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The Impact of 'new' Interregional Transmission Line on Prices and Volumes on Russian Electricity Market[2]

This paper investigates the change in the behavior of prices and volumes on the Russian electricity market, caused by changes in the electrical grid. The analysis is performed on two previously unconnected macro regions, which currently have a "fictional" interregional transmission line. We use a dataset with economic variables together with the flow frequency as a technical variable of the electrical grid and prove that the latter matters. Our estimates indicate that given the existence of the interregional link, prices in the regions converge to some extent and generation volumes in the regions are shaped by its regions' and the adjacent regions' load. In the future research, the whole electrical grid of Russia should be taken into account.

JEL Classification: Q41, L94, C32

Keywords: wholesale electricity market, Error-correction model, flow frequency, electrical grid change

1. Introduction

The aim of our research is to investigate empirically how connecting line between previously isolated CPS of Ural and Siberia CPS affects price and volume's behavior in the short run and in the long run.

According to Doucet, Kleit, & Fikirdanis (2013) currently there are two approaches of estimating value of transmission expansion. The first approach (Deb, 2004; Bresesti et al, 2009) concerns electrical grid construction, which accounts for actual overflow and capacity constraints in each line. This type of models is rather methodologically complicated and requires detailed information about the whole electrical grid, what makes it difficult to apply. Another approach is to analyze economical result of congested transmission lines through comparing prices. Congested transmission line can be identified through comparison of prices, which are shaped on adjacent nodes of electricity network (Serletis & Bianchi, 2007; Gianfreda & Grossi, 2012; Haldrup & Nielsen, 2006), or through node price comparison with competitive price, that is formed without capacity transmission constraints (Hadsell & Shawky, 2006; Gianfreda & Grossi, 2009).

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[2] The article was prepared within the framework of the Academic Fund Program at the National Research University Higher School of Economics (HSE) in 2015- 2016 (grant № 15-05-0063) and supported within the framework of a subsidy granted to the HSE by the Government of the Russian Federation for the implementation of the Global Competitiveness Program.

Given value of congestion in transmission lines, several articles provide empirical evidence of its influence on electricity prices (Clements, Herrera, & Hurn, 2015) and, consequently, its implication in exercising market power (Mirza & Bergland 2012, 2015). Moreover, some theoretical models (Joskow & Tirole, 2000; Borenstein, Bushnell & Stoft, 2000) account for capacity of transmission lines and actual overflow, which allows to identify conditions in the electricity market for possibility of exercising market power by producers. Borenstein et al. (2000) theoretically investigate the case, when transmission line is built between two regions, which previously were not connected, and find this transmission capacity expansion beneficial.

In this paper the line between macro regions is treated as totally congested line before the change of the protocols, while after the change - as unlimited capacity line. Given that, following Borenstein et al (2000), we investigate the question how this "fictional" line affects price shaping and economic dispatch. However, contrary to their research we apply empirical approach to calculate this effect. Price convergence is identified by comparing prices on sides of the transmission line, following Serletis & Bianchi (2007), Gianfreda & Grossi (2012) and Haldrup & Nielsen (2006). Contrary to Clements et al (2015) we apply vector-error correction model to estimate the effect in both short-run and long-run periods. We found strong evidence of price convergence between two regions with different speed of price adjustment.

The analysis was carried out accounting for electricity net frequency and we are the first to take this variable into consideration. Electricity net frequency is a crucial element of any energy system (Kirsch & Singh, 1995; Raineri, Rios, & Schiele, 2006) as it reveals quality of produced and transmitted electricity and is taken into consideration during economic dispatch. Our results prove significant influence of electricity net frequency on equilibrium prices and volumes in the market.

The setup of the article is the following. In Section 2 an overview of the Russian electricity market is presented, followed by data description and methodology in Section 3. Section 4 contains empirical results for the model with further interpretation of the results, while Section 5 concludes and outlines research limitations.

2. Electricity sector in Russia

Electricity sector in Russia is quite complex in terms of its organization. Firstly, it covers a huge territory and comprises approximately 700 power stations and 10700 transmission lines[1]. This system is dispatched simultaneously and on a centralized basis by uniform operating protocols. At the same time some parts of the country are technologically isolated due to the

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scarcity of transmission lines. This leads to electricity being sold in these parts at regulated prices. Liberalized wholesale electricity market operates in other parts of the country. Furthermore, regions in the country differ in generation capacity and load. Some territories are self-sustaining systems (for example, Perm Territory and Novosibirsk Region), whereas others partly or totally depend on "imported" electricity (Chechen Republic and Republic of Kalmykia). The scarcity of interregional line capacity leads to the shortage of electricity in these regions and, consequently, significantly affects prices. In this case, electricity overflow between regions is essential for price shaping in the Russian electricity market.

