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Understanding the Failure (so far) of the Liberalization of the Czech Market in Natural Gas : some Models

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Understanding the Failure (so far) of the Liberalization of the Czech Market in Natural Gas: Some Models

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Abstract

I present a series of models capturing the (possibly future) situation on the Czech natural gas market. I focus in particular on the impact of EU-wide market liberalization on a specific country characterized by the lack of domestic production, very limited foreign upstream competition and highly concentrated (and bundled) control over an essential input in the production of the final product - gas storage – in an attempt to explain the non-emergence of competition on the Czech natural gas market so far. Using static successive oligopoly models augmented with a storage component I make a comparison of two periods: before and after market liberalization. The main results of the investigation are that, although a sufficiently high number of competitors may drive the price down below the pre-liberalization level, the outcome is hindered by the fact that upstream producers are capable of capturing a significant share of the formerly regulated price margin. Due to this change in producer pricing the wholesale price offered to new traders is higher than the wholesale price provided to the incumbent based on long-term contracts. This result shows that concentrated and bundled storage ownership and the potential for the abuse of the dominant position are not the only reasons why there has been no influx of new traders to the Czech natural gas market.

Contents

1 Introduction

The Czech natural gas sector is currently undergoing significant changes which are driven by the efforts of the European Union to make the industry more competitive. Following EU directives, in 2005 the Czech authorities have started to open up the market allowing the 35 largest consumers to choose their supplier and extended this option to all non-household consumers in 2006. Despite these market liberalization efforts, there is no significant influx of traders who would be willing to supply gas to consumers and almost the whole market is served by a single dominant importer/trader (the formerly regulated and former state-owned monopoly). In light of this development on the market in natural gas, summarized below in 6 stylized facts, I use a series of oligopoly models to understand the situation on the Czech market after deregulation. I particularly focus on the Czech market to investigate the consequences of EU-wide liberalization efforts on a market which plays only a minor role (from the perspective of total consumption) on the European market and which is completely dependent on foreign gas imports. For that purpose I use successive oligopoly models with two levels of competition: upstream gas producers compete to supply gas to downstream traders who in turn compete for end customers. I make a comparison of the results of the models before and after market liberalization and discuss how specific characteristics of the natural gas market, such as gas storage and the ownership of storage facilities, influence the final outcome. The main contribution of this paper is the analysis of the impact of storage on successive oligopoly models, the adjustment of these models to the specific conditions of the Czech natural gas market and investigation of these models within the framework of liberalization.

2 Liberalization and the Czech Natural Gas Market

The energy sector, and in particular the gas industry, has been traditionally perceived as a market exhibiting features of a natural monopoly especially due to savings which could be realized by building a single network for the transportation and distribution of energy. In consequence, in many European countries there was a single

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(and often state owned) company possessing, operating and using this network to supply the commodity to all domestic end-users as well as for international gas transit.

In recent years the European Union has implemented measures to introduce competition into the energy industry. This change in attitude reflects the belief that one can continue to capture the economies of scale arising from a single network, but can do better overall by introducing competition into trading and production, thus eliminating the need for regulation of some activities and reducing the final price for consumers through competition. This market opening is being implemented in all EU member states which are obliged to follow EU directives (Directive 2003/54/EC of the European Parliament and of the Council – electricity and Directive 2003/55/EC of the European Parliament and of the Council – natural gas).

While the basic rationale for market liberalization is straightforward, the latest developments on the Czech gas market vividly demonstrate that there are many critical issues associated with such reform (see also Van Koten 2006 for related development in the market for electricity and Van Koten and Ortmann 2006 for a discussion of legislative and regulatory capture in that area). In order to analyze the impact of market opening on end-users, it is necessary to consider not only reform on the European scale, but also to investigate the consequences of the restructuring for individual countries and the specific market infrastructure they face. To facilitate this investigation and motivate my theoretical work, I first summarize the developments and situation on the Czech market in natural gas.

The Czech Republic has essentially no own natural gas resources. It therefore has to import almost all of this energy source. For historical reasons, it bought almost all its natural gas from Russia, however, in 1997 a contract with a consortium of Norwegian firms was concluded. These historic conditions, and geography, have shaped the physical structure of the gas supply system.

The gas supply system in the Czech Republic consists of a backbone network called the transmission system, eight regional distribution systems and natural gas storage facilities (and a series of operating elements such as regulating stations and compressors stations). The transmission system, which is used for international transit of natural gas (transmission of Russian gas to Western Europe) and the transport of gas

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to distribution systems, has three system input/output stations at the state border: one at the Czech-Slovak border (Lanžhot) and two on the Czech-German border (Hora Sv. Kateřiny and Waidhaus). The transmission system is also connected to all distribution systems, to underground storage facilities (which is for the purposes of trading conceptualized as a single virtual gas storage reservoir) and directly to a few natural gas consumers. Regional distribution systems receive gas from the transmission system and deliver it to connected end-users. In order to supply gas to end-users, the commodity has to be bought abroad and transported to the Czech Republic (or bought from domestic producers[1]), transported through the Czech transmission system to the respective regional distribution system (or first transported to gas storage facilities and only later transported from gas storage facilities through the transmission system to the distribution systems) and then transported through the respective regional distribution system to the end-user.

Before privatization of the Czech gas industry and the market opening the whole system was state-owned. The integrated system operator/trader (Transgas) operated the transmission and storage system and supplied gas to distribution companies which in turn supplied gas to end-users. The price of natural gas was regulated. In May 2002 the German company RWE purchased the integrated transmission system operator and trader Transgas and stakes in 8 distribution companies (RWE holds majority stakes in 6 of them). A very important part of the business activities of the transmission monopoly is the transit of natural gas through the territory of the Czech Republic, specifically from Russia to Western Europe. This activity was and still is not regulated in any way, i.e. the network owner and operator rents out transit capacity based on contracts and contracted prices.

Following the EU directive 2003/55/EC the Czech Republic has enacted the "Energy Act" (Act No. 458/2000 governing the opening of the market) and subsequently the Czech energy regulator (ERO – Energy Regulatory Office) has issued a series of associated decrees including Decree No. 673/2004 and Decree No. 524/2006 which lay down the rules for the organization of the gas market. These regulations determine the gradual opening of the market in natural gas. They define two groups of

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[1] Domestic producers account for less than 1% of annual consumption.

customers: eligible customers, who are entitled to choose their gas supplier, and captive customers, who are served by the former monopoly. As the natural gas market is gradually opened, customers are shifted from the group of captive customers to the group of eligible customers, with a full-scale market opening scheduled for 1st January 2007 when all households will be allowed to freely choose their gas supplier. Starting from 1st January 2005 all large-volume customers (with annual offtake in 2003 exceeding 15 million m^3 – overall 35 companies) are eligible customers and starting from 1st January 2006 all customers except for households are eligible customers. In the meantime the price of gas supplied to captive customers is regulated by the Energy Regulatory Office.

In order to ensure transparency and equal conditions, the former monopoly (i.e. integrated transmission system operator and trader and integrated regional distribution companies and traders) is obliged to legally unbundle[2]. This step ensures a clear separation of the activities of system operators (transmission system operator, distribution system operators), which exhibit features of natural monopoly, and the traders. The desired outcome should be that system operators should provide transport, storage and distribution services to traders on non-discriminatory basis (i.e. they should deliver equal services to associated traders as well as independent traders) while transmission and distribution prices are regulated by the Energy Regulatory Office (using RPI-X regulation). The competition among these traders should reduce the price of gas for the final consumers and provide more equal profit opportunities for all companies.

At first sight it seems that market opening should be a viable way to introduce competition, reduce profit margins of the former monopoly and consequently reduce prices for final customers. However, at the present time the market is not developing as hoped for, as evidenced by the press release of the Energy Regulatory Office from 14th October 2005, re-introduction of regulation in 2006 and the penalties imposed on RWE Transgas in summer 2006. In their announcement the Czech Energy Regulatory Office

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[2] The integrated TSO and trader was obliged to unbundle by 1st January 2006 (and has fulfilled this obligation). Regional distribution companies are obliged to unbundle by 1st January 2007. For more on unbundling see also Van Koten and Ortmann 2006.

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admitted that the reform has been a failure so far, there are no new natural gas suppliers[3] and prices for eligible customers have significantly increased. Due to these facts, in the beginning of 2006 the ERO re-introduced regulation of prices even for eligible customers.

If justified, these accusations of the regulatory authorities should find support in increased profits of the incumbent. However, we do not observe such development of the figures. On the contrary, even though the revenues of RWE Transgas as well as the whole RWE group in the Czech Republic increased in 2005 in comparison with 2004, the profit, both for RWE Transgas and the Czech RWE Group declined[4]. Nevertheless, since the financial figures are reported for all activities in aggregate (transmission, trading, storage, international transit) and cannot be disentangled based on publicly available financial statements, it is impossible to conclude based only on such data whether the incumbent has or has not earned excessive profits from the sale of gas to domestic customers[5].

3 Stylized Facts

Having briefly described the situation on the Czech natural gas market I now enumerate the facts which are the most relevant for my modeling and which I will repeatedly refer to in the following sections.

1.   After the first step of market opening on 1st January 2005 there has been no significant influx of new entrants to the market, the overwhelming majority of the market is served by the incumbent.

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[3] Even though there are currently about 60 registered gas traders, only 2 new traders seem to be active on the Czech market while in the middle of 2006 only one of them was serving a Czech customer with the annual gas consumption of about 0.35% of the total annual domestic gas consumption. The second active trader announced the start of gas supply to a gas distribution company on 1st October 2006. This basically means that the incumbent has kept much of his monopolistic position.
[4] The net profit of RWE Transgas was CZK 5.168 billion in 2005 compared to CZK 7.602 billion in the previous year. RWE Transgas revenues increased from CZK 57.839 billion to CZK 69.627 billion. In the whole RWE Group in the Czech Republic net profit declined by approx. 21 % to CZK 7.78 billion, while total revenues increased by CZK 19.3 billion to CZK 123.75 billion.
[5] Perhaps the financial figures of 2006 (which should be available in March 2007) will provide more evidence as the statements will be elaborated separately for the unbundled activities.

2. Following a price increase in 2005 and complaints from eligible customers, in 2006 ERO reintroduced regulation of prices set by the monopoly even for eligible customers (price cap on prices from RWE companies). This regulation is scheduled to be lifted in 2007.

3. Czech Republic is almost completely dependent on foreign gas producers, the main supplier being Russia.

4. Gas is supplied to the Czech Republic based on long-term take or pay contracts[6] which will expire in the next decade.

5. Domestic storage facilities are almost completely controlled by the domestic monopoly[7]. Even though storage fees represent a relatively minor component of the final price, storage is an essential strategic component for supplying the right amount of gas each day.

6. Storage prices are not directly regulated (only indirectly through price cap on end-user price as long as it is regulated)

While some of these stylized facts simply describe the circumstances and therefore need no further clarification (in particular 3, 4, 5, 6) and will be used as a basis for the models, others (in particular 1, 2) beg for further explanation which the elaborated models should provide.

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[6] In a take or pay contract the purchaser has to pay for the contracted amount of gas (or at least a significant share of the contracted volume) regardless of whether he has actually taken it.
[7] In the Czech Republic there are 8 underground gas storage facilities of which 6 are owned by RWE Transgas, one is leased to RWE Transgas and one is used solely for the needs of the Slovak gas system.

4 Existing Literature

Much of the work in this paper is based on standard concepts of industrial organization, such as Cournot and Stackelberg competition, which can be found in many texbooks (e.g. Tirole 1988, Shy 1995 and Carlton and Perloff). A more elaborated model, which is relevant for this work, is formulated by Greenhut and Ohta 1979, who use market structure consisting of an upstream and downstream level – successive oligopoly – to investigate the effects of vertical integration, an objective which differs from the purpose of my work.

The literature on energy markets, and in particular on natural gas markets, draws on these concepts and often uses a structure based on the two-level model of Greenhut and Ohta 1979. Authors investigating this market either use numerical models to simulate a large and complex market or focus on a smaller part of the market and find closed form solutions. The second approach is the most relevant for my research, however, it is also useful to review some notions and specification of the first approach. The first group of authors includes Golombek and Gjelsvik 1995, Golombek et al. 1998, Day et al. 2002, Boots et al. 2004, Holz and Kalashnikov 2005 and Egging and Gabriel 2005, who draw on industrial organization concepts to define, calibrate and numerically solve simulation models of the market with natural gas. The second group is represented by Nesse and Straume 2005, Willems 2000 (and of course the work of Greenhut and Ohta 1979 which is not formulated specifically for the natural gas market).

Golombek and Gjelsvik 1995 develop a numerical model for six Western European countries investigating the effects of radical liberalization. After calibrating the model (demand elasticities, costs etc.), in which agents compete following the principles of Cournot, and numerically solving it, the authors conclude that the biggest winners of liberalization will be the end-users whose consumer surplus will increase significantly, while profits to producers, transporters and distributors will decline.

