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Zweifel, Peter ; Krey, Boris ; Schirillo, Sandro

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Russian gas to western Europe: a game-theoretic analysis

Peter Zweifel

Socioeconomic Institute, University of Zurich, Hottingerstrasse 10,
CH-8032 Zurich, Switzerland; email: pzweifel@soi.uzh.ch

Boris Krey

AWK Group, Leutschenbachstrasse 45, Zurich, CH-8050 Switzerland;
email: boris.krey@awk.ch

Sandro Schirillo

Socioeconomic Institute, University of Zurich, Hottingerstrasse 10,
CH-8032 Zurich, Switzerland

Since the fall of the Soviet Union it has been necessary for Russia to form a coalition with at least one of the transit countries Belarus and Ukraine in order to be able to ship gas to western Europe. This paper models the gas transit game using a cooperative module to determine the bargaining power of the three countries. The bargaining power is dependent on the coalition that is achieved. In the non-cooperative module, the three countries involved decide whether or not to cooperate, with Russia using side payments to induce cooperation. On the basis of published demand and cost estimates, the predicted Nash equilibrium is the cooperative one resulting in the grand coalition. Predicted gas quantities correspond quite closely to actual 2004 and forecast 2010 and 2030 figures. The completion of the North Transgas pipeline will benefit Russia, to the detriment of the others, particularly Ukraine.

1 INTRODUCTION

Russia is the most important supplier of gas worldwide, and especially for Europe. When the Soviet Union was in existence, transportation and routing was not an issue, since there was no third party involved. This changed when the Soviet Union collapsed. Newly independent states became indispensable parts of the Eurasian gas chain, causing a dramatic change for Russia. The transit countries Ukraine and Belarus now seek

The authors benefited from comments and criticisms made by participants in the Industrial Economics Group 2008 meeting in Karlsruhe (Germany).

to profit from their geographical location, while Russia wants cheap and reliable transport routes to sell its gas to western Europe. This paper purports to determine the bargaining power of the three countries when negotiating over transit fees, taking account of new projects such as the North Transitgas (NT) pipeline (formerly the North European gas pipeline (NEGP)). However, it also uses estimated payouts to predict which of the possible coalitions will form. Thus, the three countries decide whether to join one of the coalitions or act independently, with important consequences for consumers in western Europe.

An early analysis of the gas supply game was performed by Grais and Zheng (1996), who modeled a Stackelberg game with Russia as the leader and Ukraine and the Czech Republic as followers. A similar approach, with Belarus replacing the Czech Republic as a transit country, was pursued by Hirschhausen *et al* (2005), who developed cooperative and non-cooperative scenarios for different routes. Finally, Hubert and Ikonnikova (2003b) analyzed the strategic behavior of the players, determining their bargaining power as indicated by the Shapley value.

This paper combines the existing approaches by using a cooperative module to determine the bargaining power of Russia, Ukraine and Belarus depending on the coalition in place. It supplements the conventional Shapley value with the more appropriate Banzhaf value to check the robustness of predicted payouts. These payouts then enter the non-cooperative module, where the three players choose whether or not to form a particular coalition. While Ukraine and Belarus decide about the transit fee to be charged, Russia, as the Stackelberg leader, optimizes its gas shipments through the two transit countries and through the NT pipeline starting in 2010. Postdiction¹ for 2004 concerning prices, quantities and profits match actual observations, while predictions for 2010 are in line with those of the International Energy Association (IEA). Forecasts for 2030 suggest that it is not economically worthwhile for Russia to build the Yamal 3 pipeline.

This paper is organized as follows. After a description of the Eurasian gas chain and the objectives of the players in Section 2, the transit game is modeled in Section 3. Bargaining power values for the possible coalitions are derived in the cooperative module of Section 3.1 in order to determine the payouts the players can count on when deciding whether or not to be part of a coalition. These decisions are analyzed in the non-cooperative module of Section 3.2. In Section 4, the data and calibrations are presented, which allow us to determine bargaining power values and conditional payouts for the cooperative module and to predict the coalition that will form in the non-cooperative module using the Nash solution concept. Postdictions for 2004 and predictions for 2010 and 2030 are derived, and players' optimal

¹ We use the term postdiction to refer to "back casting" the past on the basis of information now available. Since the past is known, this can serve as a test for the model we are using.

strategies are explained and justified. Section 5 contains a summary and concluding remarks.

2 THE EURASIAN GAS CHAIN

2.1 Historical development of transport routes

The former Soviet Union began delivering gas to western Europe during the Cold War, completing the first pipeline connection to Austria in 1968 and a second one to West Germany in 1973 (Stern (2005)). At that time, no independent countries stood between the producer and consumers. The Brotherhood pipeline went through Ukraine, which was part of the Soviet Union, to former Czechoslovakia, which was highly dependent on the Soviet Union (Hubert and Ikonnikova (2004)). The Soviet gas industry was a government agency whose actions were driven by politics (Hirschhausen and Engerer (1998)). A new export route in the north, from Belarus through Poland and East Germany, would have been economically viable, but Moscow decided that Czechoslovakia was politically more reliable than Poland.

After the collapse of the Soviet Union, Russia found itself in an unfavorable situation because its only export route to western Europe went through the newly independent states of Ukraine, Slovakia and the Czech Republic, which inherited a quasi-monopolistic position for gas transit. Slovakia and the Czech Republic never capitalized on this fact because they were seeking integration into the European Union (EU) as reliable partners. Their segments of the pipeline were privatized quickly, with the Czech part bought by a consortium of German Ruhrgas, Gaz de France and Russian Gazprom, and the Slovakian part bought by the German company RWE. Ukraine, by contrast, was not a candidate for membership in the EU, permitting it to pursue its objectives independently. It received an in-kind transit fee and cheap gas from Russia. Problems arose when Ukraine started leaving its gas bills unpaid. It was also accused by Russia of stealing gas designated for export to western Europe.

Both Russia and the EU had strong concerns about Ukraine's reliability and looked for alternative transit routes. The northern corridor through Belarus and Poland to Germany seemed to be the solution. Belarus was Russia's close ally, while Poland was vying for integration with the EU. In addition, Gazprom managed to buy into the Polish transit grid EuroPolGaz, on a par with Polish PGNiG. This paved the way for building the massive Yamal–Europe pipeline. While this project was repeatedly scaled down to become Yamal 1 with 18 billion cubic meters per annum (bcm/a) capacity, it contained the option of building a second and third parallel pipeline, Yamal 2 and 3, for a total capacity of 56 bcm/a and 84 bcm/a, respectively (Hirschhausen (2003)).

Increasing frustration with the transit countries led Russia to develop direct export routes. The first to be realized was the Blue Stream pipeline from Russia through

the Black Sea to Turkey, causing Ukraine to lose its transit monopoly on the route to southeastern Europe. Transmission through Blue Stream started in 2003 with 2 bcm/a, and it is scheduled to increase steadily to capacity (16 bcm/a) by 2010 (according to Gazprom²). A direct pipeline between Russia and Germany through the Baltic Sea, called the North Transgas pipeline, is the object of a joint venture between Gazprom (51%) and the German companies BASF (24.5%) and E.ON (24.5%). Construction work started in 2005 on the Russian side, with a planned capacity of 55 bcm/a. The first pipeline is expected to go on stream in 2010, providing 27.5 bcm/a capacity. The remainder of this section is devoted to a description of the players' objectives.

