INVESTMENT OPTIONS AND BARGAINING POWER: THE EURASIAN SUPPLY CHAIN FOR NATURAL GAS*

Franz Hubert†

Svetlana Ikonnikova‡

We use cooperative game theory to analyze the power structure in the pipeline network for Russian gas. If the assessment is narrowly focussed on the abilities to obstruct flows in the existing system, the main transit countries, Belarus and Ukraine, appear to be strong. Once investment options are accounted for, Russia achieves clear dominance. Competition between transit countries is of little strategic relevance compared to Russia's direct access to its customers. Comparing our theoretical results with empirical evidence, we find that the Shapley value explains the power of major transit countries better than the core and the nucleolus.

I. INTRODUCTION

Natural gas from the Russian federation covers about a quarter of Western Europe's gas consumption. Over four decades, through cold war, economic collapse, and political turmoil, Russia worked hard to establish a reputation as a secure gas supplier. However, in January 2009, old conflicts with Ukraine about debts, prices for Ukraine's gas imports and transit tariffs escalated to the point where supplies on the major transit route were completely cut off. For two weeks European gas consumers were held hostage in the dispute and in the Balkans parts of the populations faced a humanitarian emergency when heating systems failed.[1] The crisis tainted Russias reputation as a reliable supplier but it also shed light on the powerful position of transit countries in the Eurasian supply chain for natural gas.

*The authors are grateful for comments of seminar participants at Humboldt-Universität zu Berlin, Wissenschaftszentrum Berlin, State University – Higher School of Economics and Cefir in Moscow as well as the annual meetings of the EEA and the EARIE. We also benefited from comments of two referees and technical information on the transportation of natural gas from engineers of Wintershall.

†Authors affiliations: Humboldt–Universität zu Berlin, Spandauer Str. 1, 10178 Berlin, Germany
email: hubert@wiwi.hu-berlin.de

‡Center for Energy Economics, Bureau of Economic Geology, University of Texas at Austin, University Station, Box X, Austin, TX, USA 78713-8924
e-mail: svetlana.ikonnikova@beg.utexas.edu

[1]For details on this and previous transit crises see Pirani *et. al* [2009] and Stern [2006].

In this paper we use cooperative game theory to analyze the power structure in the gas network. We model the interdependencies in the supply chain as a game in value function form, which is calibrated using information on the cost of different pipelines, assumptions on demand, etc. The solution of the game allocates to each country a share in the total profit, which is interpreted as its bargaining power, or power index. Cooperative game theory allows us to derive the power structure endogenously from the architecture of the network without involving specific assumptions about details of the bargaining process, sequencing of moves etc. about which little is known. For cooperative games various solutions have been proposed, none of which acquired dominance either on theoretical or empirical grounds. In this paper we compare three well known solution concepts: the Shapley value, the core, and the nucleolus.

During a crisis, like the January cut-off, observers tend to focus on the immediate impact of actions, such as the obstruction or diversion of flows. From this narrow and shortsighted perspective, the control of existing transport capacities appears to be decisive. The status quo, however, can be changed by adding new pipelines to the existing system. A broad assessment of bargaining power should, therefore, take into account the options to extend the network as well as the time needed to realize new investments. The analysis of power will depend on what is considered to be the relevant *scope* of the game.[2] We vary the scope in two ways. First, we add or withdraw single investment options to study the strategic relevance of particular pipelines.[3] The narrowest possible scope is captured by the 'status quo' game, for which the game's characteristic function (or value function) is derived by allowing for the usage of existing capacities only. At the other end of the spectrum is the 'all options' game, for which the value of a coalition is derived by allowing for optimal investment in all pipelines, which do not cross the territory of outsiders. To focus on the strategic impact of options, however, we initially assume that the projects can be implemented immediately. In a second step we generalize the game by introducing a delay in executing options. Intuitively, the faster additional capacities can be made available, or the more forward looking and patient the players are, the less relevant will be inertia, hence the status quo for the assessment of power in the 'general' game.

Solving the model numerically, we find that the scope of the game is of outmost importance for the assessment of the power structure. Independently of the solution concept employed (Shapley value, core, or nucleolus), Ukraine and Belarus appear to be much stronger in the narrowly framed status quo game than in the broad assessment of the all options game. This observation suggests that delays in implementing options and the players' time preferences

[2]We use the notion *scope* in a similar spirit as Brandenburger and Nalebuff [1997], even though their examples are mainly coined in terms of strategy spaces of players i.e. the non-cooperative framework.

