Interaction of generation companies in the electricity market of Russia

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Abstract

Objective

- to analyze the mechanisms for electricity market organization on the basis of economic and mathematical modeling with regard to specific features of the industry;
- to analyze the empirical facts of wholesale trade on electricity market;
- to assess the market power of individual companies and effectiveness of introducing competition;
- to simulate the wholesale electricity market in the second price zone - Siberia;
- to compare the performance of different patterns of market organization with the aim of furthering the best rules of market operation.

Modeling criteria

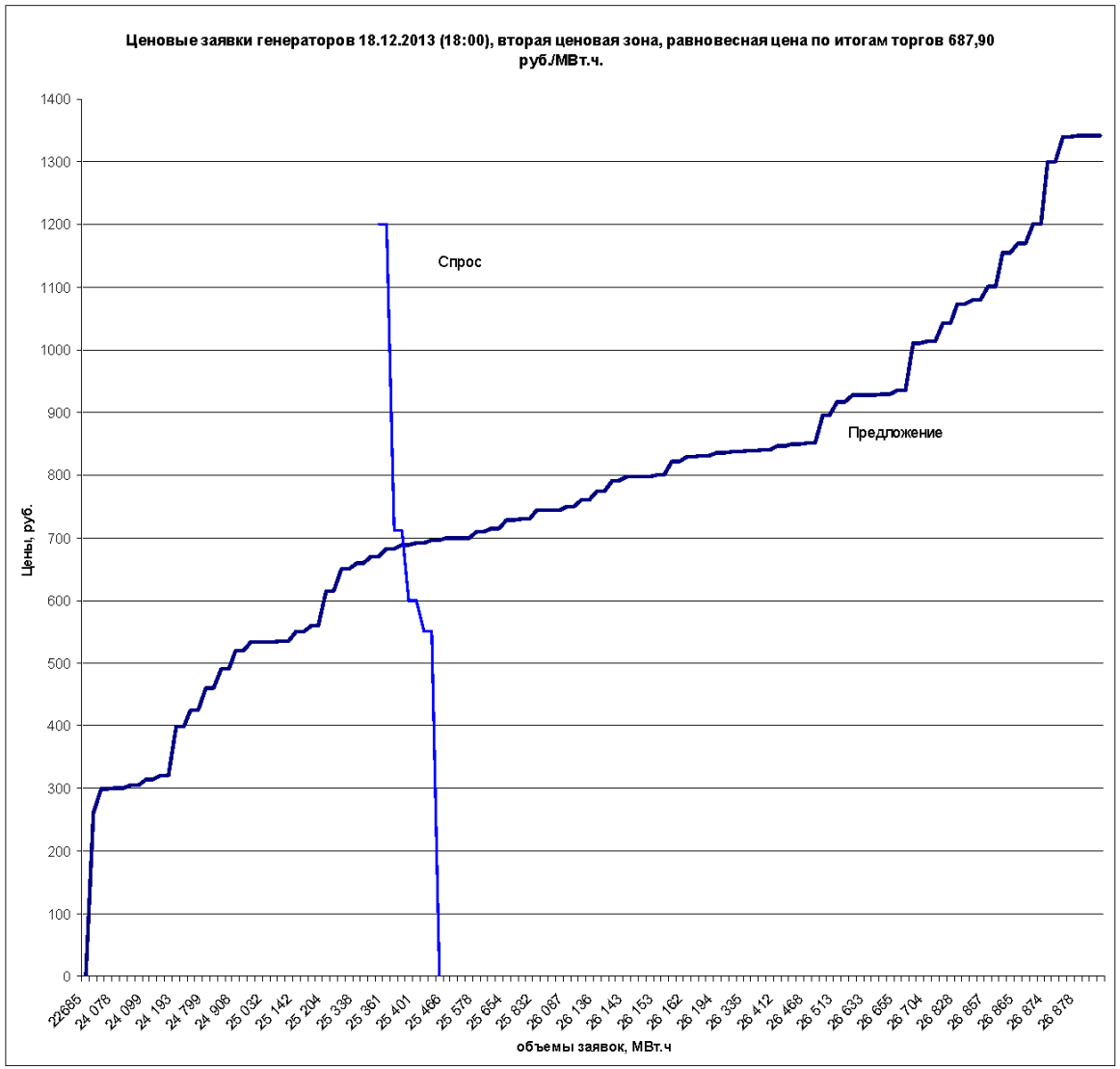
1. Welfare maximization.
2. Market stability (absence of stimuli to change the rules of behavior, long-term stable price level).