Electricity is generated, transmitted and distributed throughout the United Energy System of Russia (here and after referred to as the UES). In the case of electrical shortage in one region electricity is transmitted to this region from another one, in which there is an electricity surplus. System Operator of the UES, a government-owned company, is responsible for this redistribution.

The UES consists of 7 consolidated power systems (here in after referred to as CPS): East, Syberia, Ural, mid-Volga, South, Center and North-West, which are named according to their geographical locations in Russia. CPSs are connected to each other with high-voltage power transmission lines and operated simultaneously. At the same time five regions of Russia are isolated from the UES and their power sector operates separately from the whole. The structure of the UES is shown on the figure 1

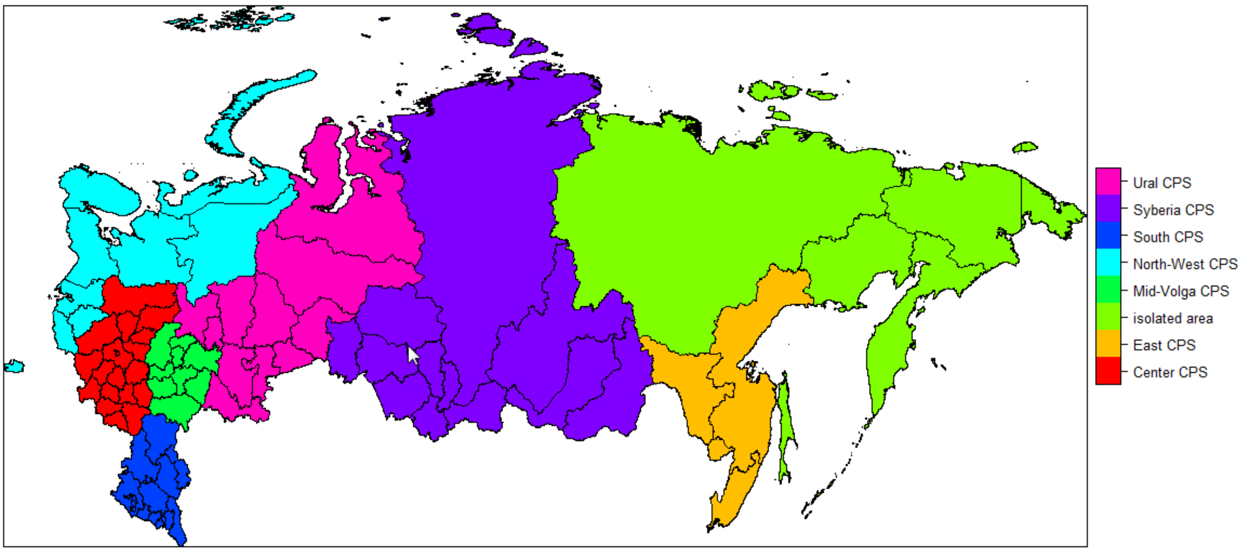

Fig 1. The structure of the Russian UES in 2013: CPS and isolated areas (источник?).

If we refer to the price shaping within the UES, contains two zones with competitive prices (here and after referred to as price zones) and areas with regulated prices where competitive pricing cannot be introduced at the moment (figure 2). The 1st price zone is located to the left of the Urals, whereas the 2nd one is located to the right of the Urals. Until 2017 these two zones were almost separated from each other technologically. The only active linking power line between them went through the territory of Kazakhstan. It is important to mention that one CPS can be located both on the territory of the price zone and non-competitive zone (for example, CPS of the Urals).

