Analysis and Design of Electricity Markets (Electricity Markets)

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The main area of investigation. This project aims to examine different variants of electricity market development, in particular, for the Russian market. The first task is to compare different kinds of everyday supply function auction: pay as bid, unique price and Vickrey auction. The second problem is to study models of the two-stage market including a forward market and a day ahead auction. We propose to consider different variants for each stage and to compare them with respect to the electricity price and the social welfare. One more direction is to study network markets and to find an efficient method for computation of equilibrium out comes for the network supply function auction. An important feature of the standard auction (with a unique price for each node) is that the number of Nash equilibria increases exponentially in the number of nodes in the network. We plan to examine a possibility of coexistence of different equilibria and evaluate their deviation from the competitive equilibria.

Expected results. We plan to obtain estimates of the price and social welfare value (depending on the concentration ratio) for different variants of the market organization. We shall determine optimal variants proceeding from the social welfare and consumer prices. We shall also evaluate a degree of the market splitting that is necessary to provide a given consumer price. For network markets we plan to find efficient methods for computation of the Cournot equilibrium that is closest to the competitive equilibrium, and also for computation of other Nash equilibria. We also plan to study the impact of the forward market on the expected prices in the two-node network market. Proceeding from these results, we shall discuss the latest variant of the Russian market reform.

Importance of the study. The optimal everyday auction organization for electricity markets is widely discussed in the special literature. Switching of England and Wales market from the unique price to pay as bid auction gives a new impulse to this discussion. While the regulative agency Forgem (2002) estimates this reform positively, several specialists, in particular, K. Wolfram (2001) do not recommend other countries to follow this example. The existing theoretical papers on this issue (N. Fabra, 2005) are not convincing since they do not consider a possibility to manipulate production capacity in producers bids. Our previous results (Vasin, Vasina, 2005) provide the appropriate base for careful study and comparison of the mentioned auctions.

The idea to use forward market for consumer price reduction is rather popular in the literature. In particular, Bushnell (2005) shows that for the case of constant marginal cost, the impact of introducing of a single round of forward trading as measured by Lerner index is equivalent to squaring of the number of firms in the market. However, this optimistic estimate strongly depends on such assumption of equal prices at the forward and spot markets due to efficient arbitrages. This seems to be in contrast to practice. Our current project results show that under possibility of price

discrimination, existence of the forward market increases the average price of the good for consumers in some cases. The prospective investigation pf the forward market organization forms seems especially of current importance with respect to last projects of the Wholesale Russian Electricity Market development.

In contrast to many other countries, the network structure of electricity market is essential for the market prices in Russia. Capacity constraints may essentially increase the market power of some companies. The problem of Nash equilibrium computation for a network market is very important for the price forecast. In our previous project we developed the corresponding methods for small networks with two and three nodes. An efficient generalization of these methods for large networks is a challenging problem.

In November, 2003 the competitive segment was introduced on Wholesale Russian Electricity Market, in May, 2005 the market area was spread to Siberia. The competitive segment allows to sell up to 15 % of working capacity (or to buy up to 30% of hour electricity consumption) at marginal node prices or through the system of vesting contracts. This year some new initiatives on the reformation of the Wholesale Russian Electricity market starts. They are designed to cut down the short-comings of the current model. Thus, in 2006 participation in the competitive segment for consumers will be changed to obligatory. Besides the regulated sector of market will be transformed into the market of long-lasting regulated vesting contracts with annual reduction of the volumes in this sector. In 2006-2007 it is also planned to introduce the market of system services and the contestable capacity market. Now there are about 160 participants of bargains in European Russia and Ural and about 30 participants in Siberia in the competitive segment. The daily consumption volume of the competitive sector reaches about 14% of the total consumption of European Russia and Ural and 3 % of the total consumption of Siberia. About 20-25% of these values are sold via vesting contracts. Also it is planned to introduce the electricity market of financial instruments, including put and call options, forwards and futures. This market aims to hedge a risk on the spot market. Recently the imitation bargains of financial contracts took place.

Literature Review.

The problem of imperfect competition in the markets for homogeneous goods (gas, electricity etc) is widely discussed in the literature. For the empirical investigation see Sykes and Robinson (1987). The corresponding theoretical models consider a local market without network structure. Static one-period models (Baldick et al. (2000), Green (1992), Klemperer and Mayer (1989)) describe a sealed bid unique-price auction as a normal form game and characterize its Nash equilibria. The latter paper studies a model of competition via arbitrary supply functions set by producers. For a given demand function they show that for any price above the Walrasian one there exists the corresponding Nash equilibrium. Green and Newbery (1992) consider a symmetric duopoly with linear supply and demand functions and obtain the explicit expressions for computation of the Nash equilibrium. Baldick et al. (2000) generalize their result for an asymmetric oligopoly. Abolmasov and Kolodin

(2002) and Dyakova (2003) apply this approach for a study of the electricity markets in two Russian regions. They use affine approximations of the actual supply functions.