2.2 Russia

Russian and central Asian gas is landlocked and, thus, has to be transported by pipeline over long distances. The biggest gas fields are along the Ural mountains and in western Siberia, thousands of kilometers away from western Europe. Other forms of transport, like liquefied natural gas, compressed natural gas or the conversion of gas into chemical liquids or electricity, are not technically mature. One metric ton of gas occupies more than a thousand times the volume of one ton of oil and is therefore much more difficult and costly to transport (IFP (2002)).

Russian gas production is projected to reach 655 bcm in 2010 and 898 bcm by 2030. Russia will have to develop several new fields to compensate for the production decline of its old giant fields while increasing total production. Russia's neighbors in the Caspian region, mainly Turkmenistan and Kazakhstan, have reserves amounting to some 8 trillion cubic meters (tcm) (8,000 bcm), and these are relatively easy to recover. To prevent them from exporting directly to western Europe, Gazprom bought over 1 trillion cubic meters of this gas under long-term deals, also permitting it to postpone the development of costly Russian fields (IEA (2004)).

Gazprom is the world's largest gas company, responsible for over 90% of Russian gas production and wielding a monopoly for exports. It provides the most important source of governmental revenue, amounting to some 25% of the federal tax budget (Bruce (2005)). Gazprom was privatized in large part, causing it to pursue interests and goals different from those of the government. Former Russian president Putin's government stepped up its share in Gazprom and installed managers loyal to Moscow (Putin's successor Medvedev had previously been chairman of Gazprom's board of directors). Recognizing the importance of the transit routes, Gazprom has striven to achieve control over gas transit assets in Ukraine and Belarus, using unpaid gas bills and the threat of supply cuts to put pressure on the two countries (Bruce (2005)). In spite of this quest for power, Gazprom is hypothesized to pursue the maximization of its profits in this paper.

² URL: www.gazprom.com/eng.

2.3 Ukraine

Until recently, Ukraine has held a quasi-monopolistic position in the forwarding of Russian gas to western Europe, the Balkans and Turkey. During the 1990s, it accounted for more than 95% of Russian gas going to western Europe, with the remainder passing through Belarus and Poland using low-pressure pipelines. Total westward transit capacity of Ukrainian pipelines is estimated at 100 bcm/a and southward capacity is estimated at 40 bcm/a. Russia pays the transit fee in gas rather than money. While Ukraine has been seeking independence from Russia since the fall of the Soviet Union, it is unable to maintain and upgrade its pipelines without financial help from Russia and Western countries. At the same time, it does not want to relinquish control over an essential facility that gives the country some power (Tyshchenko (2002)). In 2004, Russia and Ukraine agreed to increase transit capacity by 19 bcm/a by 2010. On the whole, it is safe to assume that Ukraine tries to maximize profit and, hence, government revenue from gas transit.

2.4 Belarus

After the collapse of the Soviet Union, Belarus maintained strong ties with Russia. Their common historical and cultural heritage suggests that reunification might be possible, but this has not materialized thus far. Like all former Soviet republics, Belarus received energy from Russia at a particularly low price that helped its economy but increased its dependency on Russia. In 2003, Belarus imported 18 bcm of Russian gas at a price of only US\$30/tcm, whereas Ukraine paid US\$50/tcm, and Western importers paid over US\$100/tcm (Bruce (2005)). Belarus has negligible gas reserves, which makes it even more dependent on Russia than Ukraine is (ENI (2005)).

Although Belarus offers the shortest, and therefore cheapest, reliable route to western Europe, problems arose shortly after the opening of the new Yamal 1 pipeline. Belarus sought to increase its revenues from gas transit (Hubert and Ikonnikova (2005)). Moreover, like other transit countries it failed to pay fully for its gas from Russia. Russia and Gazprom tried to take control over the state company Beltransgaz by offering gas debt swaps, but without success. Consequently, Russia lost interest in constructing the additional Yamal pipelines as originally planned. Another project, connecting the Yamal pipeline from Belarus through Poland and Slovakia in order to bypass Ukraine, is even more uncertain (Bruce (2005)). On the whole, assuming that Belarus uses its transit fees to maximize profits and, hence, government revenue seems to be justified.

3 THE MODEL

The crucial assumptions are the following. Firstly, gas is assumed to be a homogeneous commodity, neglecting differences in quality, eg, between Russian and Dutch

natural gas. Secondly, there is no collusion between Russia and other suppliers such as Norway. Thirdly, for the transit countries, Russia is the only purchaser of gas transit services. The market structure is thus a monopsony with very few suppliers of transit service, justifying the assumption of Cournot competition in the case of no cooperation.

The set of risk-neutral players consists of Russia, Ukraine and Belarus, denoted as R, U and B, respectively. The total amount of gas transported from the Russian border to western Europe is denoted by x_T no matter where it comes from. The quantities transported through Ukraine, Belarus and the NT are x_U , x_B and x_N , respectively, such that $x_T = x_U + x_B + x_N$. A linear demand function is assumed, following the lead of other authors (eg, Hirschhausen *et al* (2005)). Western Europe is modeled as an aggregate of passive consumers in spite of EU attempts to organize an import cartel. Thus, its inverse demand function can be written as $p = a(x_T + x_{\text{others}}) + \beta$. In order to focus on gas from Russia, x_{others} is viewed as exogenous. In view of the assumed homogeneity of the product, the inverse demand function for Russian gas can be written as:

$$p = ax_T + b \quad \text{with } a < 0, b = \alpha x_{\text{others}} + \beta > 0, \frac{dx_T}{dp} < 0 \quad (1)$$

Furthermore, let the cost of Russian gas production (including transport to its border) be constant at c_R . The per unit cost of transport is also constant at c_U and c_B , respectively, and c_N through the NT. Since the number of players is taken as predetermined, barriers to entry are not at issue. Therefore, the costs of past and future pipeline construction are taken as sunk and will be neglected.

3.1 The cooperative module

In order to predict which of the possible coalitions will form, players' conditional payouts need to be determined, which presumably depend on their bargaining power. Shapley values are calculated as in Hubert and Ikonnikova (2003b), but with different assumptions and for different years. However, Banzhaf values are deemed more appropriate in the present context (see below). They will also be calculated to check the robustness of predictions. Both values are *ex ante*: predicting payouts before it is known which players will cooperate.

The total number of players is denoted by n , which is equal to 3 in all cases considered here. Coalitions $K \subseteq n$ can be formed with $k \leq n$ players and payouts $v(K)$. Usually, a coalition's payout also depends on the actions of excluded players. This does not apply here because Russia is an essential player, without whom no positive payout can be realized. A coalition comprising Ukraine and Belarus does not form a complete supply chain, since they have no gas production of their own. The

possible coalitions thus are $\{R, U, B\}$, $\{R, U\}$, $\{R, B\}$, $\{U, B\}$ and the case where each player stands alone. The formula for the Shapley value is:

$$\varphi_i(v) = \sum_{i \in K} \frac{(k-1)!(n-k)!}{n!} [v(K) - v(K \setminus \{i\})] \quad (2)$$

This formula shows that each player receives the average of its marginal contributions $v(K) - v(K \setminus \{i\})$, with $v(K \setminus \{i\})$ denoting the payout achieved in player i 's absence. Players join randomly, making the probability of every sequence of players the same. Bargaining power, s_i , is then obtained by calculating the relative contribution of a player (see Section 4):

$$s_i = \frac{\varphi_i(v)}{\sum_{j=1}^n \varphi_j(v)} \quad \text{with} \quad \sum_{i=1}^n s_i(v) = 1 \quad (3)$$

The Banzhaf value Z_i differs from the Shapley value in the following sense. Rather than assigning equal probabilities to sequences of players, it assigns equal probabilities to all possible coalitions. This seems more realistic in the present context, as tense political relations between all players do not favor any specific coalition. The Banzhaf value is thus given by:

$$Z_i(v) = \frac{1}{2^{n-1}} \sum_{i \in K} [v(K) - v(K \setminus \{i\})] \quad (4)$$

Bargaining power, h_i , is calculated by analogy to Equation (3):

$$h_i = \frac{Z_i(v)}{\sum Z_i(v)} \quad (5)$$

Coalitions are assumed to maximize profits in keeping with Section 3, given by:

$$\Pi_K = \sum_{i=1}^k (p - c_i)x_i \quad (6)$$

Optimal quantities of gas have to satisfy the constraints $0 \leq x_U \leq C_U$, $0 \leq x_B \leq C_B$ and $0 \leq x_N \leq C_N$, where, for example, C_U stands for the capacity of Ukrainian transit pipelines.