Golombek et al. 1998 use a numerical model with Cournot competition on the production (upstream) level and regulated returns on lower levels, investigating in particular the effect of liberalization on the upstream production. The authors claim that after market liberalization and break up of former monopolies it will be optimal for gas

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producing countries to break up their producing consortia. However, no formal proof or closed form solutions are specified.

Boots et al. 2004 (and their full report Boots et al. 2003) formulate a model of the market in natural gas which has a structure of a successive oligopoly, i.e. they assume oligopolistic competition both on the side of traders as well as producers. Drawing on the notion of double marginalization (e.g. Tirole 1988, Spengler 1950) they assume that producers anticipate the behavior of traders and maximize producer profits given the traders' actions. In addition to being able to distinguish between countries, producers are also able to distinguish between market segments. Their empirical model (called GASTALE) is very ambitious in the sense that the authors calibrate it to capture a market including several Western European countries and use numerical non-linear programming solvers to obtain the results. That means that there are no closed form expressions presented for prices, quantities etc. Furthermore, no comparison is made with the situation when gas supply on the domestic market is regulated.

Holz and Kalashnikov 2005 have a similar approach to Boots et al. 2004, however, they consider iso-elastic demand functions. Using their own simulation model they analyze double marginalization and perfect competition scenarios.

Day et al. 2002 present a model in which competition on the electricity market is simulated using the conjectured supply function approach. Conjectured supply function model is an alternative to other competition models such as the widely used Cournot competition. The authors point out that this approach might be useful especially when demand elasticities are low and Cournot models give equilibria with unrealistically high prices. In conjectured supply models the firm considers a conjectured reaction of other firms to the action of the firm. In a way the conjectured supply function approach is a generalization of Cournot competition which is obtained when each firms considers the sales of other firms to be fixed. Similarly to Boots et al. the authors define the maximization problems of individual actors and apply the methodology to a specific market (England-Wales electricity market) numerically deriving the resulting quantities and prices. Again no closed form solutions describing market trends are provided.

Egging and Gabriel 2005 realize how market power could be detrimental to the consumers and set up a model in which foreign gas producers can adjust their

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production levels to alter the end-user price. However, instead of using a successive oligopoly approach with traders, producers directly consider the downstream demand. Storage is explicitly modeled, however, storage operators are considered perfectly competitive and have no market power.

Moving to literature with closed form solutions, Nesse and Straume 2005 use a successive oligopoly structure with two upstream producing countries, which they believe has the highest relevance in particular for the European natural gas market, to analyze strategic behavior of policy makers in setting taxes. Their results are interesting in that they show how a decision on one level influences the other level and the wholesale and end-user price. However, their paper, which focuses primarily on strategic trade policy, does not consider gas storage, costs and market liberalization.

Another example of economic modeling of processes in the energy sector with closed form solutions is Willems 2000, who uses the concept of Cournot competition to develop a simple model of the electricity market where two producers compete à la Cournot to supply electricity to a city where the supply line is constrained in terms of the capacity. Willems derives the conditions under which the market outcome is a duopoly or a monopoly and conditions under which the transmission capacity constraint is effective. The author further focuses on the role of the transmission system operator in assigning transmission capacity to producers-bidders. However, the author models only one level of competition (production side) and does not consider the case when producers use different supply lines (i.e. there is only one constraint on the overall quantity supplied).

5   Approach to Modeling

In this paper I use static models of an economy with two levels of competition frequently called successive oligopoly models. In line with the empirical reality, the upstream segment consists of only very few producers (one or two) while the structure of the downstream segment depends on the discussed scenario. For each type of model I calculate the results of two scenarios: before market liberalization when the downstream is served by a single company and after liberalization when the market is split up by *n*

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traders. I then make a comparison of the two scenarios focusing on the wholesale price, end-user price and the total quantity supplied. I gradually develop the model from a very simple monopoly-monopoly situation by adding storage, multiple markets, upstream duopoly and upstream competitive fringe. The second scenario models (after liberalization) are not intended to capture the current situation on the market; instead, they describe a situation after liberalization has been achieved, e.g. after new traders have entered the market. The comparisons of the regulated and liberalized scenarios then provide hints why it might be difficult to achieve such liberalized outcome as well as the potential benefits of liberalization. Dynamic development of the market from a regulated to liberalized state will be the subject of my further studies.

In all models each market level (downstream and upstream) with multiple players is modeled using Cournot competition in quantities (except for the competitive fringe model). This approach is in line with the standard used in much of literature on the economics of natural gas (see e.g. Nesse and Straume 2005, Boots et al. 2004, Holz and Kalashnikov 2005, Golombek and Gjelsvik 1995) and corresponds to the physical organization of the market and the way how gas supply is secured. When purchasing gas, traders not only have to contractually arrange for the commodity, but they also have to book the corresponding transmission and storage capacities, which are often limited, in order to serve the customer. Therefore, under these conditions Bertrand competition in prices would not be feasible since it assumes that a trader can readily sell as much quantity as the consumers demand at the price set by the trader. The introduction of capacity constraints into Bertrand competition does solve this issue, however, it leads to the problem of how to assign capacity limits to individual traders. Furthermore, Kreps and Scheinkman (1983) analyze a two stage duopolistic competition with quantity precommitment in the first stage followed by Bertrand competition in the second stage and show that under fairly weak assumptions, which are satisfied by the linear downward sloping demand function used in this research, this Bertrand competition leads to Cournot outcomes, therefore there is no reason why not to use Cournot competition directly. Moreover, due to the marginality of the Czech market with respect to the whole European market and the total size of Norwegian and Russian production no capacity constraints apply to the Czech market on the production level. In such case

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Bertrand competition in prices in case of at least two upstream producers would lead to price outcomes equal to perfect competition outcomes, which is surely not the case considering the profits of the gas producers.

Having specified the structure of the competition on individual levels, it is now possible to define the interaction between the two levels. Here I use the notion that upstream producers may consider the structure of the downstream market and establish their pricing strategies contingent on the downstream structure. This process, which is also frequently used in other natural gas successive oligopoly models (e.g. Nesse and Straume 2005, Boots et al. 2004, Holz and Kalashnikov 2005), corresponds to Stackelberg competition where the upstream producers are Stackelberg leaders with respect to the downstream market. Therefore, the solution procedure is as follows: downstream traders engage in competition à la Cournot using the downstream market demand function treating the wholesale price as fixed. The resulting quantity supplied to the market is expressed as a function of the wholesale price and defines the derived demand function for the upstream level. The upstream level engages in competition (à la Cournot or competitive fringe) using the derived demand function. This yields the wholesale price which maximizes the profit of individual upstream producers and which can be used in downstream expressions to obtain the quantities and prices as a function of costs, number of firms etc.

As for the demand of the downstream market I use a linear downward sloping function which is in line with much of the natural gas literature (Golombek and Gjelsvik 1995, Golombek et al. 1998, Egging and Gabriel 2005, Gabriel and Smeers 2005, Nesse and Straume 2005, Boots et al. 2004).

6 The Models

The basic building block of the modeling used in majority of models is a Cournot market structure with n firms. The market is characterized by a linear demand function

$$Q = a - bp \qquad\qquad [1]$$

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where Q is the quantity demanded, *p* is the price and *a* and *b* are parameters of the demand function. This specification holds for the demand function of the downstream market as well as the upstream market (with different parameters) as I will show in the individual models. Each firm chooses a profit maximizing quantity treating the quantities supplied by other firms as given, i.e. firm *i* maximizes

$$\pi_i = q_i * (p - k_i) = q_i * (\frac{a - q_i - q_{-i}}{b} - k_i)$$ [2]

with respect to q_i. In this expression q_{-i} denotes the quantity supplied by all other traders except for trader *i* and k_i denotes the unit (and also marginal cost) cost of firm *i*. Besides being computationally convenient, constant marginal costs have their justification both on the upstream and the downstream level. On the upstream level, one can argue that even if the production function were not linear, the overall quantity consumed on the downstream market in the Czech Republic is such a minor share of the overall production of the upstream producers that the producers act as if it were linear. On the downstream level the costs consist of the commodity price charged by the upstream producers, who charge the same price for each unit consumed, the transmission and storage cost, which is also the same for all units consumed as a result of legislative requirements and regulation, and administrative (transaction) costs[8].

    Due to concavity of the profit functions [2] the first order conditions yield the optimal solution

$$\frac{d\Pi_i}{dq_i} = \frac{a - q_i - q_{-i}}{b} - k_i - \frac{q_i}{b} = 0 \text{ for } i = 1..n$$ [3]

These conditions give a system of linear equations

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[8] I do not explicitly consider the „portfolio effect", however, I touch on this issue in the discussion in chapter 7.

$$2q_i + q_{-i} = a - bk_i, \ i = 1..n \tag{4a}$$

or

$$\mathbf{A} * \mathbf{q} = \mathbf{r} \tag{4b}$$

where $\mathbf{A}$ is a matrix n x n with 2 on the diagonal and 1 everywhere off the diagonal, $\mathbf{q}$ is a vector n x 1 of the quantity variables q_i and $\mathbf{r}$ is a vector n x 1 of the right hand side values

$$r_i = a - bk_i. \tag{5}$$

This system can be solved by using the inverse matrix $\mathbf{A}^{-1}$, which is an n x n matrix with all diagonal elements equal to $\dfrac{n}{n+1}$ and all elements off the diagonal equal to $\dfrac{-1}{n+1}$. Therefore the optimal quantities supplied by individual downstream suppliers are

$$q_i = r_i * \frac{n}{n+1} - \frac{1}{n+1}\sum_{j \neq i} r_j \tag{6}$$

By summing this up I obtain the total quantity supplied on the downstream market:

$$Q = \sum_i q_i = \frac{n}{n+1}\sum_i r_i - \sum_i \frac{1}{n+1}\sum_{j \neq i} r_j = \frac{n}{n+1}\sum_i r_i - \frac{n-1}{n+1}\sum_i r_i = \frac{1}{n+1}\sum_i r_i \tag{7}$$

Substituting [5] into [7] I obtain the expression for the quantity as

$$Q = \frac{n}{n+1}a - \frac{b}{n+1}\sum_i k_i \tag{8}$$

Having specified the basic building block, I now proceed with the specific models. I start with a simple structure (Models 1 and 1a) which demonstrates the rationale for liberalization in an environment when the upstream is not able to optimize

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over the downstream structure. In Models 2 and 2a I introduce the successive oligopoly structure where the upstream is Stackelberg leader with respect to the downstream. Model 3 is the first model which takes into account natural gas storage (regulated environment) and Model 3ab captures the realistic case when storage is controlled by the incumbent. In Model 3as I consider the counterfactual scenario of unbundled ownership of storage and in Model 3ar I introduce regulation of the price of storage service. Model 4a extends Model 3ar by adding another downstream market. In Model 5 I introduce upstream duopoly with regulated downstream and Model 5a is a liberalized version of Model 5. In Model 6a I consider the counterfactual (but possibly in the future factual) scenario of upstream competitive fringe. An overview of the structure of individual models is provided in a table below.

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Summary Table: Structure of the Individual Models

Model	No. of upstream producers	Wholesale price (exogenous, endogenous)	No. of downstream traders	Downstream market mode (liberalized / regulated)	No. of downstream markets	Storage	Storage control	Storage price mode (regulated / unregulated)
1	1	exo.	1	regulated	1	no	-	-
1a	1	exo.	n	liberalized	1	no	-	-
2	1	end.	1	regulated	1	no	-	-
2a	1	end.	n	liberalized	1	no	-	-
3	1	end.	1	regulated	1	yes	bundled monopoly	regulated*
3ab	1	end.	n	liberalized	1	yes	bundled monopoly	unregulated
3as	1	end.	n	liberalized	1	yes	separate monopoly	unregulated
3ar	1	end.	n	liberalized	1	yes	bundled monopoly	regulated
4a	1	end.	n	liberalized.	2	yes	bundled monopoly	regulated
5	2	end.	1	regulated	1	yes	bundled monopoly	regulated*
5a	2	end.	n	liberalized	1	yes	bundled monopoly	regulated
6a	$1 + k$**	end.	n	liberalized	1	yes	bundled monopoly	regulated

* Storage price is regulated indirectly through the regulation of the end-user price.

** Dominant firm with a competitive fringe

*** Note on the numbering of models: A number without any letters denotes a model of the market prior to liberalization. The letter "a" stands for "after" and labels models after liberalization (as in 1a, 2a, 3as etc.). The letter "s" denotes **s**eparate storage monopoly (in 3as), "b" denotes **b**undled unregulated storage monopoly (3ab) and the letter **r** denotes regulated storage prices (in 3ar).

6.1 Models with Exogenous Wholesale Price

6.1.1 Model 1

- **exogenous wholesale price**
- **regulated downstream monopoly**

Model 1 is a simple sketch of the natural gas sector prior to liberalization. In fact, there is no optimization involved as the domestic regulated monopolist purchases gas at a fixed exogenous wholesale price p_w^1 and sells it at a regulated end-user price p_e^1 composed of the wholesale price, unit cost and an allowed margin, i.e.

$$p_e^1 = p_w^1 + m + c \qquad\qquad [9]$$

where

c is the unit cost (marginal cost) of the downstream supplier,

m is the margin allowed by the regulator.