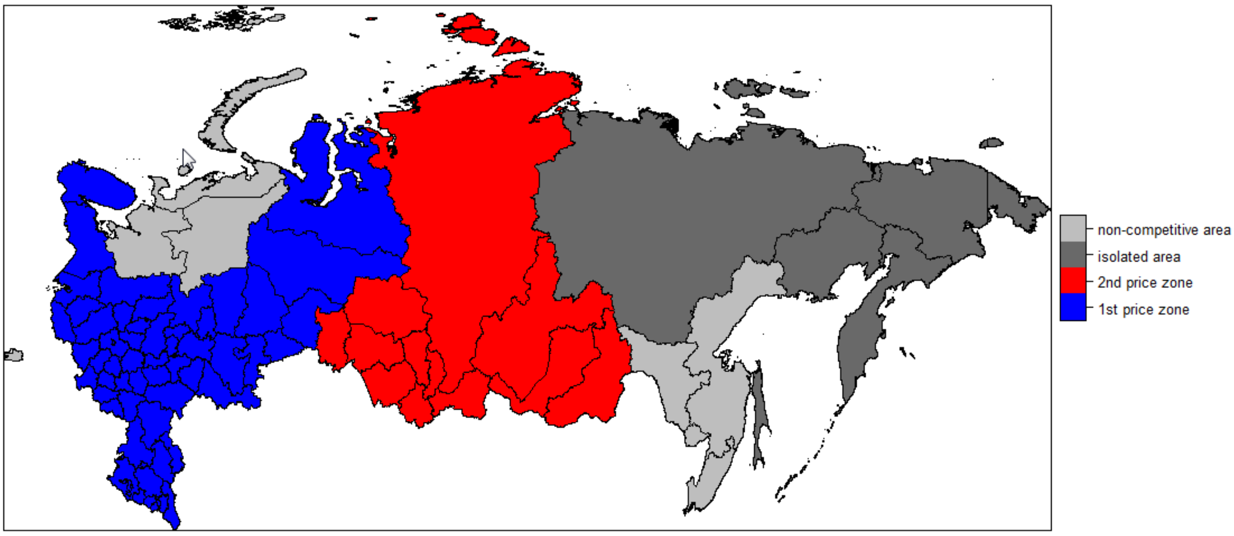

Fig 2. The structure of the Russian UES in 2013: price zones, non-competitive and isolated areas

Electricity process of generating and delivering in price zones is organized on the base of consequent steps. On the first step a double auction is carried out in every node of the UES (here and after referred to as day-ahead market). The procedure of the auction is as follows. Producers bid volumes of electricity, which they plan to generate the next day, and their corresponding willing prices. At the same time consumers bid capacity loads. As a result, equilibrium prices and volumes are calculated for each node by Trading System Administrator[1]. On the next step planned generation volume is adjusted every 3 hours to cover the required load and market participants' penalties are calculated. After these two steps the delivery comes.

Before the 31st of August 2014 volumes and prices in the day-ahead market were calculated separately for each price zone. Technically it was organized due to the substantial constraint on the available active-power flow that goes through the territory of Kazakhstan. But from the 31st of August 2014 this constraint has been eliminated due to the change in the market operating protocols. Since then calculations in the day-ahead market are performed for the territory, which units the 1st and the 2nd price zones. Meanwhile transmission power line, that connects price zones, is not put into operation yet.

[1] Trading System Administrator is a private company, which organizes auctions in the Russian wholesale electricity market.

This structural change led to a significant rise in prices in the 2nd price zone, which can be explained in the following way. In the 2nd price zone electricity is produced mainly by hydro power stations with negligible costs per 1 MW and their capacity is enough to cover the main part of the load. Therefore the average price of the whole price zone was substantially determined by the hydro power stations. Elimination of the constraint between price zones led to cheap electricity, produced by hydro power plants in the 2nd price zone, being transmitted to the 1st price zone. This became possible as the main criteria in the auction of the day-ahead market is to buy as much cheap electricity as possible, according to constraints on the generated volumes and transmission capacity. Only after that additional electricity at a higher price is bought to cover load. Flow of cheap electricity to the 1st price zone was supposed to result in price convergence between price zones. Given a constraint in line transfer capacity between price zones, price didn't become equal, but changed in the following way. Prices in the 1st price zone have decreased negligibly, whereas prices in the 2nd price zone significantly increased.

3. Data and Methodology

3.1.Data

Our study covers 2 CPSs: CPS of the Urals and Siberia CPS that are located in the 1st and the 2nd price zones respectively. The database under consideration consists of 24 hourly prices and loads for each day for the period from August 2010 to May 2015, yielding a total of 5114 daily (or 122,736 hourly) observations.

Electricity load and generation volume in each hour is a sum of consumed and generated electricity respectively in every node of the CPS (measured in MW). Flow frequency is calculated as an average frequency of all transmission lines of CPS for each hour in Hz. Temperature is measured as an average indicator for 24 hour for the whole territory of each CPS in °C. This type of date is the only available though day and night temperatures could vary significantly. The data are downloaded from the System Operator of the UES website.

Hourly nominal prices are obtained from the Trading System. They are calculated as a weighted average of every CSP's node in rubles per MWh. The price weight is a ratio of electricity volume at the particular node to the total CPS bought load.