In the case of the comprehensive coalition $K = \{R, U, B\}$, the maximization problem reads:

$$\begin{aligned} \max_{x_U, x_B, x_N} \Pi_{R,U,B} = & [a(x_U + x_B + x_N) + b - c_R - c_U]x_U \\ & + [a(x_U + x_B + x_N) + b - c_R - c_B]x_B \\ & + [a(x_U + x_B + x_N) + b - c_N]x_N \end{aligned} \quad (7)$$

A coalition with Russia and Ukraine, $K = \{R, U\}$, faces the maximization problem:

$$\max_{x_U, x_N} \Pi_{R,U} = [a(x_U + x_N) + b - c_R - c_U]x_U + [a(x_U + x_N) + b - c_N]x_N \quad (8)$$

The corresponding formula for $K = \{R, B\}$ is:

$$\max_{x_B, x_N} \Pi_{R,B} = [a(x_B + x_N) + b - c_R - c_B]x_B + [a(x_B + x_N) + b - c_N]x_N \quad (9)$$

Russia is the only player that can establish a complete supply chain on its own in the future (beginning 2010). Its profit maximization problem then becomes:

$$\max_{x_N} \Pi_R = [ax_N + b - c_N]x_N \quad (10)$$

The capacity constraints and parameters of the demand functions change over the years, as will be shown in Section 4.

3.2 The non-cooperative module

The objective of this section is to predict the payouts that are available to the several coalitions that may form, to be shared between members according to the cooperative module of Section 3.1. Players can choose whether or not to take part in a given coalition. Thus, a player may not join a coalition but still participate in the game as an independent agent. The game is superadditive with side payments, since coalitions generate more profit than the sum profits attainable on one's own. Side payments are possible because payouts, being in money (or money equivalents of gas), are transferable. The choice variables are the quantities of gas on the different routes (for Russia) and the transit fees (for Ukraine and Belarus). For simplicity, the transit fee is paid by Russia in US\$/tcm rather than in gas.

At the beginning of the year considered, quantities and transit fees are set anew. There is perfect information about cost, demand and bargaining power. With regard to Russia and the cost of the transit countries, this assumption is realistic since Russia built these transit pipelines or was involved in their construction. Therefore, Russia can act as a Stackelberg leader who takes the reaction functions of the transit countries into account. Once the transit fees and gas quantities are set, there is no renegotiation during the current period and all parties fulfill their commitments. The transit fee is the result of negotiations between Russia and the respective player. The responsiveness of Russia's shipments to the transit fee determines the outcome of these negotiations. Ukraine and Belarus, acting as independent, non-cooperative players, have the same type of maximization problem. For Ukraine it reads:

$$\max_{t_U} \Pi_U = (t_U - c_U)x_U \quad (11)$$

The first-order condition (FOC) is:

$$x_U^* + (t_U - c_U) \frac{\partial x_U}{\partial t_U} = 0 \quad (12)$$

because the amount of x_U depends on t_U . In the following, we define $\sigma := \partial x_U / \partial t_U = \partial x_B / \partial t_B < 0$, indicating how strongly Russia can decrease shipments in response to the transit fee. The equality of the two parameters can be justified by noting that the two transit routes terminate not too far apart in western Europe. The response functions of Ukraine and Belarus are therefore:

$$t_U^* = c_U - \frac{x_U}{\sigma} \quad \text{and} \quad t_B^* = c_B - \frac{x_B}{\sigma} \quad (13)$$

respectively.

The years considered are 2004, 2010 and 2030. The different constellations of players are $(R \setminus U \setminus B)$, $(\{R, U\} \setminus B)$, $(\{R, B\} \setminus U)$ and $(R \setminus \{U, B\})$. The grand coalition, $\{R, B, U\}$, is analyzed in Section 3.1.

When deciding about the amount of gas to be exported, Russia has to take the marginal cost of transit along the different routes, MC_U , MC_B and MC_N , into account. While MC_N is constant, given by $MC_N = c_N - c_R \cdot MC_U$, marginal transit cost values MC_U and MC_B vary with x_U and x_B , according to (13). This holds true unless Ukraine (or, respectively, Belarus) is in a coalition with Russia, in which case the transit country charges its marginal cost only. As the data from Section 4 shows, Belarus has the lowest MC for small values of x , with MC increasing in x , however. Thus, Russia is predicted to first use the pipelines through Belarus until $MC_B = MC_U$, then those of Belarus and Ukraine jointly, keeping their marginal costs equal, until $MC_U = MC_B = MC_N$. At that point, Russia shifts to NT with its constant marginal cost. If there should still be unmet demand beyond NT's capacity, Russia presumably distributes the remaining amount between Ukraine and Belarus, again keeping $MC_U = MC_B$. With total shipping cost to Russia given by $T = t_U^* \cdot x_U$, Equation (13) implies that the equality of marginal cost $MC_U = MC_B$ calls for:

$$c_U - \frac{2x_U}{\sigma} = c_B - \frac{2x_B}{\sigma} \quad (14)$$

Therefore, we have:

$$x_U^* = \frac{(c_U - c_B)\sigma + 2x_B}{2} \quad \text{and} \quad x_B^* = \frac{(c_B - c_U)\sigma + 2x_U}{2} \quad (15)$$

In the case where none of the players cooperate, $(R \setminus U \setminus B)$, the profit maximization problem for Russia is:

$$\begin{aligned} \max_{x_U, x_B, x_N} \Pi_R = & [a(x_U + x_B + x_N) + b - c_R - t_U]x_U \\ & + [a(x_U + x_B + x_N) + b - c_R - t_B]x_B \\ & + [a(x_U + x_B + x_N) + b - c_N]x_N \end{aligned} \quad (16)$$

Taking the FOCs of Equation (17) and using Equation (13), one obtains:

$$x_U^* = \frac{c_R + c_U - b - 2ax_B - 2ax_N}{2a + 2/\sigma} \quad (17)$$

$$x_B^* = \frac{c_R + c_B - b - 2ax_B - 2ax_N}{2a + 2/\sigma} \quad (18)$$

$$x_N^* = \frac{c_N - b - 2ax_U - 2ax_B}{2a} \quad (19)$$

In the scenario $(\{R, U\} \setminus B)$, $MC_U = c_U = 5.14$ (see Hirschhausen *et al* (2005)) is constant, since Ukraine, being part of the coalition, does not charge a profit-making transit fee. At the end of the period, Russia will transfer a certain share of its profits as a side payment, the value of which is not yet determined. Thus, Russia's profit maximization problem is:

$$\begin{aligned} \max_{x_U, x_B, x_N} \Pi_{R,U} = & [a(x_U + x_B + x_N) + b - c_R - c_U]x_U \\ & + [a(x_U + x_B + x_N) + b - c_R - t_B]x_B \\ & + [a(x_U + x_B + x_N) + b - c_N]x_N \end{aligned} \quad (20)$$