Analysis tools – models of imperfect competition markets

Oligopoly market for homogeneous product with barriers to entry is created:

- some producers have market power;
- prices do not correspond to the marginal costs (incentives arise for participants to use the strategy of overstating their costs when submitting bids in order to get the maximum profit).

Equilibrium in the spot market



A day-ahead market (the second price zone)

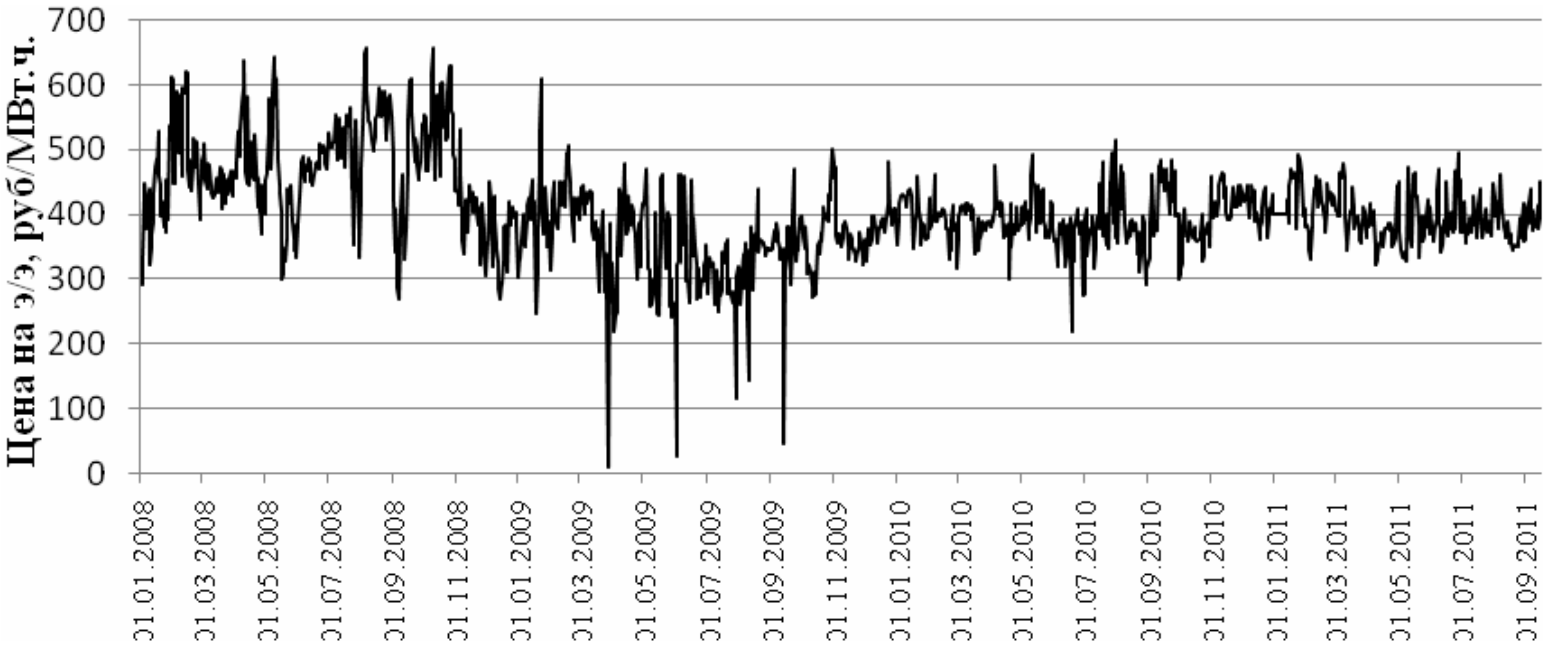
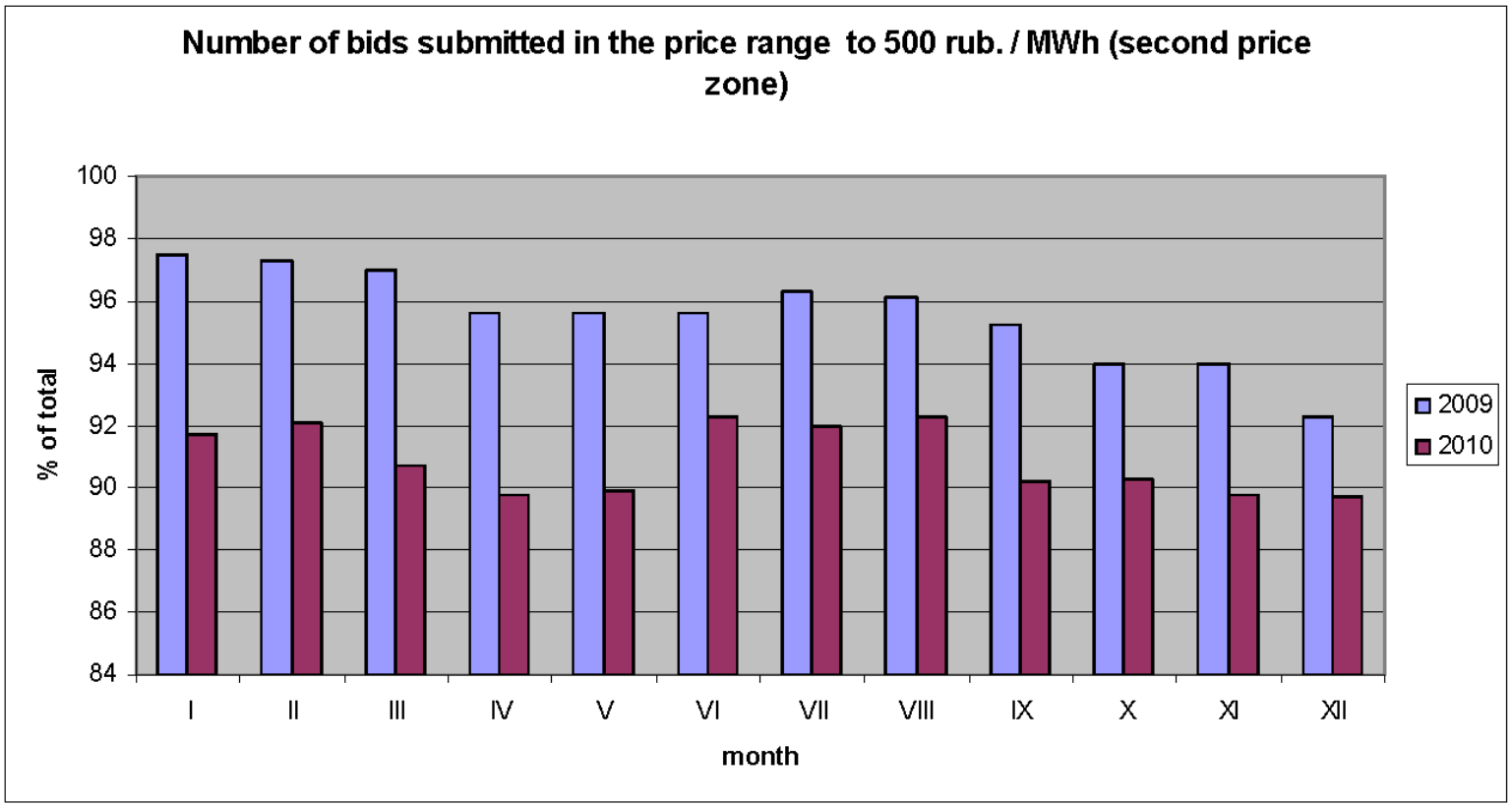
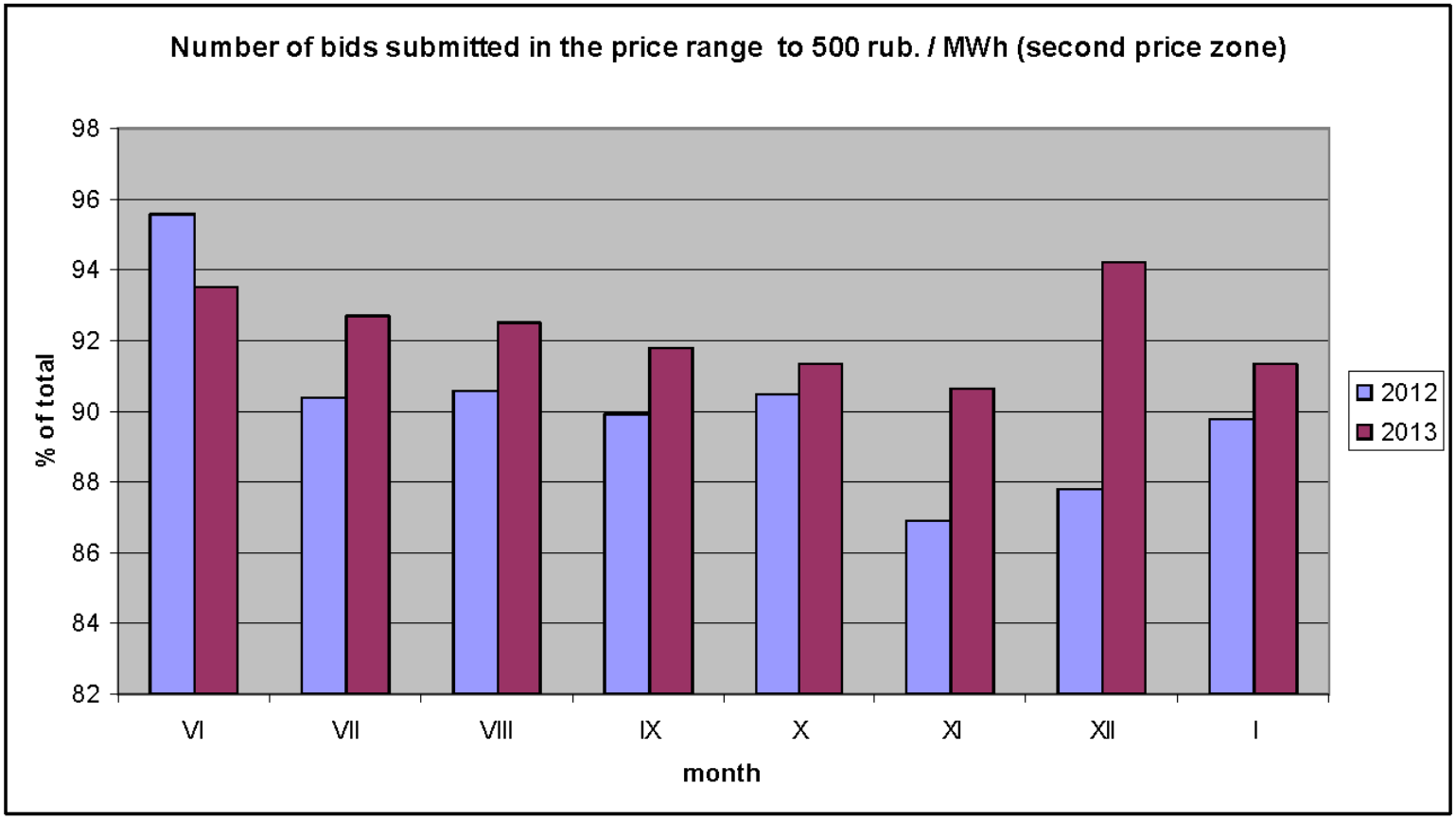