Loads, generation volumes and prices are highly seasonal data. The load in winter is much higher than in summer, on weekdays it is much higher than at weekends, and in peak hours it is much higher than in other hours of the day. Holidays affect the load as well and lead to its sharp increase.

It is mainly explained by residential part of electricity load, which in its turn totally depends on household daily activities [1]. Another explanation of load fluctuations is could be temperature changes. Since every electricity system should be in balance, generation volume follows the same seasonal parttern as load.

As it can be seen in table 1 load and generated volume for each time period in CPS Ural is higher than in CPS Siberia. We don't find substantial difference between load and generated volume series for each CPS in data. One possible explanation is that historically CPS were formed on a territory, which was a self-sustaining energy system.

Table 1. Descriptive statistics

Variable	Mnemonic	Units	Mean				Min	Max
			1†	2†	3†	4†		
Ural data								
Load	Load_U	MW	28867.55 (3127.794)	29321.1 (3115.084)	29328.18 (2973.251)	30338.08 (2751.032)	23067	37525
Generated volume	Gen_U	MW	29037.59 (3686.585)	29570.46 (3512.418)	29225.91 (3135.903)	30296.66 (3154.065)	21334	39366
Price	Price_U	Rubles per MWh	917.134 (170.017)	1005.687 (165.060)	1091.061 (176.527)	1058.697 (187.776)	0.000	1873.21
Frequency deviation from normative level	Fr_U	Hz	0.003 (0.013)	0.004 (0.014)	0.003 (0.012)	0.003 (0.013)	-0.06	0.06
Temperature	Temp_U	°C	4.393 (14.172)	3.146 (13.211)	2.088 (12.655)	-1.661 (10.802)	-34.74	27.4
Siberia data								
Load	Load_S	MW	23483.16 (3192.889)	23863.26 (3303.004)	23049.61 (2838.138)	24036.45 (2548.703)	17406	31838
Generated volume	Gen_S	MW	22605.07 (3191.443)	22687.48 (3042.840)	22453.56 (2888.137)	23340.15 (2446.014)	16048	30742
Price	Price_S	Rubles per MWh	636.815 (81.104)	750.550 (83.802)	665.023 (105.906)	946.786 (158.323)	0.000	1499.48
Frequency deviation from normative level	Fr_S	Hz	0.003 (0.013)	0.004 (0.014)	0.003 (0.012)	0.003 (0.013)	-0.06	0.06
Temperature	Temp_S	°C	1.732 (15.116)	0.150 (14.611)	2.432 (12.627)	-1.83 (10.689)	-34.5	24.28
Number of observation			9120	8760	8760	6960	33600	33600

Note: standard deviation is presented in the parentheses, descriptive statistics are calculated for nominal prices.
† - the 1st time period is from 1 August 2011 till 14 August 2012, the 2nd - from 15 August 2012 till 14 August 2013, the 3rd - from 15 August 2013 till 14 August 2014 and the 4th - from 15 August 2014 till 31 May 2015.

Flow frequency is equal to 50 Hz, when the system is balanced (load equals to generated electricity). The deviation from this normal frequency level reveals system imbalance. The deviation, in absolute magnitude on more than 0.2 Hz, results in system shortage. Proactively System Operator controls the level of flow frequency at every instant. In case of negative deviation System Operator gives a command to raise capacity in a system or to turn part of the consumers off the line, in the case of positive deviation - to decrease capacity. As presented in

[1] Seasonality pattern is a well documented feature of electricity consumption (Harvey and Koopman,1993; Cargill, and Meyer, 1971; Taylor, 2010)

table 1 in both CPS of Ural and Siberia CPS the average flow frequency deviation is a bit more than zero for every time period. Consequently, on average generated electricity volume is slightly higher than load. It can be a result of overestimated demand for electricity, which is provided by suppliers and System Operator.

In table 1 the 4th time period reflects the period with changed operating market protocols, whereas the 1st till the 3rd are the periods before change. This change has led to negligible decrease in nominal prices in the CPS of Ural, whereas in Siberia CPS prices increased roughly by 42 per cent. However prices in the CPS of Ural are used to be at a higher level than Siberia CPS prices during all 4 periods.

3.2.Methodology

Following Fatai, Oxley & Scrimgeour (2003), Hondroyiannis (2004), Athukorala &Wilson (2010) to capture the short-run as well as the long-run relations between electricity prices and volumes for each CPS we apply vector error-correction model (VECM) that implies 3 steps.

On the 1st step prices, generation volumes and loads for each CPS are tested separately for stationarity. Augment Dickey-Fuller test is calculated on the basis of OLS estimator for that.