Determining optimum values remains the same as before. Beyond the point where $MC_B = MC_U = 5.14$ is reached, Ukraine's pipelines will only be used to their capacity limit in view of their constant marginal cost. The FOC of Equation (20) yields the same values for x_B^* and x_N^* as in Equations (18) and (19). The only difference is Ukraine's quantity:

$$x_U^{**} = \frac{c_R + c_U - b - 2ax_B - 2ax_N}{2a} \quad (21)$$

In the case when $(\{R, B\} \setminus U)$, it is Belarus that charges Russia a transit fee $t_B = c_B$. The decision problem for Russia is then:

$$\begin{aligned} \max_{x_U, x_B, x_N} \Pi_{R,B} = & [a(x_U + x_B + x_N) + b - c_R - t_U]x_U \\ & + [a(x_U + x_B + x_N) + b - c_R - c_B]x_B \\ & + [a(x_U + x_B + x_N) + b - c_N]x_N \end{aligned} \quad (22)$$

The transit capacity of Belarus will always be used up to its limit first because its marginal cost is lowest. Remaining demand is met through Ukraine and NT. The FOC of Equation (22) results in Equations (17) and (20) for x_U^{***} and x_N^{***} . For Belarus, we have:

$$x_B^{***} = \frac{c_R + c_B - b - 2ax_U - 2ax_N}{2a} \quad (23)$$

Finally, if the two transit countries form a transit coalition ($R \setminus \{U, B\}$), they charge a uniform transit fee, t_{UB} . In turn, Russia decides on its own about the total amount of transit gas through these countries, $x_{UB} = x_U + x_B$, and the amount of gas through its own NT pipeline. The transit countries then allocate the gas to their pipelines. Knowing marginal costs, the two transit countries use Belarus's pipelines first. The coalition's maximization problem then becomes:

$$\max_{t_{U,B}} \Pi_{U,B} = (t_{UB} - c_U)x_U + (t_{UB} - c_B)x_B \quad (24)$$

By taking the FOC as before, one obtains the new reaction function:

$$t_{UB}^* = \frac{(c_U + c_B)\sigma - x_{UB}}{2\sigma} \quad (25)$$

Russia's maximization problem then becomes:

$$\max_{x_{UB}, x_N} \Pi_R = [a(x_{UB} + x_N) + b - c_R - t_{UB}]x_{UB} + [a(x_{UB} + x_N) + b - c_N]x_N \quad (26)$$

with the FOC given by Equation (19) for x_N^* and:

$$x_{UB}^* = \frac{c_R + (c_U + c_B)/2 - b - 2ax_N}{2a + 1/\sigma} \quad (27)$$

The use of the different pipelines follows the same logic as above, with the capacity of the transit countries used to the point where $MC_{UB} = MC_N$, followed by a shift to NT.

4 DATA AND RESULTS

It is very difficult to obtain consistent and reliable data. Most figures, such as marginal transport cost and the demand function, are based on estimations. Even easily measured quantities such as transit capacities or volumes shipped do not seem to be known exactly in view of the wide range of figures published by analysts as well as the pertinent companies and institutions. In this situation, maximum values were retained. Maximum effective pipeline capacities are presented in Table 1 on the next page. The data for Ukraine refers to the total capacity of routes to western Europe. Foreign investors are assumed to stay out; the increase in capacity between 2004 and 2030 therefore comes from upgrades, ie, replacing old compressors with new ones. The data for Belarus contains the Yamal 1 pipeline (which, as of 2008, has 18 bcm/a capacity) and low-pressure pipelines whose capacity is estimated at a constant 2 bcm/a. Expansion of Yamal 1 to 28 bcm/a can be expected by 2010, resulting in a total of 30 bcm/a. Depending on relationships with Russia, the development of alternative transport routes and western European demand, Yamal 2 and 3 could be

TABLE 1 Maximum westbound transit capacities in bcm/a.

Pipelines	2004	2010	2030
Ukraine	100	120	120
Belarus	20	30	58/86
NT (NEGP)	—	27.5	55

Sources: Hirschhausen *et al* (2005), Opitz and Hirschhausen (2000), NEGP (2006), Hubert and Ikonnikova (2005) and Naftogaz (2006).

accomplished by 2030. At least Yamal 2 is likely to be constructed by 2030 because Belarus is seeking to increase revenue from transit fees. Yamal 3 is also possible, provided foreign investors can be found. Both variants are entered in Table 1. Finally, NT will start in 2010 with a first pipeline. The second one can be expected to be ready by 2030, doubling capacity.

Marginal production and transport costs are taken as constant over time in real terms. On the one hand, development of new gas fields in difficult terrain might drive up marginal cost. On the other hand, technical progress has reduced marginal costs in the past. Estimations are based on the Observatoire Méditerranéen de l'Energie (OME) report (2002), which takes future developments into account. They are $c_R = \text{US\$}12.3/\text{tcm}$, $c_U = \text{US\$}5.14/\text{tcm}$, $c_B = \text{US\$}4.77/\text{tcm}$ and $c_N = \text{US\$}12.3/\text{tcm}$, taken from Hirschhausen *et al* (2005). The demand function shifts outward over time, reflecting the fact that total demand is expected to further increase, while western Europe's own production will decline after the depletion of UK reserves (expected around 2010). The constant parameter over the years is $a = -0.789$ (see Equation (1) again). The outward shifting effect is reflected by an increase of b . Estimates are $b = \text{US\$}141.1/\text{tcm}$ for 2004, $b = \text{US\$}220/\text{tcm}$ for 2010 (which corresponds to the scenario "demand expansion" in Hirschhausen *et al* (2005)) and $b = \text{US\$}260/\text{tcm}$ for 2030, in keeping with a further increase in demand for Russian gas.

4.1 Results for the cooperative module

4.1.1 Postdictions for 2004

To obtain the solution for the comprehensive coalition, Equation (7) has to be maximized. This can be done in a simple, intuitive way, avoiding Kuhn–Tucker conditions. Since the marginal cost of transport through Belarus is lowest, routes through Ukraine will not be used unless Belarus reaches its capacity. Therefore, the first step is to take the FOC of (7) with respect to x_B (assuming $x_U = 0$ for now), which gives:

$$\frac{\partial \Pi_{R,U,B}}{\partial x_B} = 2ax_B + b - c_R - c_B = 0 \quad (28)$$

TABLE 2 Parameter values used in the text.