Our papers Vasin, Vasina (2005) provide the last findings on existence and properties of the Nash equilibrium for the Cournot oligopoly and supply function auctions with step bids. In every case, the underlying market includes a fixed finite number of producers that are heterogeneous in production capacities and non-decreasing marginal costs of production. Consumers do not play any active role in the models. Their behavior is characterized by the demand function that is the common knowledge.

We develop a descriptive method for computation of the Cournot outcome under any affine demand function and obtain an explicit upper estimate of the deviation of the Cournot outcome from the Walrasian outcome proceeding from the demand elasticity and the maximal share of one producer in the total supply.

Then we consider a unique price supply function auction. We show that, besides the Cournot outcome, there exist other Nash equilibria. However, only the Nash equilibrium corresponding to the Cournot outcome is stable with respect to some adaptive dynamics.

The estimates of the Cournot outcome deviation from competitive equilibrium as well as the results of calculations for the concrete market show that the market price in the supply function auction can essentially (3-5 times) exceed the Walrasian price under the current market organization. Our report(2005) considers Vickrey auction with reserve prices as an alternative. In this case reporting the actual costs and production capacities is a weakly dominating strategy. In absence of information on production costs the guaranteed value of total profit reaches its maximum at the corresponding Nash equilibrium. Our calculations for the Central Economic Region of Russia show that Vickrey auction price for consumers exceeds the Walrasian price only 1,5 times.

Our latest paper (Vasin, Vasina, 2005b) discusses standard criteria of the market competitiveness related to Concentration ratio and Herfindahl-Hirschman index and show that they are too soft for the unique-price auction at the electricity market. We obtain the more strict conditions that provide a sufficiently small deviation of the market price from the Walrasian price.

We also examine some problems related to the network structure of electricity and gas markets. In order to reduce the number of possible Nash equilibria under consideration, we employ two ideas. First, we show that some equilibria are incompatible, and provide a simple rule that distinguishes one of three variants as a possible NE under given parameters of the market. Then we show that an equilibrium of any market with losses may be approximated by

some equilibrium of the similar market without losses. Thus we show that at most two *NE* may coexist for a 2-node market without losses.

Several papers compare a unique-price and "pay as bid" auctions in context of the recent reforms of the electricity market in UK. C. Wolfram note that switching from uniform to discriminatory pricing may lead to inefficient production. Although prices in the Pool have undoubtedly been higher than marginal costs, a switch to discriminatory pricing is unlikely to solve that problem, given the dominance of a small number of generating companies.

Because a discriminatory auction compensates companies based on their ability to predict the market-clearing price rather than on their relative efficiency, and because coal plants currently dominate the industry, owners of coal plants generally will predict prices more accurately. Hence, adoption of a discriminatory auction would cause coal plants to be used more than they are under the unique-price system. That would subsidize the coal industry at the cost of higher electricity prices for consumers.

On the other hand, the UK regulations agency, Ofgem, reports about positive results of the reform (Ofgem, 2003). The New Electricity Trading Arrangements (NETA) were successfully introduced in England and Wales on Tuesday 27 March 2001. NETA replaced the Electricity Pool whose centralized, inflexible arrangements for setting wholesale electricity prices meant that prices failed to reflect falling costs and competition. NETA with falling input prices, a generous capacity margin and more competition in generating have led to substantial reductions of around 40 per cent in thoulesale electricity prices since the reforms were proposed in 1998. Industrial and commercial customers have reported substantial reductions in their bills.

More than 98 per cent of electricity is sold like any other commodity, with on average only two per cent of sales taking place in the balancing mechanism.

Let us note that now the price is higher than before the reform started.

Fabra et al. (2004) study theoretical models of the unique price and pay-as-bid auctions for a duopoly with asymmetric capacities and constant marginal costs and demand. Their main conclusions may be summarized as follows. Equilibrium outcomes in either auction format fall essentially into one of two categories, depending upon the level of demand. In low-demand realizations prices are competitive, in the sense that they cannot exceed the cost of the most efficient non-despatched supplier: in high-demand realizations, on the other hand, prices exceed the cost of even the most inefficient supplier. In high-demand states there are multiple, price-equivalent pure strategy equilibria in the uniform auction, while in the discriminatory auction the equilibrium is in mixed strategies. With certain demand (i. E.

short-lived bids), payments to suppliers (or average prices) are lower in the discriminatory auction and numerical examples suggest that the difference can be substantial. The comparison in terms of productive efficiency, however, is ambiguous and depends on parameter values as well as which pure-strategy equilibrium is played in the uniform auction. Let us note that their conclusions are not very convincing since the model assumes fixed production volumes in the bids and considers mixed-strategy equilibrium in the price competition (see Friedman,1996, for criticism of this approach).