The quantity sold on the market is given by the market demand function [1]. Therefore using [1] and [9] the total quantity supplied is

$$Q^1 = a - b(p_w^1 + m + c) \qquad\qquad [10]$$

Model 1 Summary Table

Variable	Expression
Wholesale price p_w^1	p_w^1
End-user price p_e^1	$p_e^1 = p_w^1 + m + c$
Total quantity sold Q^1	$Q^1 = a - b(p_w^1 + m + c)$

6.1.2 Model 1a

- **exogenous wholesale price**
- **liberalized downstream with *n* traders**

The basic principle of energy market liberalization (and in fact liberalization of any market with regulated monopoly) is that instead of having a single monopolistic supplier with a regulated price, more entities should compete on the market eliminating the need for regulation and pushing the end-user price down. The following model simply introduces competition to the downstream market and shows how the former regulated margin is competed away by multiple suppliers.

In this model I assume the same exogenous wholesale price as in the previous regulated case ($p_w^1 = p_w^{1a}$) and I assume that there are *n* downstream suppliers each of whom can purchase the good at this wholesale price. The domestic suppliers then compete in quantities (Cournot competition) to serve the domestic market, which is characterized by the same linear demand function [1]. Since the unit costs in this model are $k_i = c_i + p_w$, the Cournot outcome [8] is

$$Q^2 = \frac{n}{n+1}a - \frac{n}{n+1}bp_w - \frac{b}{n+1}\sum_i c_i \qquad [11]$$

Clearly it can be seen that as n approaches infinity, the quantity approaches the value of $a - bp_w - b\bar{c}$ where $\bar{c}$ is the average unit cost across downstream firms. Comparing this with the result for the regulated case [10] and assuming that $c = \bar{c}$, we can see that the margin *m* disappears from the equation, so competition does indeed eliminate the margin and reduce the prices.

Moreover, in addition to this straightforward result, it is also possible to specify the minimum number of firms which should compete on the market in order to push the price down below the formerly regulated price level. This can be done by equaling the quantities for the two cases, i.e.

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$$Q^1 = Q^{1a} \text{ or } a - b(p_w^1 + m + c) = \frac{n}{n+1}a - \frac{n}{n+1}bp_w - \frac{b}{n+1}\sum_i c_i \qquad [12]$$

which yields (under the assumption that the average trader unit cost does not change with the number of traders and that it is equal to the monopoly unit cost)

$$n_{min}^{1,1a} = \frac{a - bp_w - bc}{bm} - 1 \qquad [13]$$

The end-user price can be obtained from the inverse demand function and the total quantity supplied [11] as

$$p_e^{1a} = \frac{1}{n+1} * \left(\frac{a}{b} + \sum_i c_i \right) + \frac{n}{n+1}p_w \qquad [14]$$

Moreover, the change in the end-user price after liberalization is

$$\Delta p_e^{1,1a} = \frac{1}{n+1}\left(p_w^{1,1a} - \frac{a}{b} \right) + m + c - \frac{1}{n+1}\sum_i c_i \qquad [15]$$

The profit earned by the downstream trader i is

$$\pi_i = q_i * \left(p_e - p_w^{ex} - c_i \right) = \left(\frac{1}{n+1}\left(a - bp_w \right) + \frac{1}{n+1}b\sum_{j \neq i} c_j - \frac{n}{n+1}bc_i \right) * \left(p_e - p_w - c_i \right) \quad [16]$$

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Model 1a Summary Table

Variable	Expression
Wholesale price p_w^{1a}	$p_w^{1a} = p_w^1$
End-user price p_e^{1a}	$p_e^{1a} = \dfrac{1}{n+1} * \left(\dfrac{a}{b} + \sum_i c_i \right) + \dfrac{n}{n+1} p_w$
Total quantity sold Q^{1a}	$Q^{1a} = \dfrac{n}{n+1} a - \dfrac{n}{n+1} b p_w - \dfrac{b}{n+1} \sum_i c_i$
Quantity sold by firm i q_i^{1a}	$q_i^{1a} = \dfrac{1}{n+1}\left(a - b p_w\right) + \dfrac{1}{n+1} b \sum_{j=1}^{n} c_j - b c_i$
Profit of firm i π_i^{1a}	$\pi_i = \left(\dfrac{1}{n+1}\left(a - b p_w\right) + \dfrac{1}{n+1} b \sum_{j \neq i} c_j - \dfrac{n}{n+1} b c_i \right) * \left(p_e - p_w - c_i \right)$
Price differential $\Delta p_e^{1,1a}$	$\Delta p_e^{1,1a} = \dfrac{1}{n+1}\left(p_w - \dfrac{a}{b} \right) + m + c - \dfrac{1}{n+1} \sum_i c_i$
Minimum efficient number of firms $n_{\min}^{1,1a}$	$n_{\min}^{1,1a} = \dfrac{a - b p_w - b c}{bm} - 1$

6.2 Models with Endogenous Wholesale Price: Considering the Impact of Pricing Strategies of Upstream Monopoly

In the basic competition models (model 1 and 1a) the wholesale price (price at which the good is sold by the upstream producers to the downstream suppliers) is exogenous, i.e. the upstream producers do not optimize their pricing strategy depending on the downstream market structure.

In the next section I am going to consider the case when there is an upstream monopolistic producer of the goods. This very much resembles the situation in the Czech gas industry where the majority of natural gas is imported from the Russian company Gazexport. (See the discussion of upstream monopoly vs. duopoly later on.)

The first model (model 2) is the benchmark case prior to the liberalization of the market. The second model (model 2a) models downstream competition after deregulation.

6.2.1 Model 2

- **regulated downstream monopoly**
- **upstream monopoly**

The following setup corresponds to the situation on the Czech natural gas market prior to liberalization. The economy consists of consumers, a single downstream supplier with regulated end-user price and a single upstream (monopolistic) producer with unregulated wholesale price. The downstream monopolist purchases goods from the upstream producer for an unregulated wholesale price. The downstream monopolist then sells the goods to the end-users for a regulated price p_e which is equal to

$$p_e = p_w + m + c \qquad\qquad [17]$$

where

p_w is the wholesale unit price

c is the unit cost (marginal cost) of the downstream supplier,

m is the margin allowed by the regulator,

The downstream supplier simply supplies the quantity equal to the demand at the given end-user price p_e, therefore no optimization is involved on the downstream level.

On the other hand on the upstream level the upstream monopolistic producer is able to set the wholesale price to maximize its profit. Therefore the producer maximizes

$$\max{}_{p_w^r} \left\{ Q(p_e) * (p_w - s) \right\} \qquad\qquad [18]$$

where

Q is the domestic demand function,

s is the producer's unit cost (marginal cost)

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Therefore the maximization problem using the demand function specification [1] is

$$\max_{p_w} \left\{ [a - b(p_w + c + m)] * (p_w - s) \right\}$$ [19]

Since the objective function is concave, the following first order condition yields the optimal price and quantity:

$$\frac{d\Pi}{dp_w} = -b(p_w - s) + a - b(p_w + c + m) = 0$$ [20]

which gives the following results:

wholesale price: $p_w = \frac{1}{2}(\frac{a}{b} + s - c - m)$ [21]

end-user price: $p_e = \frac{1}{2}(\frac{a}{b} + s + c + m)$ [22]

total quantity sold: $Q = \frac{1}{2}(a - b(s + c + m))$ [23]

Note that unlike in models 1 and 1a, where the wholesale price was considered exogenous, here I have an explicit expression for the wholesale price.

Model 2 Summary Table

Variable	Expression
Wholesale price p_w^2	$p_w^2 = \frac{1}{2}(\frac{a}{b} + s - c - m)$
End-user price p_e^2	$p_e^2 = \frac{1}{2}(\frac{a}{b} + s + c + m)$
Total quantity sold Q^2	$Q^2 = \frac{1}{2}(a - b(s + c + m))$

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6.2.2 Model 2a

- **liberalized downstream**

- **upstream monopoly**

Model 2a describes the natural gas industry after liberalization with a single upstream producer. Therefore the economy consists of a single upstream producer, n downstream suppliers and domestic end-users whose demand is again characterized by a linear demand function [1].

The competition on the downstream level is similar to model 1a, i.e. n downstream suppliers compete in quantities therefore the downstream competition results are captured by [11]. However, similarly to model 2, the upstream monopolist considers the downstream structure and optimizes its pricing strategy taking into account the quantity demanded by the downstream suppliers at different wholesale price levels. Therefore, the upstream monopoly maximizes its profit

$$\max_{p_w} \left(Q\ (p_w) * (p_w - s) \right) \qquad [24]$$

where $Q\ (p_w)$ comes from [11]. Therefore, [24] is expressed as

$$\max_{p_w} \left(\left(\frac{n}{n+1} a - \frac{n}{n+1} b p_w - \frac{b}{n+1} \sum_i c_i \right) * (p_w - s) \right) \qquad [25]$$

Since the objective (profit) function is concave, first order conditions may be used to obtain the optimal solution from the perspective of the upstream monopolist.

$$\frac{d\pi}{dp_w} = \frac{n}{n+1} a - \frac{n}{n+1} b p_w - \frac{b}{n+1} \sum_i c_i - \frac{n}{n+1} b (p_w - s) = 0 \qquad [26]$$

which after simplification gives

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$$p_w = \frac{1}{2}\left(\frac{a}{b} - \frac{\sum_i c_i}{n} + s\right)$$

[27]

This wholesale price may now be used in many of the expressions of model 2. The results are summarized in Model 2a Summary Table below.

Model 2a Summary Table

Variable	Expression
Wholesale price p_w^{2a}	$p_w^{2a} = \frac{1}{2}\left(\frac{a}{b} - \frac{\sum_i c_i}{n} + s\right)$
End-user price p_e^{2a}	$p_e^{2a} = \frac{1}{2}\left(\frac{a}{b} * \frac{n+2}{n+1} + \frac{sn}{n+1} + \frac{\sum_{i=1}^{n} c_i}{n+1}\right)$
Total quantity sold Q^{2a}	$Q^{2a} = \frac{n(a-bs)}{2(n+1)} - \frac{b\sum_{i=1}^{n} c_i}{2(n+1)}$
Quantity sold by firm i q_i^{2a}	$q_i^{2a} = \frac{a-bs}{2(n+1)} + \frac{2n+1}{2(n+1)n}b\sum c_j - bc_i$
Profit of firm i π_i^{2a}	$\pi_i^{2a} = \frac{1}{2}\left[\frac{a-bs}{2(n+1)} + \frac{2n+1}{2(n+1)n}b\sum c_j - bc_i\right]\left[\frac{a}{b2(n+1)} - \frac{s}{2(n+1)} + \frac{\sum_{i=1}^{n} c_i}{n}\frac{2n+1}{2(n+1)} - c_i\right]$
Price differential $\Delta p_e^{2,2a}$	$\Delta p_e^{2,2a} = \frac{1}{2}\left[\frac{a}{b(n+1)} - \frac{s}{n+1} + \frac{\sum_{i=1}^{n} c_i}{n+1} - c - m\right]$
Minimum efficient number of firms $n_{min}^{2,2a}$	$n_{min}^{2,2a} = \frac{a-bs-bc}{bm} - 1$

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It is now interesting to see how the endogeneity of the wholesale price changes the results obtained for models 1 and 2. In particular, if all traders have the same unit cost ($\bar{c}$), the wholesale price is

$$p_w^{2a} = \frac{1}{2}\left(\frac{a}{b} - \bar{c} + s\right) \tag{28}$$

which is by 0.5 m higher than the original wholesale price before liberalization. Therefore, by optimizing over the downstream structure the upstream producer is capable of capturing one half of the price benefit brought about by liberalized downstream regardless of the number of downstream traders. Nevertheless, even if the wholesale price increases, consumer may still benefit from the deregulation. Perfect competition yields the end-user price

$$p_e^{2a,comp} = \frac{1}{2}\left(\frac{a}{b} + s + \bar{c}\right) \tag{29}$$

which is by 0.5 m lower than the price under regulation, i.e. the original margin is split equally between consumers and the upstream producer. However, due to the increasing wholesale price, the minimum efficient number of firms is in this case higher than in the case of exogenous wholesale price, in particular by

$$\Delta n_{min}^{2,2a-1,1a} = \frac{p_w^1 - s}{m} \tag{30}$$

Therefore, when analyzing the effects of liberalization, it is important to carefully consider which approach should be used (exogenous or endogenous wholesale price) as the outcomes will differ significantly especially if the markup charged by the upstream is large relative to the original regulated margin.