	Symbol	2004	2010	2030	
				Variant 1	Variant 2
Ukraine capacity (bcm/a)	C_U	100	120	120	120
Belarus capacity (bcm/a)	C_B	20	120	58	86
NT capacity	C_N	—	27.5	55	55
Russia's bargaining power	σ	-11.00	-25.62	-50.32	-51.55
X_B where $MC_B = MC_U = 5.14$	—	2.04	4.74	9.31	9.95
X_B where $MC_B = MC_U = MC_N = 6.24$	—	—	18.83	36.99	37.89
X_U where $MC_B = MC_U = MC_N$	—	—	14.09	27.68	28.35
Russian MC, US\$/tcm	c_R	12.3	12.3	12.3	12.3
Ukraine MC, US\$/tcm	c_B	4.77	4.77	4.77	4.77
Belarus MC, US\$/tcm	c_U	18.54	18.54	18.54	18.54
NT MC, US\$/tcm	c_N	—	—	—	—
Slope of demand function	a	-0.789	-0.789	-0.789	-0.789
Constant of demand function	b	141.1	220.0	260.0	260.0

implying:

$$x_B^* = \frac{c_R + c_B - b}{2a} \quad (29)$$

When inserting the data of Section 4 (see also Table 2) into Equation (29), one finds that $x_B^* > c_B$. Therefore, there is excess demand to be met by Ukraine. Knowing this, one can differentiate Equation (7) with respect to x_U to determine x_U^* :

$$\frac{\partial \Pi_{R,U,B}}{\partial x_U} = 2ax_U + 2ax_B + b - c_R - c_U = 0 \quad (30)$$

implying:

$$x_U^* = \frac{c_R + c_U - b - 2ax_B}{2a} \quad (31)$$

One obtains $x_B^* - c_B = 20$ bcm/a, $x_U^* = 58.365$ bcm/a, $x_T^* = 78.365$ bcm/a, $p^* = \text{US\$}79.27/\text{tcm}$ and $\Pi_{R,U,B} = \text{US\$}4,853$ million.

In the case of $K = \{R, U\}$, differentiation of Equation (8) yields:

$$x_U^{**} = \frac{c_R + c_U - b}{2a} \quad (32)$$

TABLE 3 Marginal contributions, Shapley value and Banzhaf value (2004).

Sequence ρ	MB _R (ρ)	MB _U (ρ)	MB _B (ρ)	Sum (US\$ million)
(R, U, B)	0	4,845	8	4,853
(R, B, U)	0	2,688	2,165	4,853
(U, R, B)	4,845	0	8	4,853
(U, B, R)	4,853	0	0	4,853
(B, R, U)	2,165	2,688	0	4,853
(B, U, R)	4,853	0	0	4,853
Sum (Shapley value after multiplication by $(1/n!)$)	16,716	10,221	2,181	29,118
Bargaining power (Shapley value)	0.574	0.351	0.075	1
Bargaining power (Banzhaf value)	0.561	0.341	0.098	1

The results this time are $x_U^{**} = 78.365$ bcm/a, $p^{**} = \text{US\$}79.27/\text{tcm}$ and $\Pi_{R,U}^{**} = \text{US\$}4,845$ million. Finally, the solution for $K = \{R, B\}$ is:

$$x_B^{***} = \frac{c_R + c_B - b}{2a} \quad (33)$$

In this case, the capacity limit is reached again so that $x_B^{***} = 20$ bcm/a, $p^{***} = \text{US\$}125.32/\text{tcm}$ and $\Pi_{R,B}^{***} = \text{US\$}2,165$ million.

To calculate the Shapley and the Banzhaf values, use is made of Table 3. Here, MB symbolizes the marginal contribution of a player to a coalition in a sequence of accession ρ , which depends on the player's position in the sequence. Bargaining power can then be calculated from Equations (2)–(5). Although the Banzhaf value is deemed more appropriate, it differs little from the Shapley counterpart. Both indicate that Russia dominates the other two countries not only individually but also jointly.

4.1.2 Predictions for 2010

As before, the cheapest alternative will be used up to its limit before using the next one in the order of merit. Thus, for $K = \{R, U, B\}$, Belarus is first, followed by Ukraine and, given demand, by the now available NT pipeline. Using Equations (29) and (31) and plugging in the figures from Table 2 on the preceding page, one can see that the capacity of Belarus is fully used. However, Ukraine's capacity limit is not reached, leaving NT idle. The results are $x_B^* = 30$ bcm/a, $x_U^* = 98.37$ bcm/a, $x_N^* = 0$ bcm/a, $p^* = \text{US\$}118.72/\text{tcm}$ and $\Pi_{R,U,B}^* = \text{US\$}13,012$ million.

In the case when $K = \{R, U\}$, Ukraine's capacity will be used before Russia's own. Inserting the relevant figures into Equation (33) shows that Ukraine's capacity is not sufficient to satisfy demand. Therefore, excess gas has to be transported through the NT pipeline. Its quantity is calculated from:

$$\frac{\partial \Pi_{R,U}}{\partial x_N} = 2ax_N + b - c_N + 2ax_U = 0 \quad (34)$$

implying:

$$x_N^{**} = \frac{c_N - b - 2ax_U}{2a} \quad (35)$$

The results this time are $x_U^{**} = 120$ bcm/a, $x_N^{**} = 7.67$ bcm/a, $p^{**} = \text{US\$}119.27/\text{tcm}$ and $\Pi_{R,U}^{**} = \text{US\$}12,992$ million. The outcome for $K = \{R, B\}$ is calculated in an analogous manner. The capacity of Belarus turns out to be below demand. To calculate the quantity allocated to NT, one forms the pertinent FOC by analogy to Equation (34) to obtain:

$$x_N^{***} = \frac{c_N - b - 2ax_B}{2a} \quad (36)$$

The results show that the NT capacity limit is exceeded as well, and, hence, $x_B^{***} = 30$ bcm/a, $x_N^{***} = 27.5$ bcm/a, $p^{***} = \text{US\$}174.63/\text{tcm}$ and $\Pi_{R,B}^{***} = \text{US\$}9,019$ million.

For Russia alone ($K = \{R\}$), differentiating (10) yields:

$$\frac{\partial \Pi_R}{\partial x_N} = 2ax_N + b - c_N = 0 \quad (37)$$

implying (with superscript $\circ$ denoting "alone"):

$$x_N^{\circ} = \frac{c_N - b}{2a} \quad (38)$$

The outcomes are therefore $x_N^{\circ} = 27.5$ bcm/a, $p^{\circ} = \text{US\$}198.3/\text{tcm}$ and $\Pi_R^{\circ} = \text{US\$}4,943$ million, taking account of the capacity constraint. The values for bargaining power can be calculated as before. The results for 2010 are presented in Table 4 on the next page. As expected, both indicators point to an increase in Russia's bargaining power compared with 2004 (see Table 3 on the facing page), mainly to the detriment of Ukraine.

4.1.3 Predictions for 2030

The calculations are analogous to the ones for the year 2010. Assuming that Belarus completes only the Yamal 2 (variant 1), they are, for $K = \{R, U, B\}$, $x_B^* = 58$ bcm/a, $x_U^* = 95.7$ bcm/a, $x_N^* = 0$ bcm/a, $p^* = \text{US\$}138.72/\text{tcm}$ and $\Pi_{R,U,B}^* = \text{US\$}18,664$

TABLE 4 Bargaining power (2010).

	Russia	Ukraine	Belarus	Sum
Bargaining power (Shapley value)	0.742	0.205	0.053	1
Bargaining power (Banzhaf value)	0.712	0.215	0.073	1

TABLE 5 Bargaining power (2030, variant 1).

	Russia	Ukraine	Belarus	Sum
Bargaining power (Shapley value)	0.849	0.093	0.058	1
Bargaining power (Banzhaf value)	0.808	0.112	0.080	1

million. For $K = \{R, U\}$, one obtains $x_U^{**} = 120$ bcm/a, $x_N^* = 33.02$ bcm/a, $p^{**} = 139.27$ and $\Pi_{R,U}^{**} = \text{US\$}18,606$ million. For $K = \{R, B\}$, the values are $x_B^{***} = 58$ bcm/a, $x_N^{***} = 55$ bcm/a, $p^{***} = \text{US\$}170.84/\text{tcm}$ and $\Pi_{R,B}^{***} = \text{US\$}17,295$ million. Finally, for $K = \{R\}$, one has $x_N^{\circ} = 55$ bcm/a, $p^{\circ} = \text{US\$}216.6/\text{tcm}$ and $\Pi_R^{\circ} = \text{US\$}10,893$ million.