Fig.3. Dynamics of equilibrium prices in the wholesale electricity market (2008-2011)

Strategies of electricity market agents 2009-2010(the second price zone)



Strategies of electricity market agents 2012-2013(the second price zone)



Strategies of electricity market agents

- a decrease in volatility of equilibrium prices (stable strategies of participants are developed, market gets more predictable; the awareness of long-term consequences of market power rises).
- a tendency towards price rise until 2012 (is partly explained by an increase in the number of participants and their diversity, abuse of market power).
- The trend of increasing of prices in the bids changes in 2012, thus there is a decline in long-term contracts.
- Long-term contracts:
  - 2011 - 9% total, 6% - the first price zone, 18% - Siberia,
  - 2014 - 3% total, ~1% - the first price zone, 11% - Siberia,

The formation of stable strategy of generation companies. Generation companies direct theirs attention to the long-term period.

The modeling is possible by the static equilibrium model.

Strategies of electricity market agents

The main issue is to what extent it is profitable for economic agents to deviate from their marginal costs when forming a strategy.

Depending on what mechanism will underlie the market, the result (market equilibrium) can correspond to one of the models of following a certain strategy.

- to be guided by a price and own marginal costs
- to be guided by a price, marginal costs and demand elasticity at each point;
- to be guided by a price, marginal costs, demand elasticity and influence of competitors on price changes.

Modeling of strategic interaction in electric power industry

Single-node models neglecting network

- Model Walras;
- Model Cournot: Green, Newbery, Vasin;
- Conjectured supply function (CSF) (asymmetric information): Hobbs, Day, Pang, Bulavsky, Kalashnikov;
- Supply function equilibrium (SFE,LSFE) (full information): Klemperer, Mayer, Green, Hogan, Baldick, Kahn, Newbery, Vasin.

All models take into consideration specific features of the industry: limitation on electricity generation, possibility of introducing a competitive environment.

Modeling

The function of industry output

$$Q(P) = \sum_{i=\overline{1,n}} q_i(P),$$

$n \geqslant 2$ - the number of firms, $q_i(P)$- supply function i-th player, $C_i(q_i)$ - the cost function of the generating company (convex increasing)
Demand - $D(P)$, $P(Q)$ - market price.
The problem of the generator - to maximize profits on the residual demand

$$\pi(P, q_i) = P \cdot q_i(P) - C_i(q_i(P)) \to \max;$$

First order conditions

$$q_i(P) + P \cdot \frac{\partial q_i}{\partial P} = MC_i(q_i(P)) \cdot \frac{\partial q_i}{\partial P}.$$

Strategy of a firm's

Indices of a firms impact on market situation

$$w_i(P) = \frac{\partial Q(P)}{\partial q_i(P)}.$$

Supply function formed by the firm:

$$q_i(P) = \frac{MC_i(q_i(P)) - P}{\frac{\partial P}{\partial Q} \cdot w_i(P)}$$

$w_i \in [0,1]$. Model Walras $w_i = 0$, Cournot - $w_i = 1$, oligopoly - w_i determined by solving the system of equations.

Basic assumptions

- Demand is line $D(p) = N - \gamma P$.
- Costs generators is convex quadratic functions, for the firm i: $C_i(q_i) = \frac{1}{2} c_i q_i^2 + a_i q_i$, $c_i > 0$, $a_i \neq 0$, $i = \overline{1, n}$.
- Maximum output of firm V_i.

In this case the equilibrium for model Kurno, LSFE exist and unique for $q \in [0, +\infty]$.
We modeled the active competitors and the pricing recipients.
Wholesale market rules suggest the participation of different types of competitors.

Model with generating companies

The model considers two types of of competitive firms.

- The company has in its composition single generating capacity

$$\pi_i(P, q_i) \to max, \quad i = \overline{1, m}$$

- The company has in its composition several generating capacity

$$\pi_{GK_j}\left(P, \sum_{r=1,k} q_r\right) \to max, \quad j = \overline{1, l}$$

l- the number of generating companies, and k - the number of generating capacity, forming part company.

- $$\begin{cases} q_k = \frac{\gamma}{w_k + c_k\gamma}(P - \alpha_k), & a_k \le P < \frac{V_k(w_k + c_k\gamma)}{\gamma} + a_k, \\ q_k = V_k, & P \ge \frac{V_k(w_k + c_k\gamma)}{\gamma} + a_k. \end{cases}$$

- ***Proposition***. The equilibrium of model SFE with generating companies exists and is unique in the case of linear demand and linear marginal cost.

