long sample are -1.62 (10%), -1.95 (5%) and -2.58 (1%) and for short sample are -1.61(10%), -1.95 (5%) and -2.6 (1%). Other versions of the test with deterministic components included were run in addition. They did not lead to reversed conclusions.

Analysis of a short sample

To study the effects of export ban, we also use short price samples to clearly isolate the period of export ban from the influence of other interventions. We construct a short sample by reducing the initial price series to 92 observations. This new sample covers a time interval since August 2009 through April 2011. It contains both a short period of free trade and a subsequent period of export ban[4].This is done to ensure the contrast that originates from transition between two distinct trade regimes.

Table 2. Results of Johansen trace test for selected market pairs

Pair of markets	Constant	# of lags	Test stat.
Test for a long sample			
Central-Black Earth	Yes	2	59.76
Black Earth-North Caucasus	Yes	2	20.94
Central-North Caucasus	Yes	2	28.35
Central-Urals	Yes	2	24.77
Central-Siberia	Yes	2	31.55
Black Earth-Siberia	Yes	2	28.41
Urals-Volga	Yes	2	21.94
Urals-Black Earth	Yes	2	25.08
Test for a short sample			
Central-North Caucasus	Yes	2	20.79
North Caucasus-Black Earth	Yes	2	19.73
North Caucasus-Volga	Yes	2	18.42

Notes: Null hypothesis is r=0, where *r* is a number of eigenvectors. Critical values of the test statistic are 17.85 (10%), 19.96 (5%) and 24.6 (1%). Regarding long sample, this table only contains selected pairs that were also successfully estimated with TVECM. The rest are available upon request.

In the context of short sample analysis, we focus exclusively on four regions, such as North Caucasus, Black Earth, Central and Volga. As previously, we first check individual prices for a unit root with ADF test. According to results, the null of unit root is confirmed for all four prices in levels, but rejected in first difference (Table 1). As mentioned in literature (Perron, 1989), ADF test has low power in the presence of structural breaks whose influence might be especially profound in short samples. Therefore, we additionally apply Zivot-Andrews unit root test that accounts for one structural break in the series (Zivot and Andrews, 1992). Results from Table 4 show that prices in levels remain non-stationary despite the break in the middle of the series. All prices in first difference are found stationary except for Black Earth. The null of unit root is also rejected for all bivariate price differentials indicating the long-term stationarity of ECTs subject to one break. Note the timing of the break defined by the test for prices in levels and price differentials. Both dates refer to the last weeks of June and first weeks of July 2010. They coincide with the inception of transitional period that separates a regime of free trade from a regime of export ban.

[4] For computational purposes we did not include into analysis the last two months (May and June) when export ban was still active.

We proceed to construct three market pairs: Central-North Caucasus, North Caucasus-Black Earth and North Caucasus-Volga. All pairs are found cointegrated by Johansen trace test (Table 2). These combinations share a similar pattern, which is unique in contrast to the rest of the market (Figure 2). The left half of the graphs is dominated by North Caucasian price. On the contrary, the right half of the graphs shows price in North Caucasus well below other prices. All prices meet and follow each other closely during the short transitional period symbolizing change in trade regime. Such a configuration of price patterns seems promising to suit the structure of three-regime TVECM.

Table 4. Results of Zivot-Andrews test for short samples

Variable	Determ. comp.	Lags	Test-stat	1%	5%	10%	Break point
			Test for individual prices				
Caucasus	Intercept***	1	-4.3732	-5.34	-4.8	-4.58	July 02,2010
Δ Caucasus	Intercept	1	-5.4223	-5.34	-4.8	-4.58	
Central	Intercept***	1	-4.3419	-5.34	-4.8	-4.58	July 02,2010
Δ Central	Intercept	0	-4.6834	-5.34	-4.8	-4.58	
Volga	Intercept***	1	-4.5271	-5.34	-4.8	-4.58	July 02,2010
Δ Volga	Intercept	0	-5.8343	-5.34	-4.8	-4.58	
Black Earth	Intercept***	1	-5.0172	-5.34	-4.8	-4.58	July 02,2010
Δ Black Earth	Intercept	1	-3.7701	-5.34	-4.8	-4.58	
Δ Black Earth	Intercept	0	-3.9083	-5.34	-4.8	-4.58	
			Test for price differentials				
Central-NC	Intercept***	1	-5.6783	-5.34	-4.8	-4.58	June 18,2010
NC-BE	Intercept***	1	-6.0274	-5.34	-4.8	-4.58	June 18,2010
NC-Volga	Intercept***	1	-6.4393	-5.34	-4.8	-4.58	June 18,2010

Notes. Asteriks denote levels of significance (*** for 1%, ** for 5% and * for 10%). Lag length is estimated with Bayesian information criteria. Abbreviations are to be read as follows: NC - North Caucasus, BE - Black Earth.