The associated values of bargaining power are displayed in Table 5. Russia's position improves even more than it does in the 2010 prediction, again to the detriment of Ukraine.

Finally, construction of Yamal 3 may be achieved by 2030 as well (variant 2). In this event, for $K = \{R, U, B\}$ the results are $x_B^* = 86$ bcm/a, $x_U^* = 67.7$ bcm/a, $x_N^* = 0$ bcm/a, $p^* = \text{US\$}138.72/\text{tcm}$ and $\Pi_{R,U,B}^* = \text{US\$}18,674$ million. For the case in which $K = \{R, U\}$, we have $x_U^{**} = 120$ bcm/a, $x_N^{**} = 33.02$ bcm/a, $p^{**} = 139.27$ and $\Pi_{R,U}^{**} = \text{US\$}18,606$ million. Coalition $K = \{R, B\}$ yields $x_B^{***} = 86$ bcm/a, $x_N^{***} = 55$ bcm/a, $p^{***} = \text{US\$}148.75/\text{tcm}$ and $\Pi_{R,B}^{***} = \text{US\$}18,486$ million, while, for $K = \{R\}$, one obtains $x_N^{\circ} = 55$ bcm/a, $p^{\circ} = \text{US\$}216.6/\text{tcm}$ and $\Pi_R^{\circ} = \text{US\$}10,893$ million. The resulting bargaining-power values are exhibited in Table 6 on the facing page. Compared with Table 5, the increase in Russia's bargaining power is minimal. Therefore, it is doubtful that Russia will ever build Yamal 3 as well.

4.2 Results for the non-cooperative module

This section is based on the same demand and cost parameters as before; only $\sigma < 0$ defined below Equation (12) is not yet determined. However, the ease with which

TABLE 6 Bargaining power (2030, variant 2).

	Russia	Ukraine	Belarus	Sum
Bargaining power (Shapley value)	0.859	0.072	0.069	1
Bargaining power (Banzhaf value)	0.811	0.096	0.093	1

Russia can switch its shipments between and away from the two transit routes (large σ in absolute value) must be related to bargaining power in the cooperative module, denoted by P . The Banzhaf value is used for P below. It makes sense to require $\sigma \rightarrow -\infty$ for $P_R \rightarrow 1$ (maximum bargaining power for Russia) and $\sigma \rightarrow -1$ for $P_R \rightarrow 0$. Note that the non-cooperative scenario can only arise if $0 < P_R < 1$. If $P_R = 0$, Russia is constrained to cooperate, whereas if $P_R = 1$, it can force the other two countries into cooperation. Hirschhausen *et al* (2005) set σ at -8.13953 for a year when $P_R = 0.5$, with Ukraine as the only transit country. Using this information for calibration, and taking account of the restrictions on extreme values, we obtain:

$$\sigma = \frac{16.56298716^{P_R}}{1 - P_R}(-1) \quad (39)$$

4.2.1 Postdictions for 2004

For the year 2004, according to Equation (39), $\sigma = -11$. Moreover, $x = 0$, since NT does not exist yet. Other parameters and the results for $K = \{R, U, B\}$ are taken from the cooperative module expounded in Section 4.1 (see Table 2 on page 15). The respective formulas from Section 3.2 can be used to calculate the outcomes of the different coalitions. The results are presented in Table 7 on the next page. The postdicted total amount of gas is lower than the actual flows of 2004. This is because the demand function was estimated for earlier years, thereby neglecting the increase in demand that had occurred in the meantime. By shifting the demand function outward, resulting in $b = 192$ in Equation (1), the simulation results could have been made to match actual observations. However, since the main findings are not modified, $b = 141.1$ is retained (see Table 2 on page 15).

As standard economic theory suggests, the largest amount of gas is transported when all players cooperate, avoiding double marginalization along the supply chain. Indeed, both x_U and x_B attain their maximum value while price attains its minimum (see column 5 of Table 7 on the next page). Also, the sum of profits is maximum in the case of the comprehensive coalition (US\$4,853 million annually). Thus, consumers get the maximum amount of gas at the lowest price, while the producer–transporter coalition reaps the highest profit. The opposite situation prevails when every player

TABLE 7 Postdictions for 2004 (annual values).

2004	(R\U\B) (1)	({R, U}\B) (2)	({R, B}\U) (3)	(R\{U, B}) (4)	{R, U, B} (5)
x_U (bcm)	52.33	76.33	52.34	54.21	58.37
x_B (bcm)	20	2.04	20	20	20
x_N (bcm)	—	—	—	—	—
p (US\$/tcm)	84.03	79.27	84.03	82.55	79.27
t_U (US\$/tcm)	9.9	5.14	9.9	8.33	5.14
t_B (US\$/tcm)	6.59	4.96	4.77	8.33	4.77
Π_R (US\$ million)	4,539	—	—	4,595	—
Π_U (US\$ million)	249	—	249	—	—
Π_B (US\$ million)	36	0.5	—	—	—
Π_K (US\$ million)	—	4,846	4,575	244	4,853
$\sum \Pi$ (US\$ million)	4,824	4,846	4,824	4,839	4,853

is on its own and no cooperation is achieved (see column 1). However, differences in total profit are small, suggesting that cooperation is not very lucrative. Moreover, the transit countries make a smaller profit when they form a coalition (compare column 4 with columns 2 and 5 of Table 7). This is a result of the uniform transit fee and Russia's high bargaining power combined with its Stackelberg leader position. A coalition between the transit countries is therefore not predicted. Nash equilibria are displayed in Table 8 on the facing page. The first entry represents the payout to Russia, the second represents the payout to Ukraine and the last one represents the payout to Belarus. The benchmark scenario is where all players choose to be non-cooperative, with payouts {4,539, 249, 36}. Whenever Russia is part of a coalition, it is assumed to receive all of the profit and to pay side payments S_i to its coalition partners, providing an incentive to form the coalition. The value of S_i depends on the player's outside option (associated with not cooperating), which varies with the constellation. The assumption is that any offer, S_i , that exceeds the player's outside option will be accepted and cooperation achieved. If the coalition consists only of the transit countries, Ukraine is assumed to receive the whole profit, ceding a share to Belarus. It could also be the other way round without affecting the final outcome.

Payouts in bold represent the player's best response to the other players' choices. There are three Nash equilibria in pure strategies. Russia and Ukraine would prefer the Nash equilibrium with (c,c,c) because they would get a higher payout than in the (nc,nc,nc) benchmark scenario, whereas Belarus would be better off in the (nc,c,nc)

TABLE 8 Payout matrix and Nash equilibria for 2004.

Russia cooperative			
		Belarus	
		Cooperative (c)	Non-cooperative (nc)
Ukraine	Cooperative (c)	$4,853 - S_U - S_{B1}; S_U; S_{B1}$	$4,846 - S_U; S_U; 0.5$
	Non-cooperative (nc)	$4,575 - S_{B2}; 249; S_{B2}$	4,539; 249; 36
Russia non-cooperative			
		Belarus	
		Cooperative (c)	Non-cooperative (nc)
Ukraine	Cooperative (c)	$4,595; 244 - S_{B2}; S_{B2}$	$4,539; \mathbf{249}; 36$
	Non-cooperative (nc)	4,539; 249; 36	4,539; 249; 36

Payouts in bold represent the player's best response to the other players' choices.