Comparison of models 1, 1a, 2, 2a

Variable	Model 1	Model 1a	Model 2	Model 2a
Wholesale price p_w	p_w^1	$p_w^{1a} = p_w^1$	$p_w^2 = \frac{1}{2}(\frac{a}{b} + s - c - m)$	$p_w^{2a} = \frac{1}{2}\left(\frac{a}{b} - \frac{\sum_i c_i}{n} + s\right)$
End-user price p_e	$p_e^1 = p_w^1 + m + c$	$p_e^{1a} = \frac{1}{n+1} * \left(\frac{a}{b} + \sum_i c_i\right) + \frac{n}{n+1} p_w^1$	$p_e^2 = \frac{1}{2}(\frac{a}{b} + s + c + m)$	$p_e^{2a} = \frac{1}{2}\left(\frac{a}{b} * \frac{n+2}{n+1} + \frac{sn}{n+1} + \frac{\sum_{i=1}^{n} c_i}{n+1}\right)$
Total quantity sold Q	$Q^1 = a - b(p_w^1 + m + c)$	$Q^{1a} = \frac{n}{n+1} a - \frac{n}{n+1} b p_w^1 - \frac{b}{n+1} \sum_i c_i$	$Q^2 = \frac{1}{2}(a - b(s + c + m))$	$Q^{2a} = \frac{n(a - bs)}{2(n+1)} - \frac{b\sum_{i=1}^{n} c_i}{2(n+1)}$
End-user price p_e^{comp} under perfect competition		$p_e^{1a,comp} = \bar{c} + p_w^1$		$p_e^{2a,comp} = \frac{1}{2}\left(\frac{a}{b} + s + \bar{c}\right)$

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6.3 Introducing Natural Gas Storage

A very important aspect of the natural gas sector, which distinguishes it e.g. from the electricity industry, is the possibility to store natural gas (usually in underground storage facilities). Due to this feature it is possible to uniformly use the full capacity of transit pipelines all year round regardless of the seasonal fluctuations in downstream demand for gas (provided that storage is close to the place of consumption).

In the following section I will incorporate this aspect into the previous models of the natural gas market making some abstraction necessary for the sake of calculation of the results. Instead of considering a demand schedule[9] for each firm (and possibly also different for each firm), I split the gas year into two periods: high season (winter) and low season (summer) and consider a fixed ratio of consumption in high and low seasons denoted γ. This abstraction is in fact not that far from the reality. Although the consumption curve of each firm is necessary for correctly supplying the right amount of gas each day (and in fact each hour), from the perspective of working gas storage capacity and the determination of prices of storage capacity all that is necessary is the amount of gas that will be injected into the storage facility in the low season and consequently extracted from the storage facility in the high season, i.e. certain volume of capacity needed to accommodate the consumer. Moreover, the assumption that the seasonal consumption ratio γ is the same throughout the economy does not necessarily mean that all firms have the same consumption profile but rather that all traders have the same mix of customers. Using equations to capture these features, trader supplying the quantity q_i to the market will deliver $q_{Hi} = \gamma q_i$ in the high season and $q_{Li} = (1-\gamma)q_i$ in the low season where $\gamma \geq 0.5$. Therefore, if the supply of gas from producers to traders is uniform over the seasons and equal to $\dfrac{q_i}{2}$, in the low season it is necessary accumulate volume of gas equal to the difference between the volume actually delivered

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[9] Instead of a simple demand curve $D : p \rightarrow q$, consumers are best characterized by a demand function which transforms the price of natural gas p to a function which captures the demanded consumption for each day of the year.

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through gas pipelines from the producer and the volume demanded in the high season, i.e.

$$q_{Si} = \gamma q_i - \frac{q_i}{2} = q_i\left(\gamma - \frac{1}{2}\right)$$ [31]

which is also the required storage capacity for the given year. Having specified the basic principles of natural gas storage and seasonal consumption, it is now possible to elaborate models of the whole economy taking into account the market structure. In all models further on I use the approach outlined in models 2 and 2a, i.e. endogenous wholesale price, since within this approach upstream traders react to the change in the downstream structure which is exactly what every profit driven firm should do.

6.3.1 Model 3

- **regulated downstream monopoly also owns all storage facilities**
- **upstream monopoly**

Model 3 captures the situation on the Czech natural gas market prior to liberalization. The downstream segment consists of a single regulated monopolist who also owns all storage facilities. Denoting the unit cost (constant marginal cost) of storage capacity as c_s, the end-user price is

$$p_e = p_w + m + c + s_s\left(\gamma - \frac{1}{2}\right)$$ [32]

Using $c + s_s\left(\gamma - \frac{1}{2}\right)$ instead of c in all results of model 3 gives results summarized in the following table.

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Model 3 Summary Table

Variable	Expression
Wholesale price p_w^3	$p_w^3 = \dfrac{1}{2}(\dfrac{a}{b} + s - c - s_s\left(\gamma - \dfrac{1}{2}\right) - m)$
End-user price p_e^3	$p_e^3 = \dfrac{1}{2}(\dfrac{a}{b} + s + c + s_s\left(\gamma - \dfrac{1}{2}\right) + m)$
Total quantity sold Q^3	$Q^3 = \dfrac{1}{2}(a - b(s + c + s_s\left(\gamma - \dfrac{1}{2}\right) + m))$

6.3.2 Model 3ab

- **liberalized downstream**

- **storage controlled by trader no. 1 (former monopoly)**

- **upstream monopoly**

In this model I assume that one of the downstream traders controls the storage capacity. This is exactly the situation on the Czech natural gas market where the former regulated monopoly controls all domestic storage facilities[7]. It is obvious that such structure, capturing stylized facts 5 and 6, must lead to some problems and keep other traders from entering the market. The following section analyzes this problem.

The profit of this trader/storage operator (denoted no. 1) is

$$\pi_1 = q_1\left(\frac{a - q_1 - q_{-1}}{b} - p_w - c - \left(\gamma - \frac{1}{2}\right)p_s\right) + (q_1 + q_{-1})\left(\gamma - \frac{1}{2}\right)(p_s - s_s) \qquad [33]$$

or

$$\pi_1 = q_1\left(\frac{a - q_1 - q_{-1}}{b} - p_w - c\right) - q_1 s_s\left(\gamma - \frac{1}{2}\right) + q_{-1}\left(\gamma - \frac{1}{2}\right)(p_s - s_s) \qquad [34]$$

This profit function is linear in p_s with the positive coefficient $q_{-1}\left(\gamma - \frac{1}{2}\right)$. Therefore, it might seem that the trader/storage operator would like to see high storage prices and

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high quantity supplied by other traders. However, only the first part is true. It is simple to show that the trader/storage operator can always do better when the amount of gas supplied by other traders is positive. For this it is necessary to assume that trader i is active on the market ($q_i > 0$) only if his profit is positive. The intuitive explanation is that the trader/storage operator may set the storage prices to a sufficiently high level to drive away all competing traders and behave as a monopoly on the whole market setting the end-user price below the unit costs of the other traders (which include the artificially exaggerated storage price).

To calculate the storage price required to exclude all other traders from the market, the trader/storage operator maximizes his profit considering only his participation on the market, i.e.

$$\pi_1 = q_1 \left(\frac{a - q_1}{b} - p_w - c - \left(\gamma - \frac{1}{2} \right) s_s \right). \qquad [35]$$

This simple maximization exercise gives the following quantity supplied and end-user price:

$$q_1 = \frac{1}{2} \left(a - b p_w - bc - b \left(\gamma - \frac{1}{2} \right) s_s \right) = Q \qquad [36]$$

$$p_e = \frac{1}{2} \left(\frac{a}{b} + p_w + c + \left(\gamma - \frac{1}{2} \right) s_s \right) \qquad [37]$$

Now the trader/storage operator sets the storage price sufficiently high so that other traders could not supply gas at this price while making a positive profit:

$$\left(\gamma - \frac{1}{2} \right) p_s + p_w + c > p_e \qquad [38]$$

or

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$$p_s > \frac{p_e - p_w - c}{\gamma - \frac{1}{2}} = \frac{\frac{1}{2}\left(\frac{a}{b} - p_w - c + \left(\gamma - \frac{1}{2}\right)s_s\right)}{\gamma - \frac{1}{2}} \qquad [39]$$

Having calculated the results for the downstream market, it is now possible to proceed with the analysis of the behavior of the upstream producer. Since both the downstream trader/storage operator and the upstream producer are monopolists on their segments, the overall economy has a structure of a successive monopoly. This structure was already investigated by Spengler [1950] and further developed by e.g. Tirole [1988] (pp. 169-198), under the term of double marginalization. Under this structure both monopolists successively exercise their monopolistic powers which results in a situation which is worse for the consumers (higher prices and lower quantity supplied) than in case of a vertically integrated monopolist.

The upstream producer optimizes his profit

$$\Pi = Q * (p_w - s) = \frac{1}{2}\left(a - bp_w - bc - b\left(\gamma - \frac{1}{2}\right)s_s\right) * (p_w - s) \qquad [40]$$

The first order condition for this problem is (the profit function is concave)

$$\frac{d\Pi}{dp_w} = \frac{1}{2}\left(a - bp_w - bc - b\left(\gamma - \frac{1}{2}\right)s_s\right) - \frac{1}{2}b * (p_w - s) = 0 \qquad [41]$$

Which gives the wholesale price

$$p_w = \frac{a - bc - b\left(\gamma - \frac{1}{2}\right)s_s + bs}{2b} \qquad [42]$$

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Model 3ab Summary Table

Variable	Expression
Wholesale price p_w^{3ab}	$p_w^{3ab} = \frac{1}{2}\left(\frac{a}{b} - c - \left(\gamma - \frac{1}{2}\right)s_s + s\right)$
End-user price p_e^{3ab}	$p_e^{3ab} = \frac{1}{4}\left(\frac{3a}{b} + s + c + \left(\gamma - \frac{1}{2}\right)s_s\right)$
Total quantity sold Q^{3ab}	$Q^{3ab} = \frac{1}{4}\left(a - bs - bc - b\left(\gamma - \frac{1}{2}\right)s_s\right)$

The results of this model are not surprising: by controlling the storage facilities, an essential input in the supply of gas to end-users, the bundled trader and storage operator is capable of using its monopolistic power on the downstream segment and exploit the market. However, the extent to which this model currently applies to the Czech natural gas is questionable – see the discussion in Chapter 7.

6.3.3   Model 3as

- **liberalized downstream**
- **storage owned by separate monopoly**
- **upstream monopoly**

In this model the downstream segment consist of traders who purchase natural gas from the upstream monopolistic producer and storage services (storage capacity) from a separate monopolistic storage operator. This setup does not reflect the actual situation on the Czech market since in line with stylized fact 5 Czech storage facilities are currently controlled by the former regulated monopoly (RWE Transgas). However, it is one of the possible scenarios of further development and should be considered.

Since the unit storage cost (in the sense of cost of storage per unit of gas supplied, not the cost of unit of gas stored) for downstream traders is

$$c_s = \left(\gamma - \frac{1}{2}\right) * p_s,$$ [43]

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where p_s is the storage price charged by the storage operator, the profit of downstream trader i is

$$\pi_i = q_i \left(\frac{a - q_i - q_{-i}}{b} - p_w - c - \left(\gamma - \frac{1}{2} \right) p_s \right)$$

[44]

Due to the concavity of the profit with respect to the quantity supplied it is again possible to use the first order condition to get the optimal solution:

$$\frac{d\pi_i}{dq_i} = \frac{a - q_i - q_{-i}}{b} - p_w - c - \left(\gamma - \frac{1}{2} \right) p_s - \frac{q_i}{b} = 0$$

[45]

Similarly to previous models this gives a system of linear equations. When solved, the total quantity supplied is

$$Q = \frac{n}{n+1} a - \frac{n}{n+1} b p_w - \frac{b}{n+1} \sum_i c_i - \frac{n}{n+1} b \left(\gamma - \frac{1}{2} \right) p_s$$

[46]

and thus the total storage capacity used is

$$Q_s = \left(\gamma - \frac{1}{2} \right) Q = \left(\gamma - \frac{1}{2} \right) * \left[\frac{n}{n+1} a - \frac{n}{n+1} b p_w - \frac{b}{n+1} \sum_i c_i - \frac{n}{n+1} b \left(\gamma - \frac{1}{2} \right) p_s \right]$$ [47]

This can now be used to define the storage operator's problem as a simple profit maximization exercise where the objective profit function is

$$\pi_s = Q_s (p_s - s_s) = \left(\gamma - \frac{1}{2} \right) * \left[\frac{n}{n+1} a - \frac{n}{n+1} b p_w - \frac{b}{n+1} \sum_i c_i - \frac{n}{n+1} b \left(\gamma - \frac{1}{2} \right) p_s \right] * (p_s - s_s)$$

[48]

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where s_s is the unit storage cost of the storage system operator. Due to the concavity of the objective function with respect to the storage price first order conditions give the optimal solution:

$$\frac{d\pi_s}{dp_s} = \left(\gamma - \frac{1}{2}\right) * \left[\frac{n}{n+1}a - \frac{n}{n+1}bp_w - \frac{b}{n+1}\sum_i c_i - \frac{n}{n+1}b\left(\gamma - \frac{1}{2}\right)p_s\right] - \frac{n}{n+1}b\left(\gamma - \frac{1}{2}\right)^2 * (p_s - s_s) = 0$$
[49]

Solving for p_s gives

$$p_s = \frac{a - bp_w - \frac{b}{n}\sum_i c_i + b\left(\gamma - \frac{1}{2}\right) * s_s}{2b\left(\gamma - \frac{1}{2}\right)}$$
[50]

Now let's investigate the optimal behavior of the upstream producer given the downstream structure. Similarly to model 2a, the upstream monopolistic producer maximizes his profit, which is defined as

$$\Pi = Q(p_w) * (p_w - s)$$
[51]

which after substituting for the various components of Q gives

$$\Pi = \left[\frac{n}{2(n+1)}a - \frac{n}{2(n+1)}bp_w - \frac{b}{2(n+1)}\sum_i c_i - \frac{nb}{2(n+1)}\left(\gamma - \frac{1}{2}\right) * s_s\right] * (p_w - s)$$
[52]

This function is again concave so FOC can be used to obtain the maximum.

$$\frac{d\Pi}{dp_w} = \left[\frac{n}{2(n+1)}a - \frac{n}{2(n+1)}bp_w - \frac{b}{2(n+1)}\sum_i c_i - \frac{nb}{2(n+1)}\left(\gamma - \frac{1}{2}\right) * s_s\right] - \frac{n}{2(n+1)}b(p_w - s) = 0$$
[53]

After simplification the wholesale price can be expressed as

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$$p_w = \frac{1}{2}\left(\frac{a}{b} - \bar{c} - \left(\gamma - \frac{1}{2} \right)s_s + s \right)$$

[54]

This formula may now be used to obtain other expressions, such as end-user price etc.