Research Methodology. We propose to study the above mentioned problems in the following theoretical framework (see Vasin, Vasina, 2005).

Consider a market with a homogenous good and a finite set of producers A. Each producer a is characterized by his cost function $C^a(v)$. Consumers' behavior is characterized by the demand function $D(p)$. Consider a model of Cournot competition for this market. Then a strategy of each producer a is his production volume $v^a \in [0, V^a]$. The market price $p(\vec{v})$ equalizes the demand with the actual supply: $p(\vec{v}) = D^{-1}(\sum_{a \in A} v^a)$. The payoff function of producer a determines his profit $f^a(\vec{v}) = v^a p(\vec{v}) - C^a(v^a)$. Thus, the interaction in the Cournot model corresponds to the normal form game Γ_C.

Combination $(v^{a*}, a \in A)$ of production volumes is Cournot equilibrium (CE) if it is a NE in the game Γ_C. Computation and properties of CE are completely discussed in Vasin, Vasina, 2005.

The unique price supply function auction.

Every producer $a \in A$ sends his bid $R^a(p)$. We assume that $R^a(p)$ is a non-decreasing step function. The bids determine the total r-supply $R(p) = \sum_a R^a(p)$ and the cut price $\tilde{c}(R^a, a \in A)$ that meets condition $D(\tilde{c}) \in R(\tilde{c})$. Producers and consumers sell and buy the good at this price.

Vasin, Vasina (2005) showed that any stable NE in this model corresponds to Cournot outcome. This paper also studied games corresponding to Betrand-Edgeworth and Vickrey auctions. Now our purpose is to construct on this base models for different variants of the two-stage market (including forward and spot markets) and to examine subgame perfect equilibria of these models.

A network market with two nodes

Every local market $l = 1,2$ is characterized by the finite set A^l of producers, the cost functions $C^a(v), a \in A^l$, and demand function $D^l(p),$. Agents' strategies $(R^a(p), a \in A^l)$ are defined as before. For a given strategy combination, the node cut prices $\tilde{c}^l$ and transmitted volume q are determined as follows.

Let $k \in (0, L)$ be the loss coefficient that shows the share of the lost good under transmission from one market to the other, Q is the maximal amount of the transmitted good. Let $\bar{c}^l(\bar{R}), l = 1,2$ denote the cut prices for isolated markets, $\lambda = (1-k)^{-1}$. If $\lambda^{-1} \le \bar{c}^2(\bar{R}) / \bar{c}^1(\bar{R}) \le \lambda$ then $q = 0$, $\tilde{c}^l(\bar{R}) = \bar{c}^l(\bar{R}), l = 1,2$, that is, the markets stay isolated. If $\bar{c}^2(\bar{R}) / \bar{c}^1(\bar{R}) > \lambda$ then q is a solution of the system

$$D^2(\tilde{c}^2) = \sum_{A^2} v^a + \bar{q}; \qquad (1)$$

$$D^1(\tilde{c}^1) = \sum_{A^1} v^a - \bar{q}; \qquad (2)$$

$\tilde{c}^2 = \lambda \tilde{c}^1$, until $\bar{q} > Q$.

If $\bar{q} > Q$ then $q = Q$, $\tilde{c}^i$ are determined from (1),(2) with $\bar{q} = Q$, $\tilde{c}^2 > \lambda \tilde{c}^1$. The capacity constraint is binding in this case.

Our paper (2005) show that there three types of possible Cournot equilibrium in this model. We provide effective methods for their computation and analysis based on the F.o.c.s. Now one of our purposes is to generalize these methods for a market with many nodes.

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Topics for the NES students MA dissertations.

1) Comparison of “pay as bid”, Cournot and Vickrey auctions for Russian electricity market.
2) Analysis of Cournot auction Nash equilibria for three- and four-node cyclic network auctions of supply functions.

3) Evaluation of the deviation of Nash equilibrium from the competitive equilibrium for a network auction of supply functions.
4) Studying of the network Vickrey auction model.
5) Development of the market model including vesting contracts and the supply function auction.
6) The optimal strategy of an allocated generating company in the network auction.
7) Analysis of the 2-stage market model including vesting contracts and the supply function auction (several variants depending on the type of competition at the first stage).

Brief CVs.

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- (joint with Miguel Gines) "Efficiency, monotonicity and rationality in economies with public goods", Economic Theory, 12, (2), 1998, 423-432
- (joint with I. Ortuno Ortin) "Income taxation, uncertainty and stability", Journal of Public Economics, 67, 1998, pp. 285-300

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