Nash equilibrium. One might argue that Russia, being an essential player with dominating power, can establish the cooperative Nash equilibrium by offering $S_U > 249$ and $S_{B1} > 0.5$. But Belarus could then try to undermine cooperation by offering Ukraine a share of its own profit. However, it could offer a maximum payment of a mere 35.5 ($= 36 - 0.5$) to Ukraine without being worse off itself, while Russia could offer up to 64.5 ($= 4,853 - 249 - 0.5 - 4,539$) for cooperation, thereby always outbidding Belarus. Therefore, the cooperative Nash equilibrium is far more likely to obtain than the non-cooperative one. Still, the fact that Belarus prefers the non-cooperative Nash equilibrium results in a higher effective payment to Ukraine. Russia has to offer $S_U > 284.5$ ($= 249 + 35.5$) to make sure that Ukraine will cooperate and will not be won over by an offer from Belarus. Therefore, Russia's side payments that suffice for establishing the grand coalition are $S_U = 284.5 + \omega$ and $S_{B1} = 0.5 + \omega$, with $S_U + S_{B1} < 314$ ($= 4,853 - 4,539$) to make Russia better off as well, and with $\omega > 0$ a small number.

4.2.2 Predictions for 2010

The total amount of gas shipped in this simulation (some 128 bcm/a; see the sum of the top three rows of Table 9 on the next page) squares quite well with the amount predicted by the IEA (see Section 2.4). However, it is remarkable that the profits

TABLE 9 Predictions for 2010 (annual values).

2010	(R\U\B) (1)	(R, U)\B (2)	(R, B)\U (3)	(R\{U, B}) (4)	{R, U, B} (5)
x_U (bcm)	67.52	120	67.52	68.55	98.37
x_B (bcm)	30	8.19	30	30	
x_N (bcm)	27.5	0	27.5	27.5	0
p (US\$/tcm)	121.36	118.85	121.36	120.55	118.72
t_U (US\$/tcm)	7.78	5.14	7.78	6.88	5.14
t_B (US\$/tcm)	5.94	5.09	4.77	6.88	4.77
Π_R (US\$ million)	12,760	—	—	12,795	—
Π_U (US\$ million)	178	—	178	—	—
Π_B (US\$ million)	35	3	—	—	—
Π_K (US\$ million)	—	13,001	12,795	182	13,012
$\sum \Pi$ (US\$ million)	12,973	13,004	12,973	12,977	13,012

going to Ukraine and Belarus (US\$178 million and US\$35 million, respectively) are lower than in 2004 (US\$249 million and US\$36 million; see Table 8 on the preceding page, column 1), although both countries expanded their transit capacities. This can be explained by the increase in Russia's bargaining power thanks to the completion of the NT pipeline. With its own transport route, Russia changes from being an essential player to a dictatorial one. Russia is clearly the big winner and the transit countries hardly benefit from the increase in demand.

A coalition including Russia and Ukraine is again profitable (see columns 2 and 5 of Table 9), whereas a coalition comprising Russia and Belarus is without extra benefit. Cooperation between Russia and Ukraine produces the second highest total profit, which is intuitive because Ukraine continues to be the lowest-cost provider of most transit capacity.

4.2.3 Predictions for 2030

As mentioned in Section 4.1.3, there are two different scenarios for 2030 (see Table 2 on page 15 for parameter values). As with variant 1 (Yamal 2 only), the quantity of gas derived from the simulation and the IEA forecast are once again quite close. Also, the grand coalition produces the highest total profit and the non-cooperative constellation provides the lowest (see Table 11 on page 24). The profit generated by coalition between Russia and Belarus again exceeds the sum of their non-cooperative profits. In contrast to earlier years, however, the increment does not quite approach

TABLE 10 Payout matrix and Nash equilibria for 2010.

Russia cooperative			
		Belarus	
		Cooperative (c)	Non-cooperative (nc)
Ukraine	Cooperative (c)	$13,012 - S_U - S_{B1}; S_U; S_{B1}$	$13,001 - S_U; S_U; 3$
	Non-cooperative (nc)	$12,795 - S_{B2}; 178; S_{B2}$	12,760; 178; 35
Russia non-cooperative			
		Belarus	
		Cooperative (c)	Non-cooperative (nc)
Ukraine	Cooperative (c)	$12,795; 182 - S_{B2}; S_{B2}$	$12,760; \mathbf{178}; 35$
	Non-cooperative (nc)	12,760; 178; 35	12,760; 178; 35

Payouts in bold represent the player's best response to the other players' choices.

zero (compare columns 1 and 3 with those of Table 7 on page 20 and Table 9 on the facing page) because Belarus has increased its capacity, resulting in cost savings. For this reason, a transit coalition formed by Ukraine and Belarus remains profitable (compare columns 1 and 4). Although Ukraine continues to have the largest capacity, its profit decreases due to Russia's higher degree of independency and consequent bargaining power. As Table 12 on page 25 shows, there are only two Nash equilibria left, namely, the fully cooperative and the fully non-cooperative. The third Nash equilibrium disappears because the transit coalition $K = \{U, B\}$, while profitable, fails to be a Nash equilibrium, since Russia prefers the grand coalition. Indeed, $K = \{R, U, B\}$ gives Russia enough payout to be able to motivate Ukraine and Belarus to cooperate. Whereas no coalition with Russia and only one transit country is more profitable than the grand coalition, the outsider would always want to offer the other transit country a payment sufficient to win it over. However, Russia can outbid the outsider; specifically, the conditions for achieving the grand coalition are $S_{U1} > 39$, $S_{B1} > 57$ and $98 < S_{U1} + S_{B1} < 160$.

For the second variant of the scenario 2030, see again Table 2 on page 15 for parameter values. Table 13 on page 26 shows that total profit is again maximized when all players cooperate (column 5) and is minimized when they fail to do so (column 1). The only difference from variant 1 is an increase in the bargaining power of Russia, which is now in a better position to play the two transit countries off against

TABLE 11 Predictions for 2030, variant 1 (Yamal 2 only).

2030 (variant 1)	(R\U\B) (1)	(R, U)\B (2)	(R, B)\U (3)	(R\{U, B}) (4)	{R, U, B} (5)
x_U (bcm)	44.15	120	39.71	39.6	95.7
x_B (bcm)	53.46	33.11	58	58	58
x_N (bcm)	55	0	55	55	0
p (US\$/tcm)	139.6	139.19	139.51	139.6	138.72
t_U (US\$/tcm)	6.02	5.14	5.93	5.92	5.14
t_B (US\$/tcm)	5.83	5.43	4.77	5.92	4.77
Π_R (US\$ million)	18,505	—	—	18,504	—
Π_U (US\$ million)	39	—	31	—	—
Π_B (US\$ million)	57	22	—	—	—
Π_K (US\$ million)	—	18,633	18,571	98	18,664
$\sum \Pi$ (US\$ million)	18,601	18,655	18,602	18,602	18,664

each other in view of their high spare capacity. In the non-cooperation scenario, these players have slightly lower profits than in variant 1 (see column 1 of Table 11 and Table 13 on page 26). This implies that it is not profitable for Belarus to build Yamal 3 by 2030, provided the other assumptions hold true.