On the 2nd step order of cointegration is calculated using Johansen, Mosconi and Nielsen approach (2000)

On the 3rd step VECM with specification of 2 step and order of cointegration, defined at the previous step, is applied to data.

4. Empirical results

4.1.Integration properties of the data

On the first step of the research Augmented Dickey– Fuller unit root test is performed for variables of CPS Ural and Siberia: loads, generation volumes, prices and frequency deviation from the normative level, used in the analysis. Moreover, we apply Augmented Dickey– Fuller test to volumes and prices accounting for seasonal variables. The results in table 2 prove that all variables, except Siberia price, are trend and drift stationary. For Siberia price we fail to reject null hypothesis.

Table 2. Augmented Dickey– Fuller unit root test in levels

Variable	τ	δ	d	Number of lags
Ural data				
Load_U	-6.049***	15.139***	18.377***	343
Gen_U	-5.664***	13.204***	16.065***	344
Price_U	-6.307***	14.267***	20.191***	340
Temp_U†	-6.166***			265

Fr_U ††	-2.175**			335
Siberia data				
Load_S	-4.935***	8.969***	12.179***	348
Gen_S	-5.796***	11.580***	16.817***	343
Price_S	-2.896	3.304	4.342	343
Temp_S†	-5.356***			337
Fr_S ††	-2.213**			335
Significant level	Critical values			
1%	-3.96	6.09	8.27	
5%	-3.41	4.68	6.25	
10%	-3.12	4.03	5.34	

Note: T-statistics for τ, δ, d, are presented in the table. τ, δ, d are included in eq.1, accounting for unit root, trend and drift term respectively. Dummy variables in the model specification are centered. Critical values for the sample N>500 are obtained from the paper Dickey and Fuller (1981). Lag length is chosen according to AIC.

† test is applied accounting only for a unit root, in model specification centered dummy variables for months are included. In this case critical values at 1%, 5% and 10% for N>500 are -2.58 -1.95 -1.62 respectively.

†† indicates that for this variable unit root test is applied not accounting for seasonal pattern, trend and drift term. In this case critical values at 1%, 5% and 10% for N>500 are-2.58 -1.95 -1.62 respectively.

* Indicates significance at the 10% level, ** at the 5% level, *** at the 1% level.

Temperature for CPS of Siberia and Ural tested for a unit root accounting only dummy-variables for months due to the specific seasonal pattern of the factor. Temperature is found to be stationary in the previously mentioned way. Consequently, constructed temperature variable $\widetilde{Temp}$ is stationary.

As far as frequency flow doesn't involve seasonal pattern, for this variable Augmented Dickey– Fuller without any additions is performed. Moreover the test is performed with specification accounting for the unit root only. Flow frequency is found to be stationary.

To capture breaks in series Zivot-Andrews test is performed for prices and volumes. We include in the model specification centered season variables and trend. Results (table 3) indicate that all variables in each CPS are trend stationary, accounting for one break. Given that, cointegration analysis can be performed for load, generation volume and price.

Table 3. Zivot–Andrews test for unit roots

Variable	Zivot–Andrews	
	t-statistic	breakdate
Ural data		
Load_U	-15.212***	19-10-2014 8:00
Gen_U	-14.443***	29-10-2013 6:00
Price_U	-15.896***	30-06-2014 7:00
Siberia data		
Load_S	-10.687***	28-10-2013 5:00
Gen_S	-9.125***	12-03-2012 4:00
Price_S	-11.590***	25-07-2013 12:00

Note: T-statistics are calculated for the model specification with unknown structural break in trend and in intercept, presented in eq. 2. Dummy variables in the model specification are centered. Critical values at 1%, 5% and 10% are -5.57, -5.08 and -4.82 respectively and were obtained from Zivot and Andrews (1992). Lag length is 48.

* Indicates significance at the 10% level, ** at the 5% level, *** at the 1% level.

4.2.Empirical results for CPS of Ural and Siberia CPS

Given trend and drift stationary variables, we applied adjusted Johansen likelihood approach with structural breaks to test for the rank of cointegrating relations in 2 energy systems: CPS of Ural and Siberia CPS. In each system we check for cointegration relation between price, generation volume and load, assuming temperature and frequency deviation from normative level as exogenous variable. We perform the test with 1 break date on the 15th August 2014. As presented in table 4 for both CPS null hypothesis of r≤2 is not rejected.