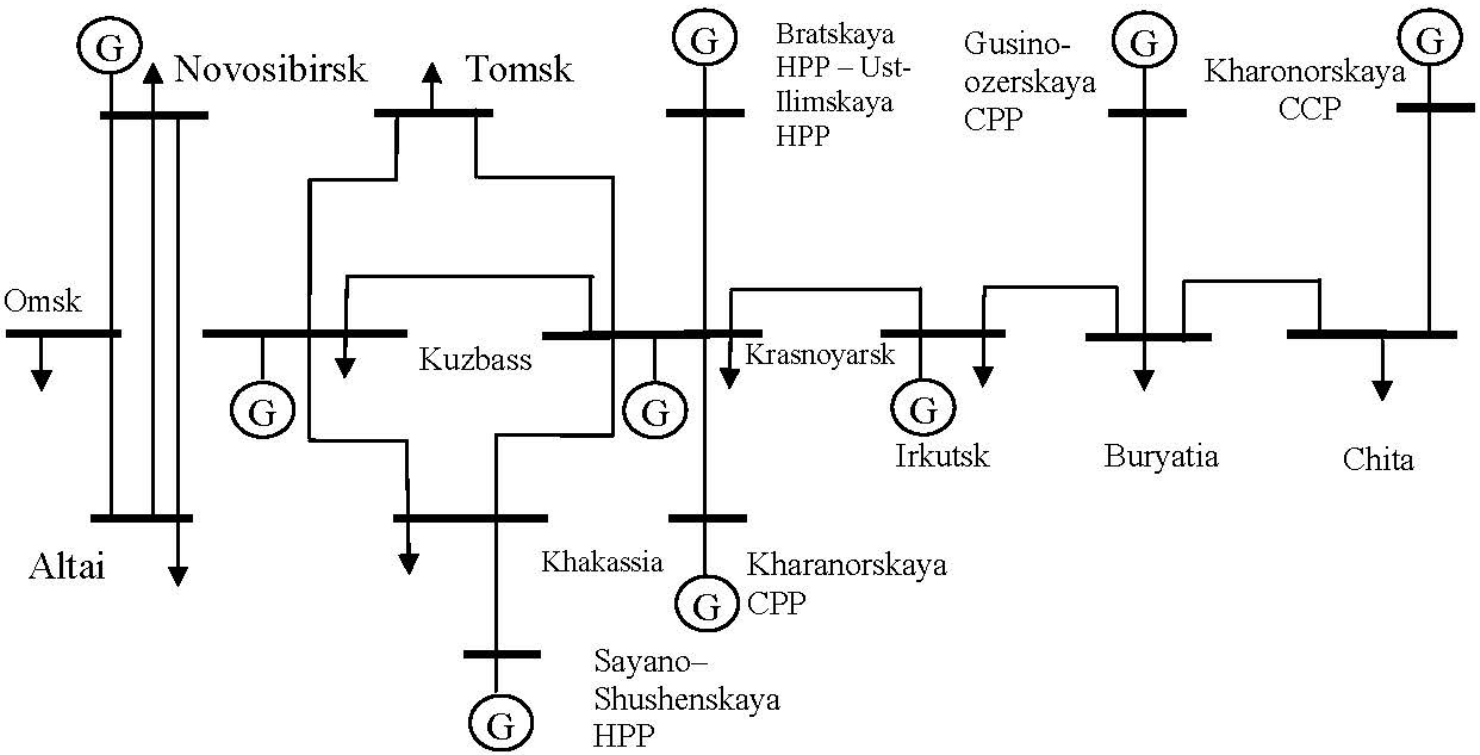
Initial data

15 nodes – 10 load and 9 generation nodes

nodes(load)	nodes(generation)
Irkutsk	Irkutsk
Altai	Gusinoozerskaya CPP
Buryatia	Kharanorskaya CPP
Krasnoyarsk	Krasnoyarsk
Novosibirsk	Novosibirsk
Omsk	Kuzbass
Tomsk	Sayano–Shushenskaya HPP
Chita	Kharanorskaya CPP
Khakassia	Bratskaya HPP – Ust-Ilimskaya HPP
Kuzbass	

Formation of demand function:

- expert estimate of demand elasticity is 0.3.


G
Novosibirsk
Tomsk
G
Bratskaya
HPP – Ust-
Ilimskaya
HPP
Gusino-
ozerskaya
CPP
G
Kharonorskaya
CCP
G
Omsk
Kuzbass
Krasnoyarsk
G
G
G
Irkutsk
Buryatia
Chita
Altai
Khakassia
Kharanorskaya
G
CPP
Sayano–
Shushenskaya
HPP
G

Oversize supply function coefficients generating companies over marginal costs interacting on the market

$$q_i(P) = \beta_i(P - a_i)$$

Oversize supply function coefficients	supply function equilibrium,%	Cournot,%	supply function equilibrium(GenCo),%
Irkutsk	17	28	15
Gusinoozerskaya CPP	6	11	4
Kharanorskaya CPP	7	4	8
Krasnoyarsk	26	38	25
Novosibirsk	21	24	20
Kuzbass	3	22	3

Conclusions

- to proposed **the methodological approach** for the estimation of the market power in Russia wholesale electricity market for a short period;
- to select the best ways – **a static single-node model LSFE** with generating companies under constraints generation;
- to prove that **the equilibrium** in this model **exists and is unique**.