Results

Impact of distance and transaction costs

To estimate the general effects of distance and transaction costs on price relationships between crop producing regions across Russia, we run price transmission model for a long sample data. We are going to build our presentation of results specifically on two parameters: speed of adjustment and threshold. Speed of adjustment refers to a time period taken by a certain market to correct deviation from the predetermined equilibrium path. Threshold is considered a proxy for transaction costs. Estimated values of both parameters are given in Table 3 (a). We begin with presentation of inaction band formed as a sum of absolute values of two opposite thresholds. Results show that the lowest values of inaction band are derived for the pairs of market-neighbors (0.039 for Urals-Volga and 0.092 for Central-Black Earth). Whereas the highest value is generated for Central-Urals (0.426), two markets separated by a long distance. This finding reflects the central notion of spatial arbitrage theory that integration of remote areas is strongly associated with high transaction costs (Goodwin and Piggott, 2001).

Additionally, we also compare the values of individual thresholds between different market pairs. In this respect, it is more convenient to concentrate on relations between Central and its counterparts as they account for the half of all results in Table 3 (a). It can be seen that the highest positive threshold is registered for Central-West Siberia (0.306), while the lowest one is found for Central-Black Earth (0.07). This finding implies that it is more than four times costlier to supply wheat from West Siberia, than from Black Earth (positive thresholds in here specify that wheat is supplied to Central). Again, this result corroborates the importance of distance for spatial wheat trade in Russia. Likewise, absolute values of negative thresholds are found to grow with distance in all pairs involving Central. However, they are also generally smaller than positive thresholds. Since wheat mostly flows to Central, we regard this finding as counterintuitive because it should be cheaper to supply commodity to the region with better infrastructure. On the other hand, the costs of delivering wheat to markets scattered far from the major centers of consumption might be lower in light of less expensive services in those locations.

Besides thresholds, we also examine adjustment parameters. In order to ascertain whether adjustment process is affected by spatial dimension, we keep our focus on market pairs involving Central. Results in Table 3 (a) show that for Central-Black Earth, speed of adjustment amounts to about 13% per week in both lower and middle regimes, while in upper regime no significant reaction is detected. Furthermore, adjustment is found to decelerate to a slightly less than 12% across all regimes for Central-North Caucasus and it almost disappears for Central-Urals (weakly correction is between 3-4% in middle and upper regimes). This path of behavior clearly recognizes the impact of increasing distance between the domestic wheat markets. However, as our results suggest, there are also pairs that do not follow the given tendency strictly. For example, for Central-West Siberia, speed of adjustment reaches 58% in upper regime which is incredibly fast given the vast distance separating the two. We hypothesize that at least partially this discrepancy can be explained with the amount of trade flows. According to railway statistics, in 2007-2013 West Siberia supplied to Central 1.5 million tons of wheat which is comparable to trade volumes for Central-North Caucasus (1.5 million), but higher than for Central-Urals (0.98 million). However, North Caucasus only supplied to Central during the short time coinciding with export ban 2010/11, while West Siberia kept gradual supplies for the entire period given.

Further inspection of adjustment parameters in Table 3(a) reveals that non-linear adjustment is not pronounced in many cases. For instance, for Central-North Caucasus, all significant coefficients of adjustment with right signs are essentially symmetric across all three regimes (adjustment varies slightly between 11.4% and 11.8%). Analogous picture is also valid for Black Earth-North Caucasus, Central-Black Earth and Urals-Black Earth (the last two have similar adjustment coefficients in just two regimes). Furthermore, in all pairs without exception there is at least one significant coefficient of adjustment in middle regime. All these findings point to the fact that the given TVECM with three regimes and two thresholds might be over-parametrized for some market pairs (Greb *et al.*, 2013). On the other hand, one has to remember that long samples contain a lot of information about economic processes that took place for nine years. Therefore, the effect of one specific event can be counterbalanced by the effect of the other leading to an eventually flat short-run dynamics. In the next section we will show how curtailment of the initial sample helps in recovering highly asymmetric results.