Table 4. Test for the Number of Cointegrating Relation for CPS of Ural and Siberia CPS

H(r)	Statistics	Critical value at 1%	Critical value at 5%	Critical value at 10%
Ural data				
r≤0	295.168	22.42	17.79	15.59
r≤1	137.381†	41.10	35.21	32.31
r≤2	8.81010	63.43	56.35	52.79
Siberia data				
r≤0	179.264	22.42	17.79	15.59
r≤1	66.081†	41.10	35.21	32.31
r≤2	6.196	63.43	56.35	52.79

Note: † indicates that null hypothesis cannot be rejected. Cointegration test is based on the model specification with restricted trend, accounting exogenous variables and one break on the 31st of August 2014. Critical values are calculated with the methodology proposed in Johansen et al. (2000) Optimal number of lags is set 48 in the model.

After that parameters of VECM are estimated separately for each CPS. The estimated conitegrated relations are presented in table 5.

The 1st cointegration relation in Table 5 reflects the long run statistically significant linkage between prices and generation volumes for each CPS separately. In both CPS an increase in generating volumes relates to decline in prices.

Table 5. The long run cointegrating relations in VECM for CPS of Ural and Siberia CPS

	Elements of β matrix	
Variables in VECM	Cointegration relation #1	Cointegration relation #2
Ural data		
Load_U	0	1
Gen_U	0.124*** (0.008)	-0.053* (0.027)
Price_U	1	0
trend	-0.009*** (0.001)	-0.005 (0.003)
intercept	-4533.64	-27843.92
Siberia data		
Load_S	0	1
Gen_S	0.314*** (0.022)	0.460*** (0.047)
Price_S	1	0
trend	0.000 (0.002)	0.021** (0.003)
intercept	-7862.93	-34330.98

Note: Coefficient estimation is based on the model specification with restricted trend and 48 lags accounting centered seasonal dummies as proposed in Johansen (1995, p. 84) and exogenous variables. Standard errors are presented in parentheses.

* Indicates significance at the 10% level, ** at the 5% level, *** at the 1% level.

To illustrate this, consider a rise in generating volumes in Ural, whereas consumption remains at the same level. This leads to generation surplus, that make prices go down. The long run linkage between load and generation volume is presented in the 2nd cointegration relation. The linkage indicates whether the energy system is in balance or not in the long run period. The results shows that CPS of Ural is balanced: increase in generated volumes leads to increase in consumption. However in Siberia the linkage is inverse and statistically significant: increase in generated volumes leads to decline in load. Siberia CPS being imbalanced in the long run period, is one possible implication of the findings. It is more likely that there are 2 balances in the system: before structural change and after (we discuss this in section 4.3).

Adjustment coefficients of the error correction model are presented in table 6. The 1st error correction term (ECT #1) indicates that, when prices in Ural are too high, load falls back, accounting for trend and intercept. Consequently, it can be considered that load is sensitive to price in Ural. In Siberia generation volumes decrease in order to return to equilibrium level. Load rise in Ural leads to to adjustment of the generation volumes, as presented in α matrix in cointegration relation 2 (ECT#2), and that is consistent with energy systems' property of balancing. However the same pattern does not operate in Siberia.

Table 6. The short run cointegrating relations and coefficients in VECM for CPS of Ural and Siberia CPS

Variable	Elements of α matrix		Exogenous variables				
	ECT #1	ECT #2	Frequency deviation	Temperature	Holidays	Change	Seasonal dummies
Ural data							
Load_U	-0.072***	-0.049***	-1823.890***	-7.722***	-131.722***	0.532	Yes
	(0.016)	(0.003)	(91.384)	(0.321)	(6.412)	(3.172)	
Gen_U	-0.257***	0.021***	518.941***	-0.997*	-62.936***	-19.504***	Yes
	(0.027)	(0.006)	(156.808)	(0.551)	(11.002)	(5.444)	
Price_U	-0.029***	0.004***	-37.125**	0.016	-6.961***	-2.358***	Yes
	(0.002)	(0.001)	(14.663)	(0.052)	(1.029)	(0.509)	
Siberia data							Yes
Load_S	0.073***	-0.058***	-111.635*	-10.052***	-73.917***	-5.738*	Yes
	(0.011)	(0.003)	(63.398)	(0.307)	(4.342)	(3.008)	
Gen_S	-0.053**	-0.023***	-1648.327***	-7.721***	-50.400***	18.384***	Yes
	(0.021)	(0.006)	(125.646)	(0.608)	(8.605)	(5.962)	
Price_S	-0.020***	0.003***	0.210	-0.263***	-3.326***	4.505***	Yes
	(0.002)	(0.001)	(14.639)	(0.071)	(1.003)	(0.695)	

Note: Coefficient estimation is based on the model specification with restricted trend and 48 lags accounting centered seasonal dummies as proposed in Johansen (1995, p. 84) and exogenous variables. Standard errors are presented in parentheses.