Model 3as Summary Table

Variable	Expression
Wholesale price p_w^{3as}	$p_w^{3as} = \frac{1}{2}\left(\frac{a}{b} - \bar{c} - \left(\gamma - \frac{1}{2} \right)s_s + s \right)$
End-user price p_e^{3as}	$p_e^{3as} = \frac{1}{4}\frac{n}{n+1}\left(\frac{3n+4}{n}\frac{a}{b} + \bar{c} + \left(\gamma - \frac{1}{2} \right)s_s + s \right)$
Total quantity sold Q^{3as}	$Q^{3as} = \frac{1}{4}\frac{n}{n+1}\left(a - b\bar{c} - b\left(\gamma - \frac{1}{2} \right)s_s - bs \right)$

It is worth noting that the storage monopoly does not influence the wholesale price [54]. The wholesale price of model 3as is basically identical with the wholesale price of model 2a, now only the storage cost is added to the trader's unit cost. Consequently, it is possible to observe the same development of the wholesale price after market liberalization as in models 2 and 2a, i.e. half of the original margin of the regulated monopoly is captured in an unregulated environment by the upstream producer due to which the wholesale price increases.

Where the monopolist structure of the storage matters is the downstream market. Let's now look at what happens as *n* gets large (the number of downstream traders increases). The end-user price in this case converges to the perfect competition outcome (that is perfect competition in trading, not perfect competition in storage services)

$$p_e^{3as,comp} = \frac{1}{4}\left(3\frac{a}{b} + \bar{c} + \left(\gamma - \frac{1}{2} \right)s_s + s \right)$$

[55]

In comparison with model 2a the end-user price is now driven more by the demand function than the actual costs.[10]

Moving to a comparison with model 3ab, notice that the results of model 3ab are identical with the results of model 3as under perfect competition and are better from the perspective of the consumers than in model 3as when perfect competition is not achieved (i.e. the end-user price is smaller). This might seem surprising at first glance, however, there is a straightforward explanation. While in model 3ab there is double marginalization, i.e. two monopolies successively charge a markup on the costs, in model 3as the markup is added on three levels. By splitting the bundled trader and storage operator, another level is created. Even though the lowest trading level is not monopolistic (there are *n* traders), unless there is perfect competition these traders charge prices above the unit costs which results in "triple marginalization". Similarly to vertical integration being superior from the perspective of end-users to two successive monopolies (as shown e.g. by Tirole 1988), two successive monopolies are superior to a structure with three levels of which two are monopolistic and the lowest one is oligopolistic, i.e. although not optimal, double marginalization is preferred over triple marginalization.

6.3.4   Model 3ar

- **liberalized downstream**
- **storage owned by trader no. 1 (former monopoly)**
- **upstream monopoly**
- **regulator sets the storage price**

In this model I introduce a regulator (an analogue of the Czech Energy Regulatory Office) who has the power to set the price of storage services. I do not consider explicitly the mechanism used to set the prices, whether this is direct

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[10] In model 2a the perfect competition price is $p_e^{2a,comp} = \frac{1}{2}\frac{a}{b} + \frac{1}{2}(\text{unit cost})$ whereas in model 3as the perfect competition price is $p_e^{3as,comp} = \frac{3}{4}\frac{a}{b} + \frac{1}{4}(\text{unit cost})$. The first term of each equation $\frac{a}{b}$ is the limit price, i.e. price for which the quantity demanded is zero.

mechanism or some kind of a system of penalties, but I simply assume that the regulator has a price enforcement mechanism. This is in line with the observed reality since although storage prices are not directly regulated (stylized fact 6), the Czech Energy Regulatory Office can regulate the end-user prices (stylized fact 2) and both the ERO and the Czech anti-monopoly office have the power impose fines on the incumbent in case that they discover that the incumbent has abused its dominant position[11].

This model consists of an upstream monopoly and downstream (Cournot) competition with trader 1 being also the monopolistic storage operator with regulated price of storage services. To solve the model I will follow the usual procedure starting with the profit optimization of downstream traders. The profit of trader 1 is

$$\pi_1 = q_1 \left(\frac{a - q_1 - q_{-1}}{b} - p_w - c \right) - q_1 s_s \left(\gamma - \frac{1}{2} \right) + q_{-1} \left(\gamma - \frac{1}{2} \right) (p_s - s_s) \qquad [56]$$

which is concave in the quantity supplied q_1 and the profit of other traders is

$$\pi_i = q_i \left(\frac{a - q_i - q_{-i}}{b} - p_w - c - \left(\gamma - \frac{1}{2} \right) p_s \right) \text{ for } i = 2,..,n \qquad [57]$$

which is also concave with respect to q_i. The maximum values of profit are thus derived from the following first order conditions:

$$\frac{d\pi_1}{dq_1} = \frac{a - q_1 - q_{-1}}{b} - p_w - c - \left(\gamma - \frac{1}{2} \right) s_s - \frac{q_1}{b} = 0 \qquad [58]$$

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[11] The ERO has imposed a fine of CZK 14.7 mil. on 26th May 2006 on four gas companies from the RWE group for breaching the Act on Prices (ERO press release from May 2006). The proceedings were initiated after complaints of the newly eligible customers concerning increasing gas prices in 2005. The Czech Office for the Protection of Competition (OPC, often referred to as anti-monopoly office) imposed a fine of CZK 370 mil. on RWE Transgas on 11th August 2006 for abusing its dominant position (yet not in force, the company may file an appeal). One of the mentioned reasons was that the price of storage services for eligible customers was too high (OPC press release August 2006).

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$$\frac{d\pi_i}{dq_i} = \frac{a - q_i - q_{-i}}{b} - p_w - c - \left(\gamma - \frac{1}{2}\right)p_s - \frac{q_i}{b} = 0 \text{ for } i = 2,..,n \qquad [59]$$

Similarly to the previous models, these first order conditions form a system of n linear equations which can be solved to obtain the quantities and prices. The resulting quantity supplied by trader 1 is

$$q_1 = \frac{a - bp_w}{n+1} + b\left(\gamma - \frac{1}{2}\right)\frac{(n-1)p_s}{n+1} - b\left(\gamma - \frac{1}{2}\right)\frac{ns_s}{n+1} + \frac{b}{n+1}\sum_{i\neq 1}c_i - \frac{bc_1 n}{n+1} \qquad [60]$$

while other traders supply

$$q_i = \left(a - b\left(p_w + c_i + \left(\gamma - \frac{1}{2}\right)p_s\right)\right)*\frac{n}{n+1} - \frac{1}{n+1}\sum_{j\neq i,1}\left(a - b\left(p_w + c_j + \left(\gamma - \frac{1}{2}\right)p_s\right)\right) - \frac{1}{n+1}\left(a - b\left(p_w + c_1 + \left(\gamma - \frac{1}{2}\right)s_s\right)\right)$$

[61].

Adding up the quantities supplied by individual traders I obtain the total quantity supplied as

$$Q = \frac{1}{n+1}\left[a - b\left(p_w + c_1 + \left(\gamma - \frac{1}{2}\right)s_s\right)\right] + \frac{1}{n+1}\sum_{i\neq 1}\left[a - b\left(p_w + c_i + \left(\gamma - \frac{1}{2}\right)p_s\right)\right] \quad [62]$$

This quantity is now used by the upstream monopolist to maximize his profit. The profit function of the upstream monopoly is

$$\Pi = Q*(p_w - s) = \frac{1}{n+1}\left(na - nbp_w - bc_1 - b\left(\gamma - \frac{1}{2}\right)s_s - b\sum_{i\neq 1}c_i - (n-1)b\left(\gamma - \frac{1}{2}\right)p_s\right)(p_w - s)$$

[63]

This function is concave in the wholesale price so the first order condition gives the maximum profit:

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$$\frac{d\Pi}{dp_w} = \frac{1}{n+1}\left(na - nbp_w - bc_1 - b\left(\gamma - \frac{1}{2}\right)s_s - b\sum_{i\neq1}c_i - (n-1)b\left(\gamma - \frac{1}{2}\right)p_s \right) - nb\frac{1}{n+1}(p_w - s) = 0$$
[64]

This expression is then used to obtain the wholesale price of gas:

$$p_w = \frac{na - bc_1 - b\left(\gamma - \frac{1}{2}\right)s_s - b\sum_{i\neq1}c_i - (n-1)b\left(\gamma - \frac{1}{2}\right)p_s + nbs}{2nb}$$
[65]

This profit maximizing wholesale price can now be used to derive all the resulting quantities and prices of this model.

Model 3ar Summary Table

Variable	Expression
Wholesale price p_w^{3ar}	$p_w^{3ar} = \frac{1}{2}\left(\frac{a}{b} - \bar{c} + s - \frac{\left(\gamma - \frac{1}{2}\right)s_s + (n-1)\left(\gamma - \frac{1}{2}\right)p_s}{n} \right)$
End-user price p_e^{3ar}	$p_e^{3ar} = \frac{1}{2(n+1)}\left((n+2)\frac{a}{b} + n\bar{c} + \left(\gamma - \frac{1}{2}\right)s_s + (n-1)\left(\gamma - \frac{1}{2}\right)p_s + ns \right)$
Total quantity sold Q^{3ar}	$Q^{3ar} = \frac{n}{2(n+1)}\left(a - b\bar{c} - b\frac{\left(\gamma - \frac{1}{2}\right)s_s + (n-1)\left(\gamma - \frac{1}{2}\right)p_s}{n} - bs \right)$
Quantity sold by firm i q_i^{3ar}	$q_i^{3ar} = \frac{1}{2(n+1)}a - \frac{1}{2(n+1)}bs - \frac{n}{n+1}bc_i - \frac{3n+1}{2n(n+1)}b\left(\gamma - \frac{1}{2}\right)p_s + \frac{2n+1}{2n(n+1)}b\left(\gamma - \frac{1}{2}\right)s_s + \frac{2n+1}{2n(n+1)}bc_1 + \frac{2n+1}{2n(n+1)}b\sum_{j\neq i,1}c_j$
Quantity sold by firm 1 q_1^{3ar}	$q_i^{3ar} = \frac{1}{2(n+1)}a - \frac{1}{2(n+1)}bs + \frac{(2n+1)(n-1)}{2n(n+1)}b\left(\gamma - \frac{1}{2}\right)p_s - \frac{2n^2-1}{n+1}b\left(\gamma - \frac{1}{2}\right)s_s + \frac{2n+1}{2n(n+1)}b\sum_{i\neq1}c_i - \frac{2n^2-1}{n+1}bc_1$
Price differential $\Delta p_e^{3,3ar}$	$\Delta p_e^{3,3ar} = \frac{1}{2b}\left[\frac{1}{n+1}a - \frac{1}{n+1}s - \frac{n}{n+1}c_1 - \frac{n}{n+1}b\left(\gamma - \frac{1}{2}\right)s_s + \frac{1}{n+1}b\sum_{i\neq1}c_i + \frac{n-1}{n+1}b\left(\gamma - \frac{1}{2}\right)p_s - bm \right]$

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Minimum efficient number of firms $n_{\min}^{3,3ar}$	$n_{\min}^{3,3ar} = \dfrac{\dfrac{a}{b} - c - s - m - \left(\gamma - \dfrac{1}{2}\right)p_s}{m - \left(\gamma - \dfrac{1}{2}\right)(p_s - s_s)}$
End-user price under perfect competition $p_e^{3ar,comp}$	$p_e^{3ar,comp} = \dfrac{1}{2}\left(\dfrac{a}{b} + \bar{c} + \left(\gamma - \dfrac{1}{2}\right)p_s + s\right)$

Let's now look at the results of model 3ar in more detail. The expression for the wholesale price is very similar to previous models, in particular models 3ab and 3as. The main difference is that the average unit cost is not constant, i.e. it depends on the number of traders. Provided that the storage price is higher than the storage cost, the average unit cost is increasing in the number of traders n due to which the wholesale price is decreasing in n. As for the comparison with the regulated case of model 3, the results are not as straightforward as in the previous models. If the storage price margin is high it might even happen that the wholesale price will decline after liberalization. On the other hand, high storage price margin has a detrimental effect on the end-user price as it increases the average unit cost. Examining the effect of an extra downstream trader on the end-user price

$$p_e^n - p_e^{n+1} = \frac{1}{2(n+1)(n+2)}\left[\left(\frac{a}{b} - \left(\bar{c} + s - \left(\gamma - \frac{1}{2}\right)p_s\right)\right) - \left(\gamma - \frac{1}{2}\right)(p_s - s_s)\right] \qquad [66]$$

it might even happen that increased competition in combination with high storage prices will lead to higher end-user prices, i.e. the increase in average unit cost prevails over the benefits brought by higher number of traders. This can be seen from equation [66] where the first part is positive (the limit price minus the total unit cost of trader $i > 1$) whereas the second part, the negative value of the storage price margin, is negative. Nevertheless, if the storage price is set "reasonably", liberalization leads to lower end-user prices and higher wholesale prices.