Impact of export ban and transport subsidies

To estimate the influence of export ban and transport subsidies on Russian regional wheat markets, we use short price samples and limit our geographical focus to four markets, such as North Caucasus, Central, Volga and Black Earth. Altogether, we create three bivariate relations (Central-North Caucasus, North Caucasus-Volga and North Caucasus-Black Earth) and analyze them as previously with the price transmission model. We begin this presentation by taking into account parameters of adjustment in outer regimes first. These estimates are given in Table 3 (b). According to results, for all three pairs entire dynamics in outer regimes is shifted to either lower or upper regime. For instance, for Central-North Caucasus both markets are found to respond to disequilibrium in upper regime. One adjustment parameter that shows the reaction of Central (0.238) has wrong sign and can not be reliably interpreted. Another parameter refers to North Caucasus and is correctly signed. It implies that North Caucasus corrects the error with the speed of 35.8% per week.

For the other two pairs, we observe error-correction process primarily in lower regime. For instance, for North Caucasus-Black Earth, both adjustment parameters are significant and have right signs. At the same time, North Caucasus reacts to deviation notably faster (47.1% per week) than Black Earth (26.3% per week). In contrast, for North Caucasus-Volga, entire correction is done by North Caucasus (24.1% per week), while adjustment parameter attached to Volga has wrong sign and appears to be insignificant. These findings clearly reflect the impact of export ban on regional price relationships. After border was closed, prices in North Caucasus went below prices in the other three markets that triggered massive outflow of wheat from North Caucasus to Central, Black Earth and Volga. In our model, the time of export ban and active interregional trade is captured in those outer regimes, where adjustment process is found to be significant. As shown before, these are upper regime for Central-North Caucasus and lower regime for North Caucasus-Black Earth and North Caucasus-Volga. Outer regimes opposite to just mentioned cover the time preceding export ban. Statistical records suggest that some trade also occurs during that period, but the magnitude of flows is rather negligible comparably to the export ban time (Rosstat, 2015,1).

It should be emphasized that for all three pairs, the fastest adjustment is registered in middle regime. For instance, for North Caucasus-Black Earth, the entire error is corrected by Black Earth in just one week (the other coefficient has wrong sign). Additionally, the duration of middle regime is considerably shorter when compared to outer regimes. The explanation lies in the nature of middle regime. In conventional terms, middle regime represents the area of prohibitive transaction costs where markets usually stay for most of time. In our case, by contrast, middle regime is associated with a transitional zone between two distinct trade regimes which markets pass through quickly. Within the transitional period, which lasts for several weeks, prices follow each other so close that the difference between them is essentially imperceptible (Figure 2). Therefore, temporary character of the transitional regime might be responsible for the instantaneous adjustment process.

Apart from adjustment parameters, we also investigate thresholds. Results in Table 3 (b) show that the values of positive and negative thresholds are asymmetric across three market pairs. For Central-North Caucasus, the absolute value of negative threshold (|-0.106|) is notably larger than the value of positive threshold (0.022). Vice versa, positive thresholds are bigger than negative for North Caucasus-Black Earth and North Caucasus-Volga. We connect this asymmetry to transport subsidies introduced by Russian government to facilitate redistribution of wheat from regions with abundant stocks (primarily, North Caucasus) to the areas suffered from drought (Central, Black Earth and Volga). In particular, North Caucasus was subject to 50% reduction in delivery fee charged by Russian railway monopoly for long-haul supplies. As a result, transportation of wheat from North Caucasus became temporarily cheaper than transportation of wheat to North Caucasus. To check this hypothesis, we compare the locations of individual thresholds across different regimes. It follows that for Central-North Caucasus, positive threshold is associated with the area when prices in Central were higher that coincides with the period of export ban. For the other two pairs, it is two negative thresholds that signal transition to the state of export ban. Since all three thresholds referring to the time of restricted trade are also smaller than their counterparts associated with the time of liberal trade, it is justified to conclude that transport subsidies had ultimately made transportation of wheat from North Caucasus cheaper.

Conclusions

In this paper, we investigated the regional dimension of Russian wheat industry by analyzing price relations between several spatially connected wheat producing regions. We specifically limited our focus to six leading crop-growing regions, namely North Caucasus, Black Earth, Volga, Central, Urals and West Siberia.

We found that price signals are generally transmitted fast between regions-neighbors. On the contrary, speed of transmission becomes quite slow if the markets in question are located far from each other. Additionally, we discovered that transaction costs might potentially have a profound influence on relations between domestic wheat markets. Our results suggest that wheat trade can be extremely costly if transportation covers long distances and occurs between the regions with unequal infrastructural development. These findings are in reliance with the basic postulates of spatial arbitrage theory.