* Indicates significance at the 10% level, ** at the 5% level, *** at the 1% level.

The table 6 results for the relation in the short-run period indicate entirely negative and strongly significant coefficients for Holidays across CPS of Ural and Siberia. This is consistent with reality when electricity on holidays is being consumed at a less level than on a workweek.

As less electricity is needed to cover demand then less electricity is produced. Moreover declining load causes price in the auction being cleared at a lower level[1].

Influence of frequency variable is strongly significant for load and generation volumes for each CPS. Declining frequency indicates a situation with capacity scarcity, when load is rising, while generation volume is decreasing. That is consistent with our results for CPS of Urals (table 6). However, estimates for Siberia CPS consider a case with increasing both load and generation volume. One possible explanation of that are line losses, which are extremely high in Siberia due to long lines and severe climate. Moreover, we don't take into account electricity transmission with CPS of the East and with other countries. And this influences our empirical results and leads to biased estimates.

An increase in temperature leads to a decline in both consumption and generation, what is proved by the results in table 6 for both CPS. Load and generation volume are more sensitive to temperature in Siberia, than in Ural due to the following feature of capacity structure. In Siberia the main part of the generation capacities are hydro-power plants, whereas in Ural the main part of the structure is thermal power plants. Generation of hydro-power plants is more sensitive to temperature than generation of thermal power plants. The explanation is as follows. Operating year of hydro power stations is defined by the moments, when rivers are covered with ice and are melting. These moments are defined only by temperature.

The conclusion to emerge from table 6 is that protocol change matters. Firstly, it significantly influences on prices: negatively on price of CPS of Ural and positively on Siberia price. Consequently, "fictional" line has led to price convergence to some extent. Given the existence of interregional transmission line, cheap generation power stations in Siberia and expensive plants in Urals should produce more and less electricity respectively, what is proved by our estimates. Load in Siberia is significant and negative affected by the change. Contrary to load in Ural, load in Siberia is sensitive to intense price increase, that showed up because of change.

4.3.Empirical results for the united territory

Since overflow between price zones operates (at least formally), CPS of Ural and Syberia can be considered as a united energy system. Currently calculations in the day-ahead market are indeed made for these territories as for a united one. Consequently, price and volumes of one CPS are supposed to influence price and volumes of the other CPS and conversely.

[1] Price is cleared at the lower bid of power station, whose produced electricity volume cumulative with electricity of all other stations with much lower bids is enough to cover load.

Given this, we should consider a vector error correction model with specification including variables for both CPS. This model is applied on the data subsample for the 4th time period- from 15 August 2014 till 31 May 2015 with 6960 observations.

Table 7. Test for the Number of Cointegrating Relation for the united territory

H(r)	Trace test			Information criteria	
	Statistics	Critical value at 5%	Critical value at 10%	SBIC	HQIC
r≤0	410.920	114.9	124.75	76.429	75.725
r≤1	194.973	87.31	96.58	76.413†	75.701
r≤2	116.060	62.99	70.05	76.415	75.697
r≤3	54.659	42.44	48.45	76.416	75.693
r≤4	26.012*	25.32	30.45	76.420	75.692†
r≤5	9.922**	12.25	16.26	76.422	75.693

Note: * Indicates significance at the 10% level, ** at the 5% level, *** at the 1% level. † indicates that null hypothesis cannot be rejected according to minimization of the information criteria: SBIC (the Schwarz Bayesian information criterion) and HQIC (the Hannan and Quinn information criterion).

On the first step cointegration rank is tested. According to trace test and the Hannan and Quinn information criterion (table 7) null hypothesis of order of cointergation $r \leq 4$ cannot be rejected.

On the second step parameters of VECM are estimated. Models specification is presented in (3), accounting only for 6 lags due to small-size sample. In this context Y is a vector of 6 variables: price, generation volume and load for CPS of Ural and for Siberia CPS.