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It is worth noting that these results are interior solution results; if the storage price margin is too high it might turn out to be optimal for trader 1 to supply the whole market at a price below the cost price of the other traders (i.e. if the monopoly price is below the unit cost of other traders).

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Comparison of models 3, 3as, 3ab, 3ar

Variable	Model 3	Model 3ab	Model 3as	Model 3ar
Wholesale price p_w	$\frac{1}{2}(\frac{a}{b}+s-c-s_s(\gamma-\frac{1}{2})-m)$	$\frac{1}{2}\left(\frac{a}{b}-c-\left(\gamma-\frac{1}{2}\right)s_s+s\right)$	$\frac{1}{2}\left(\frac{a}{b}-\bar{c}-\left(\gamma-\frac{1}{2}\right)s_s+s\right)$	$\frac{1}{2}\left(\frac{a}{b}-\bar{c}-\frac{\left(\gamma-\frac{1}{2}\right)(s_s+(n-1)p_s)}{n}+s\right)$
End-user price p_e	$\frac{1}{2}(\frac{a}{b}+s+c+s_s(\gamma-\frac{1}{2})+m)$	$\frac{1}{4}\left(\frac{3a}{b}+s+c+\left(\gamma-\frac{1}{2}\right)s_s\right)$	$\frac{1}{4}\frac{n}{n+1}\left(\frac{3n+4}{n}\frac{a}{b}+\bar{c}+\left(\gamma-\frac{1}{2}\right)s_s+s\right)$	$\frac{n}{2(n+1)}\left(\frac{2n+1}{n}\frac{a}{b}+\bar{c}+\frac{\left(\gamma-\frac{1}{2}\right)(s_s+(n-1)p_s)}{n}+s\right)$
Total quantity sold Q	$\frac{1}{2}(a-b(s+c+s_s(\gamma-\frac{1}{2})+m))$	$\frac{1}{4}\left(a-bs-bc-b\left(\gamma-\frac{1}{2}\right)s_s\right)$	$\frac{1}{4}\frac{n}{n+1}\left(a-b\bar{c}-b\left(\gamma-\frac{1}{2}\right)s_s-bs\right)$	$\frac{n}{2(n+1)}\left(a-b\bar{c}-\frac{b\left(\gamma-\frac{1}{2}\right)(s_s+(n-1)p_s)}{n}-bs\right)$
End-user price p_e^{comp} under perfect competition			$\frac{1}{4}\left(3\frac{a}{b}+\bar{c}+\left(\gamma-\frac{1}{2}\right)s_s+s\right)$	$\frac{1}{2}\left(\frac{a}{b}+\bar{c}+\left(\gamma-\frac{1}{2}\right)p_s+s\right)$

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6.3.5 Model 4a

- **liberalized downstream**

- **storage owned by trader no. 1 (former monopoly)**

- **upstream monopoly**

- **regulator sets the storage price**

- **two downstream markets, each modeled by Cournot competition**

In this model I introduce multiple markets on the downstream segment, which is a widely spread phenomenon in the real-world gas industry. Such setup may be interpreted in several ways: two different markets may correspond to two different types of consumers – households and industrial customers each of which may have different storage requirements or costs (unit distribution costs are usually lower for larger industrial customers); two geographically separated areas (two different countries) with different demand functions, storage requirements and costs. A key assumption of this model is that the upstream producer cannot discriminate between the two markets, i.e. the producer sells gas to traders without having any effective mechanism to restrict the traders to a specific market.

The driving force of the model is again the demand, however, this time there are two demand functions (in general may be *m*) with two (or *m*) storage parameters. For market *k* the demand function is

$$Q^k(p_e^k) = a^k - b^k p_e^k, \, k = 1,2 \tag{67}$$

and the quantity of storage capacity demanded is

$$Q_S^k = Q^k\left(\gamma^k - \frac{1}{2}\right), \, k = 1,2 \tag{68}$$

There are *n* traders and trader 1 controls the storage capacity. The profit of trader 1 is the sum of profits from the two markets

$$\pi_1 = \sum_{k=1,2} \left[q_1\left(\frac{a^k - q_1^k - q_{-1}^k}{b^k} - p_w - c_1 - c^k - \left(\gamma^k - \frac{1}{2}\right)s_s\right) + q_{-1}^k\left(\gamma^k - \frac{1}{2}\right)\left(p_s^k - s_s\right) \right] \tag{69}$$

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In this formula, c^k is the market-specific unit cost (each market may have different unit costs). It is worth mentioning that while the unit storage cost s_s is the same for both markets, the storage price p_s^k may be different for each market.

Similarly, the profit of other traders also consists of two components each corresponding to the relevant market:

$$\pi_i = \sum_{k=1,2}\left[q_i\left(\frac{a^k - q_i^k - q_{-i}^k}{b^k} - p_w - c_i - c^k - \left(\gamma^k - \frac{1}{2}\right)s_s \right)\right] \quad i=2,..,n \qquad [70]$$

Since the profit functions are again concave with respect to all quantities first order conditions may be used to derive the optimal allocations. The FOC for trader 1 is

$$\frac{d\pi_1}{dq_1^k} = \frac{a^k - q_1^k - q_{-1}^k}{b^k} - p_w - c_1^k - \left(\gamma^k - \frac{1}{2}\right)s_s - \frac{q_1^k}{b} = 0 \quad k = 1,2 \qquad [71]$$

where I use the notation $c_i^k = c_i + c^k$. A similar expression is obtained for other traders:

$$\frac{d\pi_i}{dq_i^k} = \frac{a^k - q_i^k - q_{-i}^k}{b^k} - p_w - c_i^k - \left(\gamma^k - \frac{1}{2}\right)p_s^k - \frac{q_i^k}{b} = 0 \quad k = 1,2 \text{ and } i=2,..,n \qquad [72]$$

These 2*n first order conditions can be solved as two separate systems of n linear equations arriving at the following quantities:

$$q_1^k = \left[a^k - b^k\left(p_w + c_1^k + \left(\gamma^k - \frac{1}{2}\right)s_s \right)\right] * \frac{n}{n+1} - \frac{1}{n+1}\sum_{i\neq 1}\left[a^k - b^k\left(p_w + c_i^k + \left(\gamma^k - \frac{1}{2}\right)p_s^k \right)\right]$$
[73]

$$q_i^k = \left(a^k - b^k\left(p_w + c_i^k + \left(\gamma^k - \frac{1}{2}\right)p_s^k \right)\right) * \frac{n}{n+1} - \frac{1}{n+1}\sum_{j\neq i,1}\left(a^k - b^k\left(p_w + c_j^k + \left(\gamma^k - \frac{1}{2}\right)p_s^k \right)\right) - \frac{1}{n+1}\left(a^k - b^k\left(p_w + c_1^k + \left(\gamma^k - \frac{1}{2}\right)s_s \right)\right)$$
[74]

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By summing these up I obtain the total quantity supplied to each market as

$$Q^k = \frac{1}{n+1}\left[a^k - b^k\left(p_w + c_1^k + \left(\gamma^k - \frac{1}{2}\right)s_s\right)\right] + \frac{1}{n+1}\sum_{i\neq 1}\left[a^k - b^k\left(p_w + c_i^k + \left(\gamma^k - \frac{1}{2}\right)p_s^k\right)\right]$$

[75]

and the total quantity supplied to both markets in aggregate as

$$Q = \sum_k Q^k = \sum_k\left[\frac{1}{n+1}\left[a^k - b^k\left(p_w + c_1^k + \left(\gamma^k - \frac{1}{2}\right)s_s\right)\right] + \frac{1}{n+1}\sum_{i\neq 1}\left[a^k - b^k\left(p_w + c_i^k + \left(\gamma^k - \frac{1}{2}\right)p_s^k\right)\right]\right]$$

[76]

This quantity is now used by the upstream monopolist to maximize his profit. The profit function of the upstream monopoly is

$$\Pi = Q*(p_w - s) = \sum_k\left[\frac{1}{n+1}\left(na - nb^k p_w - b^k c_1^k - b^k\left(\gamma^k - \frac{1}{2}\right)s_s - b^k\sum_{i\neq 1}c_i^k - (n-1)b^k\left(\gamma^k - \frac{1}{2}\right)p_s^k\right)\right](p_w - s)$$

[77]

This function is concave with respect to the wholesale price, therefore the first order conditions yield the maximum profit:

$$\frac{d\Pi}{dp_w} = \sum_k\left[\frac{1}{n+1}\left(na^k - nb^k p_w - b^k c_1^k - b^k\left(\gamma^k - \frac{1}{2}\right)s_s - b^k\sum_{i\neq 1}c_i^k - (n-1)b^k\left(\gamma^k - \frac{1}{2}\right)p_s^k\right) - nb^k\frac{1}{n+1}(p_w - s)\right] = 0$$

[78]

$$\frac{d\Pi}{dp_w} = \frac{1}{n+1}\sum_k\left[na^k - 2nb^k p_w - b^k c_1^k - b^k\left(\gamma^k - \frac{1}{2}\right)s_s - b^k\sum_{i\neq 1}c_i^k - (n-1)b^k\left(\gamma^k - \frac{1}{2}\right)p_s^k + nb^k s\right] = 0$$

[79]

This gives the wholesale price

$$p_w = \frac{\sum_k\left[na^k - b^k c_1^k - b^k\left(\gamma^k - \frac{1}{2}\right)s_s - b^k\sum_{i\neq 1}c_i^k - (n-1)b^k\left(\gamma^k - \frac{1}{2}\right)p_s^k + nb^k s\right]}{\sum_k 2nb^k}$$

[80]

or

$$p_w = \frac{n(a^1 + a^2) - (b^1 + b^2)\sum_{i=1}^{n}c_i - nb^2 c^2 - b^1\left(\gamma^1 - \frac{1}{2}\right)s_s - b^2\left(\gamma^2 - \frac{1}{2}\right)s_s - (n-1)b^1\left(\gamma^1 - \frac{1}{2}\right)p_s^1 - (n-1)b^2\left(\gamma^2 - \frac{1}{2}\right)p_s^2 + ns(b^1 + b^2)}{2n(b^1 + b^2)}$$

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[81]

where I normalize the market-specific cost of market 1 to zero. This formula may be used to investigate how one market effects the other. The simplest way how to examine these impacts is to assume that all parameters of the markets except for one are the same. For example, higher market specific cost in one market (c^2) reduces the wholesale price for both markets by $\dfrac{c^2}{4}$. If compared with the case when the upstream producer is capable of applying destination clauses (separate markets), the wholesale price is now lower than the wholesale price on the separate market 1 by $\dfrac{c^2}{4}$ and higher than the wholesale price on the separated market by $\dfrac{c^2}{4}$. Therefore, market 1 benefits from the unification of the two markets while market 2 is hurt by this unification. Due to this fact traders operating on market 2 would like to commit to selling only on this market and thus receive a better wholesale price.

It is also possible to investigate how the regulator may set the storage prices to influence the wholesale price. By increasing the storage price on one market (the less preferred market) the regulator can reduce the wholesale price for both markets (including the more preferred market).