Furthermore, our analysis reveals that the export ban 2010/11 deeply affected price relations between North Caucasus and three spatially proximate regions, namely Central, Black Earth and Volga. We found that in the period before export ban there is no visible price transmission as trade is not active that time. By contrast, during export ban price shocks are quickly transmitted as a result of increased trade flows. Besides, we found that transaction costs were affected by transport subsidies implemented for the time of export ban. By our estimation, transport subsidies resulted into a cheaper transportation of grain supplied from North Caucasus to the other three regions.

Our study offers several important implications in terms of trade policy and food security. First, due to long distances and poor infrastructure, distribution of grains between spatially protracted areas can be challenging. As a result, grain-deficit areas remain increasingly vulnerable in the face of possible harvest failures. To improve the regional connectivity and cushion potential production shocks, it is important to increase investments in transport infrastructure and storage facilities in the areas where they are underdeveloped. Secondly, export restrictions are capable of enhancing regional integration at the expense of activation of domestic trade relations. Although such measures can be relatively effective to cope with grain deficits in the short run, their long-term implications are rather negative for development of grain production. As pointed out in Welton (2011), recurring governmental interventions are expected to discourage investments in grain production.

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Figure 2. Trade reversal between North Caucasus and market-neighbors, 2009-2011

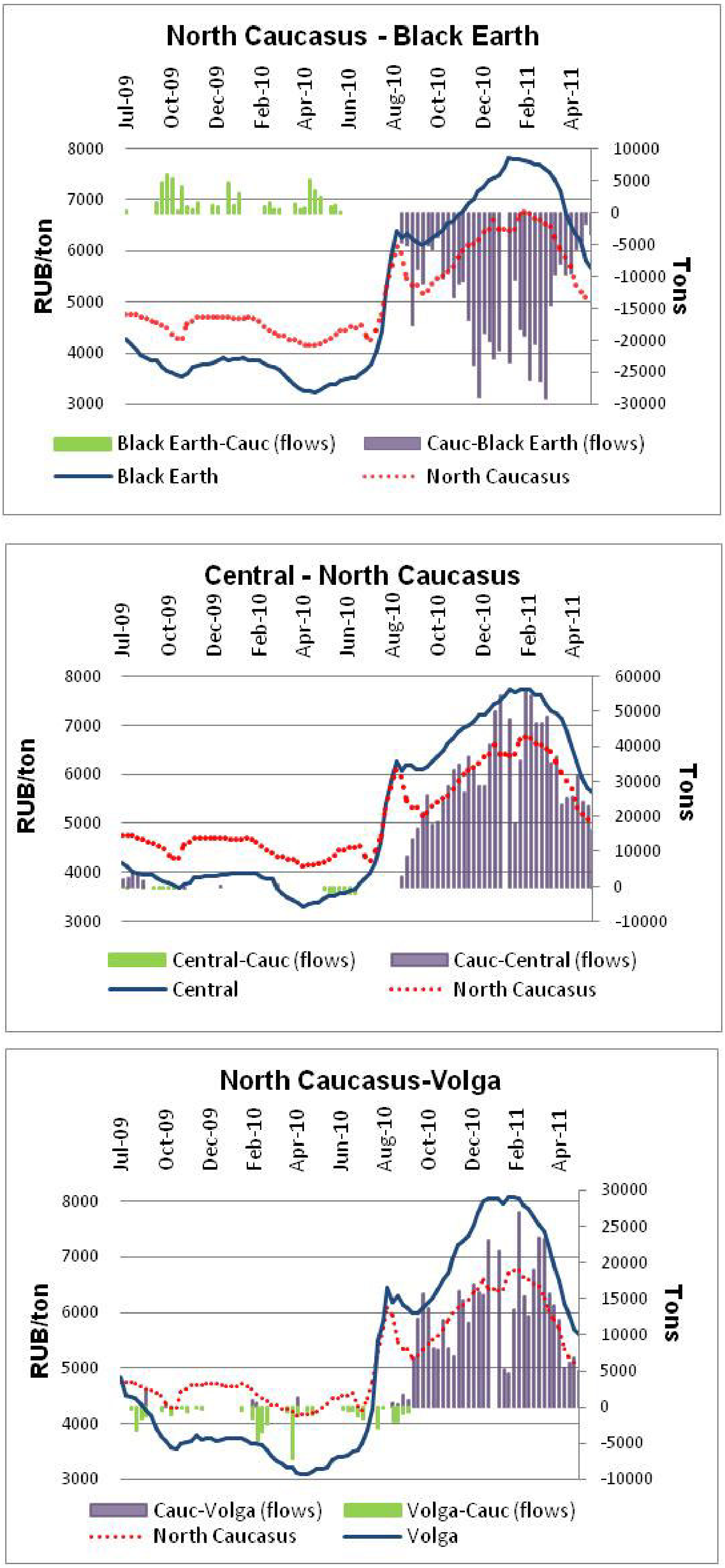

Table 3. Results of three-regime TVECM estimation

# of lags	Estimator	Δ (Dep var)	Lower regime Rho1	[Pvalue]	**LowerThr**	Middle regime Rho2	[Pvalue]	**UpperThr**	Upper regime Rho3	[Pvalue]	Total adjustment [number of obs.] Lower	Middle	Upper	Band of inaction
a) Estimation of long sample														
2	RB	Central	**-0.134**	[0.015]	***-0.022***	**-0.132**	[0.017]	***0.070***	0.014	[0.913]	0.202	0.195	0.187	0.092