4.2.4 Strategy analysis

As shown in the preceding subsections, the grand coalition is a Nash equilibrium, constituting the dominant solution for rational players under stated assumptions. It is Pareto efficient, since no player can increase its payout without diminishing that of another player. Cooperation is also the dominant strategy in a repeated game provided that the discount rate is zero or the same for all players. Differing discount rates would affect the bargaining power of the players over time, possibly resulting in changed strategies.

As can be seen from Table 8 on page 21 and Table 9 on page 22, the opening of the first NT pipeline by 2010 has an enormous effect on Russia's profit. However, the increase in capacity thanks to the second NT pipeline still brings significant additional payout (see Table 11 and Table 13 on page 26). Thus, Russia's strategy of continuously developing and increasing its own transport capacity is very lucrative. Because in the grand coalition NT is not used at all, a question arises as to whether its construction makes sense. Yet without this addition to capacity, Russia's bargaining power would be decreased. This, in turn, would require higher side payments for establishing the

TABLE 12 Payout matrix and Nash equilibria for 2030 (variant 1).

Russia cooperative			
		Belarus	
		Cooperative (c)	Non-cooperative (nc)
Ukraine	Cooperative (c)	$18,664 - S_{U1} - S_{B1}; S_{U1}; S_{B1}$	$18,633 - S_{U2}; S_{U2}; 22$
	Non-cooperative (nc)	$18,571 - S_{B2}; 31; S_{B2}$	$18,505; 39; 57$
Russia non-cooperative			
		Belarus	
		Cooperative (c)	Non-cooperative (nc)
Ukraine	Cooperative (c)	$18,504; 98 - S_{B2}; S_{B2}$	$18,505; 39; 57$
	Non-cooperative (nc)	$18,505; 39; 57$	$18,505; 39; 57$

Payouts in bold represent the player's best response to the other players' choices.

grand coalition, resulting in reduced profits. Also, it is questionable whether the mere threat of building the NT pipeline would lead to the same outcomes, its credibility being limited in view of long construction times. However, since the construction of the first NT pipeline can probably no longer be stopped, Russia's commitment could be seen to be strong enough to render the threat of adding the second pipeline credible while also allowing Russia to benefit from the associated increase in its bargaining power.

Moreover, it is rational for Russia to encourage Belarus to increase its capacity. The logic is that Belarus has the lowest marginal cost of operation, which determines the transit fee to be charged. This serves to minimize Russia's shipping cost. Another important factor is that an increase in the capacity of Belarus serves to weaken Ukraine's position as the main transit country, at least to a certain point, thereby lowering the value of Ukraine's outside options and making it less costly for Russia to achieve the grand coalition.

Belarus's strategy of continuously increasing its transit capacity results in increased payouts. It is the only way to substantially profit from the gas transit game, combined with offering favorable prospects to foreign investors, who are to finance the projects. Even Russia is interested in an increase of Belarus's capacity and would presumably act in its favor. After all, Yamal 1 was built on Russia's initiative and with its financial

TABLE 13 Predictions for 2030 (variant 2).

2030 (no. 2)	(R\U\B) (1)	(R, U)\B (2)	(R, B)\U (3)	(R\{U, B}) (4)	{R, U, B} (5)
x_U (bcm)	44.05	120	28.35	11.63	67.7
x_B (bcm)	53.58	33.13	86	86	86
x_N (bcm)	55	0	38.66	55	0
p (US\$/tcm)	139.57	139.18	139.27	139.57	138.72
t_U (US\$/tcm)	5.99	5.14	5.63	5.9	5.14
t_B (US\$/tcm)	5.81	5.41	4.77	5.9	4.77
Π_R (US\$ million)	18,507	—	—	18,506	—
Π_U (US\$ million)	38	—	16	—	—
Π_B (US\$ million)	56	21	—	—	—
Π_K (US\$ million)	—	18,633	18,616	106	18,674
$\sum \Pi$ (US\$ million)	18,601	18,654	18,632	18,612	18,674

support. Any extension of capacity by Belarus would mainly cut into Ukraine's profit, adding to the existing tension between the two countries.

5 SUMMARY AND CONCLUSION

The emergence of independent transit countries in the Eurasian gas chain has forced Russia to reassess its options. Specifically, Ukraine and Belarus have been trying to capitalize on their strategic transit position, hiking up transit fees while failing to pay their gas bills. Russia, in turn, is reluctant to pay high transit fees to “its former provinces”. It seeks to attain autarky with regard to its gas transport by means of the NT pipeline and to foreclose competition from Blue Stream by buying up the gas from the Caspian region. This paper analyzes the decision-making process for Russia, Ukraine and Belarus, applying both cooperative and non-cooperative game theory. The cooperative module shows that the building of transport routes under its exclusive control boosts Russia's bargaining power vis-à-vis the two transit countries in all coalitions, enabling it to siphon off future profits from an increasing demand for gas. Using side payments, it is predicted to have the capability of establishing the grand coalition (comprising all the three countries considered). Ukraine turns out to be the biggest loser, with its bargaining power and profits decreasing continuously during the next two decades. It does not have the option of increasing its transit capacity, as the predicted outcome of the non-cooperative module is that this capacity will remain idle while Russia is building the first pipeline of the NT project, at the very least.

TABLE 14 Payout matrix and Nash equilibria for 2030 (variant 2).

		Russia cooperative	
		Belarus	
		Cooperative (c)	Non-cooperative (nc)
Ukraine	Cooperative (c)	$18,674 - S_{U1} - S_{B1}; S_{U1}; S_{B1}$	$18,633 - S_{U2}; S_{U2}; 21$
	Non-cooperative (nc)	$18,616 - S_{B2}; 16; S_{B2}$	$18,507; 38; 56$
		Russia non-cooperative	
		Belarus	
		Cooperative (c)	Non-cooperative (nc)
Ukraine	Cooperative (c)	$18,506; 106 - S_{B2}; S_{B2}$	$18,507; 38; 56$
	Non-cooperative (nc)	$18,507; 38; 56$	$18,507; 38; 56$

Payouts in bold represent the player's best response to the other players' choices.

The only viable alternative for Ukraine is to cooperate, upgrading its pipeline system in order to reduce its marginal cost and to gain a competitive edge over Belarus. In all, the game-theoretic analysis performed in this paper leads to the prediction that Russia will succeed in forging the grand coalition comprising all the three countries analyzed here. The grand coalition is also the only Pareto-efficient Nash equilibrium of the gas transit game, offering maximum payout to each player, with side payments sufficient for its creation and maintenance. Even for consumers in western Europe, the grand coalition is a favorable outcome because it delivers the maximum amount of gas at the lowest price.

A few caveats need to be pointed out, however. Firstly, the analysis performed here is a purely economic one. In reality, the gas transit game also involves geopolitical and military interests. The gas companies are not independent from their governments, and they are often used to pursue political objectives. Secondly, there exist no formal enforcement mechanisms for international contracts. As the experience of 2006 shows, transit countries can breach agreements without having to fear hard sanctions. Indeed, breach of contract constitutes a big threat to all sides of any gas transit agreement, at least until construction of the NT is completed, solving the hold-up problem for Russia. In spite of this threat, gas flows have never been interrupted for a prolonged period of time, which speaks in favor of a certain dominance of economic over political objectives. Indeed, the likelihood of such an interruption is small since Russia can

put enormous pressure on transit countries, who depend on Russia in many ways. Therefore, the economic analysis performed here is useful for understanding the impacts of future developments on the gas chain supplying western Europe.

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