The formula for the wholesale price may be used to derive other interesting variables (quantities, end-user prices etc.). The quantity supplied on each market is

$$Q^k = \frac{1}{n+1}\left[na^k - nb^k p_w - b\sum_{i=1}^{n} c_i^k - b^k\left(\gamma^k - \frac{1}{2}\right)s_s - b^k(n-1)\left(\gamma^k - \frac{1}{2}\right)p_s^k \right]$$ [82]

$$Q^k = \frac{1}{n+1}\left[na^k - b^k\sum_{i=1}^{n} c_i^k - b^k\left(\gamma^k - \frac{1}{2}\right)s_s - b^k(n-1)\left(\gamma^k - \frac{1}{2}\right)p_s^k - b^k \frac{\sum_j\left[na^j - b^j c_i^j - b^j\left(\gamma^j - \frac{1}{2}\right)s_s - b^j\sum_{i\neq 1} c_i^j - (n-1)b^j\left(\gamma^j - \frac{1}{2}\right)p_s^j + nb^j s\right]}{\sum_j 2b^j} \right]$$

[83]

The end-user prices on the two markets are

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$$p_e^k = \frac{a^k - Q^k}{b^k} = \frac{a^k}{b^k} - \frac{1}{(n+1)b^k}\left[na^k - b^k\sum_{i=1}^n c_i^k - b^k\left(\gamma^k - \frac{1}{2}\right)s_s - b^k(n-1)\left(\gamma^k - \frac{1}{2}\right)p_s^k - b^k\frac{\sum_j\left[na^j - b^j c_1^j - b^j\left(\gamma^j - \frac{1}{2}\right)s_s - b^j\sum_{i\neq 1}c_i^j - (n-1)b^j\left(\gamma^j - \frac{1}{2}\right)p_s^j + nb^j s\right]}{\sum_j 2b^j}\right]$$

[84]

6.3.5.1 Model 4a Summary Table

Variable	Expression
Wholesale price p_w	$p_w = \dfrac{n(a^1 + a^2) - (b^1 + b^2)\sum_{i=1}^n c_i - nb^2 c^2 - b^1\left(\gamma^1 - \frac{1}{2}\right)s_s - b^2\left(\gamma^2 - \frac{1}{2}\right)s_s - (n-1)b^1\left(\gamma^1 - \frac{1}{2}\right)p_s^1 - (n-1)b^2\left(\gamma^2 - \frac{1}{2}\right)p_s^2 + ns(b^1 + b^2)}{2n(b^1 + b^2)}$
End-user price p_e^k	$p_e^k = \dfrac{a^k - Q^k}{b^k} = \dfrac{a^k}{b^k} - \dfrac{1}{(n+1)b^k}\left[na^k - b^k\sum_{i=1}^n c_i^k - b^k\left(\gamma^k - \frac{1}{2}\right)s_s - b^k(n-1)\left(\gamma^k - \frac{1}{2}\right)p_s^k - b^k\dfrac{\sum_j\left[na^j - b^j c_i^j - b^j\left(\gamma^j - \frac{1}{2}\right)s_s - b^j\sum_{i\neq 1}c_i^j - (n-1)b^j\left(\gamma^j - \frac{1}{2}\right)p_s^j + nb^j s\right]}{\sum_j 2b^j}\right]$
Total quantity sold Q	$Q = \dfrac{1}{2(n+1)}\sum_k\left[na^k - b^k\sum_{i=1}^n c_i^k - b^k\left(\gamma^k - \frac{1}{2}\right)s_s - b^k(n-1)\left(\gamma^k - \frac{1}{2}\right)p_s^k - nb^j s\right]$
Quantity sold on each market Q^k	$Q^k = \dfrac{1}{n+1}\left[na^k - b^k\sum_{i=1}^n c_i^k - b^k\left(\gamma^k - \frac{1}{2}\right)s_s - b^k(n-1)\left(\gamma^k - \frac{1}{2}\right)p_s^k - b^k\dfrac{\sum_j\left[na^j - b^j c_i^j - b^j\left(\gamma^j - \frac{1}{2}\right)s_s - b^j\sum_{i\neq 1}c_i^j - (n-1)b^j\left(\gamma^j - \frac{1}{2}\right)p_s^j + nb^j s\right]}{\sum_j 2b^j}\right]$

6.4 Modeling Upstream Competition

The following model is motivated by the fact that the gas upstream market is not totally monopolistic, although the number of possible gas producers which could supply gas to the Czech Republic is quite limited. Moreover, due to the geographic location (and perhaps also other reasons) the gas production and transportation costs of the Russian gas producer are lower than of other producers (in particular Norwegian producers). Therefore in this model I will analyze how the introduction of limited competition (duopoly with unequal marginal costs) influences the market and in particular market liberalization.

I will start by modeling the upstream market as Cournot competition in quantities with m gas producers. In the previous models the total quantity supplied to all markets could always be expressed as a linear function of the wholesale price

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(e.g.[76],[62] etc.) , i.e. the price which the producers receive from the downstream traders:

$$Q = f - gp_w \qquad\qquad [85]$$

where the parameters f and g depend on the structure of the downstream market. The form of [85] implies that standard Cournot competition can be used to derive the optimal allocation. (I can again use the same procedure as with the downstream market.) The inverse of [85] together with the Cournot outcome [8] gives the wholesale price

$$p_w = \frac{f-Q}{g} = \frac{f}{g} - \frac{1}{m+1}\sum_{i=1}^{m}\left(\frac{f}{g} - s_i\right) = \frac{1}{m+1}\left(\frac{f}{g} + \sum_{i=1}^{m} s_i\right) \qquad\qquad [86]$$

This expression may be used in the results of the downstream market (quantities supplied by traders which are the functions of the wholesale price, the end-user price).

One interesting question is how the wholesale price changes in comparison with the setup with a monopolistic upstream producer. The wholesale price in that case is

$$p_w^1 = \frac{1}{2}\left(\frac{f}{g} + s_1\right) \qquad\qquad [87]$$

and the price difference is

$$\Delta p_w = p_w^1 - p_w^m = \frac{1}{2}\left(\frac{f}{g} + s_1\right) - \frac{1}{m+1}\left(\frac{f}{g} + \sum_{i=1}^{m} s_i\right) = \left(\frac{f}{g} + s_1\right)\left(\frac{m-1}{2(m+1)}\right) - \frac{1}{m+1}\sum_{i=2}^{m} s_i$$

[88]

For $m = 2$ this translates to

$$\Delta p_w = \left(\frac{f}{g} + s_1\right)\left(\frac{1}{6}\right) - \frac{1}{3} s_2 \qquad\qquad [89]$$

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It is clear that the second producer cannot enter the market if his unit cost is too high. The upper limit of the second trader's unit cost is equal to the monopoly price (this cost leads to the price differential being equal to zero).

This notion is very important for the situation on the Czech natural gas market. At the current time the whole market is served by two upstream producers: the Russian Gazexport (about 3/4 of the supply) and a consortium of Norwegian producers (about 1/4 of the supply). In a competitive environment this would indicate that, although the unit costs of the two producers are different, they are within the bounds of the monopoly price of the other producer. However, the contracts for the supply of natural gas were signed under the regulated conditions and the decision to conclude a contract with the higher cost producer (Norway[12]) might have been driven by strategic efforts to reduce the dependence on Russian gas, a decision made by the Czech state, the former owner of the whole Czech gas industry[13].

6.4.1 Model 5

- **regulated downstream monopoly**
- **storage controlled by downstream monopoly**
- **upstream duopoly**

This model attempts to capture the situation on the Czech market prior to liberalization. It consists of two upstream producers and a single downstream trader whose price is regulated by the energy regulator. The downstream trader also controls the gas storage facilities. Therefore the end-user price consists of the wholesale price plus all unit costs plus the margin allowed by the regulator.

$$p_e = p_w + m + c + s_s\left(\gamma - \frac{1}{2}\right) \qquad\qquad [90]$$

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[12] For indications of this see Kubátová 2006

[13] The contract for the supply of natural gas from Norway was concluded between Transgas (currently RWE Transgas) and the Norwegian State Committee for the Sale of Natural Gas GFU on 14th April 1997 for the period of 20 years. Source: MFA CR 2006b. The Czech natural gas industry was privatized only on 30th January 2002, i.e. the new private owner (RWE) did not have a choice concerning the gas producer.

This end-user price together with the downstream demand function [1] yields the derived demand for the upstream market

$$Q = \left(a - b \left(m + c + s_s \left(\gamma - \frac{1}{2} \right) \right) \right) - b p_w \qquad [91]$$

The results of this model are obtained by setting

$$f = a - b \left(m + c + s_s \left(\gamma - \frac{1}{2} \right) \right) \text{ and } g = b \qquad [92]$$

in equation [86].

Model 5 Summary Table

Variable	Expression
End-user price p_e^5	$p_e^5 = \frac{1}{3} \left(\frac{a}{b} + s_1 + s_2 \right) + \frac{2}{3} \left(m + c + s_s \left(\gamma - \frac{1}{2} \right) \right)$
Wholesale price p_w^5	$p_w^5 = \frac{1}{3} \left(\frac{a}{b} - \left(m + c + s_s \left(\gamma - \frac{1}{2} \right) \right) + s_1 + s_2 \right)$
Total quantity supplied Q_w^5	$Q_w^5 = \frac{2}{3} \left(a - b \left(m + c + s_s \left(\gamma - \frac{1}{2} \right) \right) \right) - \frac{b}{3} (s_1 + s_2)$

Already in this model it is possible to investigate the benefits of increased upstream competition. Assuming that the two upstream producers have the same unit cost *s*, in comparison with model 3, the wholesale price declines by

$$p_w^3 - p_w^5 = \frac{1}{6} \left(\frac{a}{b} - c - s_s \left(\gamma - \frac{1}{2} \right) - m - s \right) \qquad [93]$$

and thus the end-user price goes down by this amount as well.

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6.4.2 Model 5a

- **upstream duopoly**
- **downstream competition**
- **trader 1 controls storage**
- **storage price is regulated**

This model describes what happens after liberalization given the setup of model 5. Liberalization of the market should result in increased competition on the downstream level. Consequently in this model the downstream market is served by n traders while there is a duopolistic upstream production. Since Cournot competition is again used, I can use the results of model 3ar, in particular the expression for the total quantity supplied as a function of the wholesale price [62]

$$Q = \frac{1}{n+1}\left[a - b\left(p_w + c_1 + \left(\gamma - \frac{1}{2}\right)s_s\right)\right] + \frac{1}{n+1}\sum_{i \neq 1}\left[a - b\left(p_w + c_i + \left(\gamma - \frac{1}{2}\right)p_s\right)\right] \quad [94]$$

This expression can be adjusted to obtain the desired derived demand formulation

$$Q = \frac{n}{n+1}[a - b\bar{c}] - \frac{b}{n+1}\left((n-1)p_s + s_s\right)\left(\gamma - \frac{1}{2}\right) - \frac{nb}{n+1}p_w \quad [95]$$

Setting

$$f = \frac{n}{n+1}[a - b\bar{c}] - \frac{b}{n+1}\left((n-1)p_s + s_s\right)\left(\gamma - \frac{1}{2}\right) \text{ and } g = \frac{nb}{n+1} \quad [96]$$

I can again use the results [86] to derive the interesting quantities and prices (see the summary table).

Model 5a Summary Table

End-user price p_e^{5a}	$p_e^{5a} = \frac{1}{n+1}\left(\frac{n+3}{3}\frac{a}{b} + \frac{2}{3}n\bar{c} + \frac{2}{3}\left((n-1)p_s + s_s\right)\left(\gamma - \frac{1}{2}\right) + \frac{1}{3}n(s_1 + s_2)\right)$

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Wholesale price p_w^{5a}	$p_w^{5a} = \dfrac{1}{3}\left(\dfrac{a}{b} - \bar{c} - \dfrac{1}{n}\left((n-1)p_s + s_s\right)\left(\gamma - \dfrac{1}{2}\right) + s_1 + s_2 \right)$
Total quantity supplied Q^{5a}	$Q^{5a} = \dfrac{1}{n+1}\left(\dfrac{2}{3}na - \dfrac{2}{3}nb\bar{c} - \dfrac{2}{3}b\left((n-1)p_s + s_s\right)\left(\gamma - \dfrac{1}{2}\right) - \dfrac{1}{3}nb(s_1 + s_2) \right)$
End-user price under perfect competition $p_e^{5a,comp}$	$p_e^{5a,comp} = \dfrac{1}{3}\left(\dfrac{a}{b} + s_1 + s_2 \right) + \dfrac{2}{3}\left(\bar{c} + p_s\left(\gamma - \dfrac{1}{2}\right) \right)$

Now let's compare these results with the regulated model 5. Looking at the wholesale price, if the storage price is set to the storage cost, the wholesale price increases by one third of the formerly regulated margin from model 5. This means that although the benefits captured by the upstream segment are smaller in magnitude than in case of upstream monopoly, the wholesale price still increases. As for the end-user price, perfect competition leads to better outcome for end-users provided that the regulated storage price margin multiplied by the unit storage capacity requirement is lower than the price margin in the regulated case 5.

6.5 Upstream Competitive Fringe

Oligopoly (duopoly) is not the only way how to introduce competition into the upstream market segment. There are several smaller Asian gas producers interested in supplying gas to Europe. However, the transmission lines to the western markets are controlled by the Russian gas company Gazprom. Consequently these producers have only indirect access to European markets by the means of sale of gas to the Russian monopoly which then markets it in European countries. Hoping that increased upstream competition would reduce the downstream price, recent initiatives of the European Union strive to ensure direct access of these Asian producers to the European market.