The first cointegration relation in table 8 represents the long run relation between prices in Siberia, Ural load and generation volumes in Siberia, accounting for trend and intercept. The signs of the elements of the cointegrating vector indicate that increase in Ural load leads to rise in Siberia prices, whereas increase in Siberia generating volume relates to Siberia price decline. This can be explained in the following way. An increase in consumption in Urals (while all other factors remain at the same level) introduces power deficiency in the region. Given operating interregional overflow between Ural and Siberia, required electricity is more likely to be produced in Siberia due to its price and be transmitted to the CSP of Urals. Consequently, generation volume in Siberia rises and price is cleared at a higher level. At the same time increase in generating volume in Siberia, while consumption in Siberia and Ural remains at the same level, leads to capacity surplus in region and, therefore, to Siberia price decline.

Table 8. The long run cointegrating relations in VECM for the united territory

Variables in VECM	Elements of β matrix			
	Cointegration relation #1	Cointegration relation #2	Cointegration relation #3	Cointegration relation #4
Load_U	-0.291***	-0.737***	-1.610***	0.002

	(0.023)	(0.031)	(0.107)	(0.014)
Gen_U	-	-	1	-
Price_U	-	-	-	1
Load_S	-	1	-	-
Gen_S	0.403***	-0.079***	-0.873***	0.161***
	(0.021)	(0.029)	(0.101)	(0.013)
Price_S	1	-	-	-
trend	0.164***	0.062	-0.768***	0.144***
	(0.052)	(0.071)	(0.247)	(0.032)
intercept	-2135.59	-159.60	42035.88	-5420.90

Note: Coefficient estimation is based on the model specification with restricted trend and 6 lags accounting centered seasonal dummies as proposed in Johansen (1995, p. 84) and exogenous variables. Standard errors are presented in parentheses. * Indicates significance at the 10% level, ** at the 5% level, *** at the 1% level.

The 2nd cointegration relation indicates balancing relation in the long run period: increase in load in Siberia leads to increase in generation volume. Moreover the results indicate that load in Ural positively affects load in Syberia. One of the possible explanations is that industrial complexes (who are the main consumers in regions) are located jointly in Ural and Syberia or different production stages of the same product are located in Ural and CPS.

The 3rd cointegration relation reflects the long run relation between Ural consumption and generated volumes in Ural and Siberia. Increase in Ural consumptions reacts in an rise of Ural generation and, unexpectedly, increase in Siberia generation affects positively on Ural generation. This result may arise because the relation between generations in different regions is not linear. An increase in electricity generation in Siberia in amount of less or equal to the capacity of interconnector leads to a decline in Ural generation. However, an increase in Siberia generation in amount, which is more than the capacity of interconnector, doesn't cover capacity scarcity in Ural and introduces an increase in Ural generation.

The 4th cointegration relation considers the long run relation between Ural prices, Ural load and generation volumes in Siberia. The signs of the elements of cointegrating vector are the same as in the 1st cointegration relation. An increase in Siberia generating volume relates to Ural price decline. Thay can be explained by the overflow between CPS.

5. Conclusion

We empirically investigate the question how connecting line between previously isolated CPS of Ural and Siberia CPS affects price and volume's behavior in the short run and in the long run. For that purpose, we simultaneously model price, load and generation separately for each CPS accounting for the date of protocol change.

Joskow (2006) emphasizes that liberalization in energy system does not undercut physical and technical properties of market operating. Given that, this research is one of the only to analyze prices and economically calculated volumes accounting for physical constraints of electrical grid. The physical constraint in this research is a flow frequency. We have shown that flow frequency exhibits significant influence on economic dispatch and price in CPS of Urals, whereas in CPS of Siberia it shows strange behavior.

The research provides empirical evidence that supply increase in the long run leads to price decline in both CPS. Moreover the balance between demand and supply is empirically revealed in CPS of Ural, but is not find in CPS of Siberia. The possible explanation is that we consider CPS of Ural and Siberia CPS as independent energy systems. In the future research the whole electrical grid of Russia should be taken into account. Transmission lines with other countries should be included as well.

Electricity load and generation volume are significantly affected by the average temperature of the CPS, what is proved by the model estimates in the article. The temperature influence is appeared to be different for CPS as far as capacity structure of Siberia mainly consists of hydro-power plants. However gathered data for temperature does not reflect hourly seasonal pattern and the effect of «satiation temperature» cannot be captured by them. Meanwhile this effect doesn't influence the long-run equilibrium, which is of the main interest in the research.

Another finding in the research, that change in market operating protocols ("fictional" connecting line) leads to price convergence in CPS in the long run to some extent. This extent of convergence depends on capacity constraints of connecting line, which was not considered in our research and should be accounted for in future. Besides that a change in the market operating protocols leads to new long run equilibrium for the territory, that units both CPS. In that equilibrium price in Siberia and price in Ural are affected by demand and supply in both CPS.

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