- generating companies are having their stable strategies in the wholesale market in Russia now;
- operation mechanism in the wholesale electricity market suggests the possibility of forming the strategies corresponding to different models of interaction, which causes abuse of market power;
- mechanism stimulates the use of the high price strategy, which corresponds to the manifestation of maximum possible (under oligopoly) market power of generating companies (the situation requires regulation).

Thanks for attention

Factors reducing market power

- Presence of free long-term contracts (it is necessary to tend to increase their period; raise their number, in particular through the regulated contracts);
- Adjustment of the bid submission rules (introduce a greater number of steps, aggregate supply function). This leads to the strategies of supply function equilibrium, and such a mechanism is stable.
- Accessibility and availability of information (additional price signals for both producers and consumers).
- Free access of new generating capacities, including small ones, to the network (which makes the competition stronger).

Models of interaction

$i = \overline{1,n}$	Walras	LFSE	Cuornout
strategy	$q_i^{LE}(P) = \frac{P-a_i}{c_i}$	$q_i^{LE}(P) = \frac{\gamma(P-\alpha_i)}{w_i+c_i\gamma}$	$q_i^{K}(P) = \frac{\gamma(P-a_i)}{1+c_i\gamma}$
constraints V_i	$a_i \le P < V_i \cdot c_i + a_i$	$a_i \le P < \frac{V_i(w_i+c_i\gamma)}{\gamma} + a_i$	$a_i \le P < \frac{V_i(1+c_i\gamma)}{\gamma} + a_i$
price	$P^{W*} = \frac{N+\sum_i \frac{a_i}{c_i}}{\gamma+\sum_i \frac{1}{c_i}}$	$P^{LE*} = \frac{N+\gamma\sum_i \frac{a_i}{w_i+c_i\gamma}}{\gamma\left(1+\sum_i \frac{1}{w_i+c_i\gamma}\right)}$	$P^{K*} = \frac{N+\gamma\sum_i \frac{a_i}{1+c_i\gamma}}{\gamma\left(1+\sum_i \frac{1}{1+c_i\gamma}\right)}$
condition of equilibrium		$\alpha_i = a_i$ $w_i = \frac{1}{\sum_{j\neq i}\frac{1}{w_j+c_j\gamma}+1}$	
competitive environment	$\hat{\gamma} = \gamma + \sum_k \frac{1}{c_k}$ **k-agrees to the price**	$a_i \le P < \frac{V_i(1+c_i\hat{\gamma})}{\hat{\gamma}} + a_i$	$\hat{P}^* = \frac{N+\hat{\gamma}\sum_i \frac{a_i}{w_i+c_i\hat{\gamma}}+\sum_k \frac{a_k}{c_k}}{\hat{\gamma}+\sum_i \frac{\hat{\gamma}}{w_i+c_i\hat{\gamma}}+\sum_k \frac{1}{c_k}}$ $w_i \in [0,1]$

Characteristics of equilibrium for different models

Model	Price (руб./МВт ч)	Volume (МВт)	Profit (тыс.руб.)	Surplus consumer	Welfare
Walras	337	41108	3656,8	5768,9	9425,7
LSFE	378	39678	4469,5	4931,8	9401,4
LSFE(GenCo)	384	39275	4599,0	4796,5	9395,2
Cournot	405	38577	4916,0	4399,5	9315,5
Monopoly	482	37495	5762,3	3071,8	8834,2

Results of the equilibrium price calculations (different scenarios)

Condition	perf. comp.	LSFE	Cuornot	Monopoly
Unchanged data(0.3)	337	378	405	482
Inelastic demand (0.15)	337	410	500	535
Dry year generation hydro↓8%	373	400	430	509

Models allow us to assess the effect of the market on the installation of additional capacities, expansion and reduction of generating companies, different patterns of bid submission to the market, etc.