6.5.1 Model 6a

- **upstream dominant firm with competitive fringe**
- **downstream competition**
- **trader 1 controls storage**
- **storage price is regulated**

In this model I attempt to capture exactly such development, i.e. upstream segment characterized by a dominant producer and competitive fringe. I base the modeling on some commonly used assumptions[14], however, I also introduce some elements which are characteristic for the given situation. In particular, in line with Carlton and Perloff (2000) I assume that the dominant firm sets the price knowing the response of the competitive fringe and that competitive fringe companies act as price-takers. However, due to transmission capacity constraints I assume that the size of the competitive fringe is fixed (corresponds to the dominant firm granting a certain transmission capacity to each firm). Consequently, instead of equating the marginal costs to the market price, as the competitive fringe firms would do in an unconstrained world, they supply a fixed amount of gas at the market price chosen by the dominant firm. For this to be true I also have to assume that the price is set within a "reasonable range", i.e. high enough so that the competitive fringe firms would be willing to supply, an assumption which is very realistic.

In order to proceed with the modeling, I start with the downstream market whose structure is similar to the previous models (e.g. model 3ar or 5a) consisting of n traders (importers) of which trader no 1 also controls the storage facilities. Therefore, as the starting point for the calculations I use the total quantity supplied expressed as a function of the wholesale price [62]:

$$Q = \frac{1}{n+1}\left[a - b\left(p_w + c_1 + \left(\gamma - \frac{1}{2}\right)s_s\right)\right] + \frac{1}{n+1}\sum_{i \neq 1}\left[a - b\left(p_w + c_i + \left(\gamma - \frac{1}{2}\right)p_s\right)\right]$$

[97]

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[14] Carlton and Perloff (2000), pp. 107 - 119

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Therefore the profit function of the dominant firm is

$$\Pi = (Q - K)(p_w - s) = \left(\frac{1}{n+1} \left[a - b \left(p_w + c_1 + \left(\gamma - \frac{1}{2} \right) s_s \right) \right] + \frac{1}{n+1} \sum_{i \neq 1} \left[a - b \left(p_w + c_i + \left(\gamma - \frac{1}{2} \right) p_s \right) \right] - K \right)(p_w - s)$$

[98]

where K is the capacity allocated to the competitive fringe. Due to concavity of the profit function the first order condition yields the profit maximizing wholesale price:

$$\frac{d\Pi}{dp_w} = \left(\frac{1}{n+1} \left[a - b \left(2p_w - s + c_1 + \left(\gamma - \frac{1}{2} \right) s_s \right) \right] + \frac{1}{n+1} \sum_{i \neq 1} \left[a - b \left(2p_w - s + c_i + \left(\gamma - \frac{1}{2} \right) p_s \right) \right] - K \right) = 0$$

[99]

or

$$p_w = \frac{1}{2} \left(\frac{a}{b} - \bar{c} + s - \frac{1}{n} \left(\gamma - \frac{1}{2} \right) (s_s + (n-1)p_s) - \frac{n+1}{nb} K \right)$$

[100]

The coefficient for the capacity allocated to the competitive fringe is negative which means that the wholesale price is decreasing as the amount of gas supplied by the competitive fringe increases, which is in line with the expected results (wholesale price decreases). Furthermore, the effect of competitive fringe on the wholesale price is more pronounced when the downstream market is served by just a few traders (since $n+1/n$ is decreasing in n).

7   Discussion of the Results

The models elaborated above pointed out some problems associated with the liberalization of the Czech natural gas market. In this section I will discuss the results making comparisons between the individual models.

Already models 2 and 2a outlined one of the principal problems of the liberalization efforts: in an environment with a single upstream supplier the wholesale price is not invariant to the changes in the downstream market structure. Considering the behavior of downstream traders, the upstream monopoly is capable of capturing one half of the originally regulated margin, i.e. the upstream monopoly increases the

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wholesale price offered to downstream traders (for further implications of this result see below). Despite the increasing wholesale price, a sufficient number of traders is capable of pushing the price below the formerly regulated price level thus increasing consumer surplus.

Starting with model 3 I introduced storage as a necessary input for the supply of gas to end-users. If I were to consider storage as an input supplied competitively at an exogenous price, the results from models 2 and 2a would not change. However, the difference rests in the scarcity of this input and the control of its production facilities. While in model 3 there is no explicit storage price charged as storage facilities are owned by the monopolistic trader, two different scenarios are presented in models 3ab and 3as: in model 3ab storage is controlled by the incumbent trader and in model 3as the storage operator is a separate storage monopoly.

Model 3ab, whose storage structure resembles the reality, yields results which were quite expected. The bundled trader and storage operator charges excessively high storage prices to prohibit other traders from entering the market. This, to a certain extent, explains the rising prices of gas after the first liberalization step and the non-emergence of new traders – stylized facts 1 and 2 – and provides a rationalization of the fines imposed on the incumbent for abusing his dominant position. However, no clear straightforward conclusion can be drawn on this topic as there are also other circumstances surrounding this issue. In his press releases the incumbent naturally denies the accusations of charging excessively high prices stating that the prices are rising only because of rising prices of natural gas substitutes (oils) since the price formula in contracts with foreign gas producers includes a component reflecting the market price of oil. (The average monthly price of Brent oil increased from USD 44.23 per barrel in January to USD 64.12 per barrel in August, i.e. by almost 50 % - Source: International Energy Agency.)[15]

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[15] There are two more reasons which support the opinion that the complaints are exaggerated and which might have contributed to the difference in the increase of prices for captive and eligible customers. One reason is that the price for captive customers is regulated and is adjusted on quarterly basis as a result of which its development lags behind the market price development. ERO is thus capable of buffering the effect of rising commodity prices by spreading the price increase into several periods. The second reason why the difference between the increase in prices for captive and eligible customers seems so high (17-19 % vs. 30-40%) is the fact that the commodity component of the final price is greater for large-volume

One straightforward and at first glance viable solution to this problem is the full ownership unbundling of the incumbent which is captured in model 3as. In this model there is a separate storage owner. However, since this separate storage operator is a monopoly in storage services, the final outcome is even worse than in the bundled case of model 3ab. Instead of double marginalization presented in the bundled model, the unbundled model exhibits triple marginalization, i.e. markups are successively added by domestic traders, separate storage monopoly and the upstream producer. Only if perfect downstream competition is achieved are the results identical with the results of the bundled model 3ab. This clearly shows that in case of storage monopoly the unbundling of storage services, even though it ensures equity among individual traders, is from the perspective of the end-user inferior to the regulated model 3 as well as the bundled model 3ab with a single domestic monopolistic trader. This result contradicts the results of Van Koten 2006, who, in a quite different setting, in which (partially) vertically integrated auctioneer and bidder participate in electricity transmission capacity auction, concludes that vertical integration or incomplete unbundling is from the perspective of welfare inferior to complete ownership unbundling.

The penalties imposed by the Energy Regulatory Office and the Office for the Protection of Competition perhaps indicate that another model should be considered in this paper: a model in which the state has a storage price enforcement mechanism, e.g. the threat of punishment through fines in case that storage prices are set "too high". This is done in model 3ar where the extending assumption is that storage price is set by the regulator. When examining this model it turns out that contrary to model 2a the wholesale price in no longer independent of the number of downstream traders. This is due to the asymmetricity in the storage costs: while trader 1 (bundled trader and storage operator) pays only the direct storage cost, other traders pay the regulated storage price. The wholesale price can be expressed as

$$p_w^{3ar} = \frac{1}{2}\left(\frac{a}{b} - \bar{c} + s - \left(\gamma - \frac{1}{2}\right)s_s\right) - \frac{1}{2}\frac{n-1}{n}\left(\gamma - \frac{1}{2}\right)m_s \qquad [101]$$

customers than for households. Therefore the same increase in commodity price will lead to smaller overall percentage increase in prices for households.

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where m_s is the regulated storage price margin. In comparison with model 2a the second component is new. A similar expression may be obtained for the end-user price

$$p_e^{3ar} = \frac{1}{2(n+1)}\left((n+2)\frac{a}{b} + n\bar{c} + n\left(\gamma - \frac{1}{2}\right)s_s + (n-1)\left(\gamma - \frac{1}{2}\right)m_s + ns\right) \qquad [102]$$

Notice that the wholesale price is decreasing and the end-user price is increasing in the storage price margin. This has a serious impact for the economy. If the margin is set low or even negative so as to promote competition and favor new traders over the incumbent, the wholesale price charged by the upstream producer increases and in case of negative storage price margin even exceeds the wholesale price of model 2a. On the other hand, high regulated storage margin increases the end-user price and favors the incumbent which is clearly not the desired effect of market liberalization. Nevertheless, if the storage margin is not too high in comparison with the formerly regulated monopoly margin, i.e. if

$$\frac{n-1}{n}\left(\gamma - \frac{1}{2}\right)m_s < m \qquad [103]$$

the wholesale price after liberalization increases similarly to models 2 and 2a. The violation of this inequality would mean that the regulator allows the storage operator to earn such a high margin on storage that the end-user price under perfect competition is higher than the end-user price in case of regulated model 3, i.e.

$$\frac{1}{2}\left(\frac{a}{b} + \bar{c} + \left(\gamma - \frac{1}{2}\right)s_s + \left(\gamma - \frac{1}{2}\right)m_s + s\right) > \frac{1}{2}\left(\frac{a}{b} + \bar{c} + \left(\gamma - \frac{1}{2}\right)s_s + m + s\right) \qquad [104]$$

This is clearly not the desired outcome of liberalization and will not be supported in the long-term.

So far the regulated/liberalized model pairs 2+2a and 3+3ar consistently show that although liberalization is capable of pushing down the end-user price, the upstream

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producer is also capable of capturing some of the benefits of liberalization by increasing the wholesale price. In models 5 and 5a a second upstream producer was introduced to examine how these results are robust to the upstream structure. It turns out that even in this case the optimal pricing strategy of the upstream is to increase the wholesale price after liberalization provided that the storage price margin is not "too high" which is again characterized by the expression [103] above. Nevertheless, there is a positive effect of increased competition on the upstream level for the downstream: upon liberalization the upstream is capable of capturing less of the formerly regulated margin. Recall that in model 2+2a this was one half of the margin while in this case, when the regulated storage price is equal to the storage cost, the upstream captures only one third of the original margin. More specifically, while in model 3+3ar the upstream captures

$$\Delta p_w^{3,3ar} = \frac{1}{2}\left(m - \frac{n-1}{n} m_s \left(\gamma - \frac{1}{2} \right) \right)$$ [105]

in models 5 + 5a the upstream captures

$$\Delta p_w^{5+5ar} = \frac{1}{3}\left(m - \frac{n-1}{n} m_s \left(\gamma - \frac{1}{2} \right) \right)$$ [106]

Looking at the individual models and specifically focusing on the pairs of models 2+2a, 3+3ar, and 5+5a there are two main results robust across the models:
1) liberalization can achieve lower end-user prices if the number of traders is sufficiently high;
2) the upstream captures some of the benefits of liberalization by changing its pricing strategy and increasing the wholesale price.

Considering the first result, it might be very difficult to achieve a sufficiently high number of competitors even when all traders have the same conditions. This is due to the fact that larger gas traders benefit from the portfolio effect, i.e. the fact that the aggregated demand of many customers is smoother and more stable than the demand of a single customer and coping with demand fluctuations is costly.

As for the second main result, it hints at why it might be difficult to reach the liberalized competitive state. It shows that storage and the potential for abusing the dominant position, as examined in model 3ab, are not the only reasons why there are no new entrants emerging (stylized fact 1). The non-emergence of new traders might be partly caused by the fact that upstream producers, expecting a competitive liberalized outcome, adapt their pricing strategies to the new conditions thus charging a higher wholesale price to new traders. In turn the entrants cannot compete with the incumbent to whom the upstream producers supply gas for a price, which has been set some time before liberalization and which cannot change until the long-term supply contracts between the incumbent and the producers expire[16].

Although this paper examines the liberalized outcome and the wholesale price result indicates that there might be a problem with achieving this liberalized outcome, the transition path from the regulated to the competitive state is not captured in these models. This transition motivates further research which I plan to pursue. I plan to employ dynamic models with at least two periods to examine how the individual players might behave in the meantime in order to build up their position and prepare for the next fully liberalized stage. In particular, I plan to investigate how market players (in particular the incumbent) may use strategic investment in the first period to reduce competition in the second period. I believe that such models will provide mode insight into the behavior of individual players in the period before long-term contracts for the supply of gas to the Czech Republic expire and will reveal other potential obstacles on the road to a truly liberalized natural gas sector.

8 Conclusion

I have used successive oligopoly models to analyze the Czech natural gas market focusing on the comparison of the pre-liberalization and liberalized outcome. I started with very simple models and gradually introduced the features of the natural gas market and the situation in the Czech Republic. The main results of the investigation are that, although a sufficiently high number of competitors may drive the price down below the

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[16] The contract with Russia expires in 2014, the contract with Norway expires in 2017.

pre-liberalization level, the outcome is hindered by the fact that upstream producers are capable of capturing a significant share of the formerly regulated price margin. This result shows that storage ownership and the potential for dominant position abuse are not the only reasons why there has been no influx of new traders to the Czech natural gas market.

However interesting and inspiring the results of this paper are, they describe only a static situation after downstream traders enter the market, a situation which might be hard to achieve. Therefore, in further research I plan to extend these models by introducing dynamic structure with strategic investment options (and possibly startup costs) and analyzing the transition path from regulation to liberalization, which will possibly help me uncover more potential obstacles facing the natural gas sector.

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