		Black Earth	0.067	[0.204]		0.063	[0.235]		0.200	[0.097]	[13]	[446]	[6]	
2	RB	Black Earth	**-0.043**	[0.035]	***-0.102***	**-0.044**	[0.032]	***0.032***	**-0.037**	[0.000]	0.032	0.033	0.040	0.134
		NC	-0.011	[0.66]		-0.011	[0.65]		0.002	[0.857]	[104]	[297]	[64]	
2	RB	Central	**-0.118**	[0.000]	***-0.127***	**-0.117**	[0.000]	***0.096***	**-0.114**	[0.000]	0.064	0.061	0.065	0.222
		NC	**-0.054**	[0.035]		**-0.056**	[0.015]		-0.049	[0.055]	[71]	[345]	[49]	
2	RB	Central	0.090	[0.234]	***-0.146***	**0.021**	[0.037]	***0.280***	0.018	[0.178]	-0.032	0.014	0.019	0.426
		Urals	0.058	[0.443]		**0.035**	[0.000]		**0.037**	[0.006]	[20]	[438]	[7]	
1	RB	Central	0.015	[0.373]	***-0.100***	0.020	[0.073]	***0.306***	0.165	[0.438]	0.019	0.017	0.417	0.406
		Siberia	**0.034**	[0.037]		**0.037**	[0.000]		**0.582**	[0.006]	[26]	[435]	[5]	
1	RB	BE	0.016	[0.415]	***-0.126***	**0.022**	[0.031]	***0.285***	0.096	[0.667]	0.012	0.012	0.376	0.411
		Siberia	0.028	[0.166]		**0.033**	[0.001]		**0.472**	[0.037	[26]	[436]	[4]	
2	RB	Urals	-0.033	[0.061]	***-0.020***	**-0.036**	[0.008]	***0.019***	-0.010	[0.833]	0.057	0.051	0.192	0.039
		Volga	0.024	[0.181]		0.015	[0.313]		**0.182**	[0.000]	[209]	[103]	[153]	
2	RB	Urals	**-0.040**	[0.000]	***-0.058***	**-0.040**	[0.000]	***0.113***	-0.025	[0.085]	0.015	0.015	0.032	0.172
		Black Earth	**-0.024**	[0.013]		**-0.024**	[0.013]		0.006	[0.653]	[167]	[247]	[51]	
b) Estimation of short sample														
1	RB	Central	-0.127	[0.134]	***-0.106***	**-0.446**	[0.005]	***0.022***	**0.238**	[0.010]	0.124	-0.242	0.120	0.128
		NC	-0.004	[0.966]		**-0.688**	[0.000]		**0.358**	[0.000]	[47]	[6]	[37]	
1	PL	NC	**-0.471**	[0.000]	***-0.049***	**0.685**	[0.000]	***0.119***	0.031	[0.723]	0.734	0.299	0.108	0.168
		Black Earth	**0.263**	[0.013]		**0.984**	[0.000]		0.139	[0.111]	[37]	[6]	[47]	
1	PL	NC	**-0.241**	[0.004]	***-0.035***	**0.210**	[0.048]	***0.205***	0.092	[0.450]	0.197	0.112	0.114	0.239
		Volga	-0.044	[0.593]		**0.323**	[0.003]		0.207	[0.092]	[39]	[16]	[35]	

Notes. Rho1, Rho2 and Rho3 stand for adjustment parameters in respective regimes. RB and PL refer to regularized Bayesian and profile likelihood estimators respectively. Lag length is according to Schwarz information criterion. All significant parameters are highlighted.