[3]The feasibility of a pipeline project depends on the players' ability to commit to future profit sharing. If contracts are incomplete, the partners will anticipate recontracting (the hold-up problem) and a coalition may fail to invest in otherwise beneficial projects. For a detailed analysis of limited commitment, hold-up, and dynamic strategies see Hubert and Ikonnikova [2004] and Hubert and Suleymanova [2008].

are critical for the determination of the power structure. The choice of the solution concept also matters. The Shapley value assigns much more power to transit countries than the nucleolus, which, for our calibration, happens to be in the center of the core. Looking at the impact of single pipeline options on the Shapley index, we find that plans for new pipelines, which have been deliberately designed to weaken particular transit countries, turn out to have very limited strategic relevance. Similarly, the possibilities to increase capacities along existing tracks do not change the balance of power dramatically. The expensive off shore pipeline through the Baltic Sea, *Nord Stream*, in contrast, strengthens Russia's bargaining position more than all other options together. In a nutshell: in the North-European gas network, competition between Belarus and Ukraine is of little strategic importance compared to Russia's direct access to its customers.

Finally, we confront the theoretical results with empirical evidence obtained from transit arrangements and prices for the transit countries' own gas imports around 2001/2. Such evidence is somewhat speculative because it requires assumptions about a counterfactuals world without gas exports to Western Europe. This caveat notwithstanding, we find that options to invest appear to substantially influence bargaining power, but so does inertia in executing projects. The Shapley value of the general game yields a surprisingly good prediction for the power indices of Ukraine and Belarus. The nucleolus in contrast appears to underestimate the power of the two transit countries. In this sense, the Eurasian gas network provides tentative *non-experimental* evidence for the usefulness of the Shapley value in applied studies of supply chains.

A reader, not particularly interested in gas networks, may read the paper as a case study in applied cooperative game theory. Overall, cooperative game theory is rarely used compared to its non-cooperative counterpart. In the theoretical literature on incomplete contracts the Shapley value is occasionally applied to determine surplus sharing at the final stage of a non-cooperative sequential game. Grossman and Hart [1986], Hart and Moore [1990], and Rajan and Zingales [1998] analyze how non-contractible investment is affected by the assignment of property rights and access to productive resources. Bolton and Scharfstein [1996] investigate how the number of creditors affects the incentives for opportunistic default. Inderst and Wey [2003] analyze how mergers affect the choice of technology in bilateral oligopolies. For stylized theoretical models the Shapley value comes in handy, because it always exist, is unique and can be easily calculated. More recently Brandenburger and Stuart [2007] proposed to analyze strategic decisions by solving the final stage game with the core, which, if it exists, is rarely unique. To resolve the indeterminacy they suggest to use additional assumptions about the players' 'confidence' in their own bargaining power. In this paper, we use the nucleolus to select a unique solution in the core.

While there are some merits in discussing the virtues of the different solutions from a theoretical perspective, eventually, they have to be confronted with real world problems. Following the pioneering work of Shapley and Shubik [1954] cooperative notions made some inroads into political science and cooperate finance as a tool for analyzing the power structure in voting games (Zwiebel [1994], Zingales [1994]). Here it is often sufficient to distinguish between winning and losing coalitions, so that the value function takes only two values, which can be easily calculated by applying voting rules. Shubik [1962] initiated a second line of literature, in which the Shapley value is used to allocate common cost. Applications include internal telephone billing rates (Billera *et al.* [1978]), water infrastructure (Suzuki and Nakayama [1976]), central facilities for profit centers (Young [1985b]), and ATM Networks (Gow and Thomas [1998]). Most of this literature is normative, explaining how cost should be allocated. A notable exception is Littlechild and Thompsen [1977], who find that the pattern of landing fees at Birmingham Airport closely matches cost allocation by the Shapley value but deviates from the nucleolus. Beyond voting games and cost allocation, however, cooperative game theory has rarely been applied to real world problems with the aim to obtain quantitative results. To the best of our knowledge, the present and two companion papers (Hubert and Ikonnikova [2004] and Hubert and Suleymanova [2008]) are the first attempts for a quantitative study of power relations in real world supply chains using cooperative game theory.[4]

The paper also contributes to the literature on transport systems for natural gas. There it is typically assumed that gas producers enjoy a first mover advantage vis-à-vis transit countries or importers, but face severe restrictions in their action space. Producers may determine the price, while importers react by choosing quantities, or they may commit to sales, while transit countries respond by setting transit fee (see e.g Grais and Zheng [1996], Hirschhausen *et al.* [2005]). We see two major shortcomings of this approach. First, the supply chain suffers from inefficiencies in equilibrium, which result from artificial and often counterfactual restrictions on feasible contracts. Real world gas contracts are rather sophisticated and able to avoid most of the inefficiencies assumed in this literature.[5] Second, the results on power and distribution of profits are driven by ad hoc assumptions on the sequencing of decisions. The cooperative approach, in contrast, assumes that the players negotiate efficiently and allows to derive their power endogenously from their role in gas production and transport. Parsons [1989] analyzes the strategic value of long–term gas supply contracts assuming that the producer designs an auction to extract revenue from customers with unknown reservation prices. In the present paper none of the players has an a priori strategic advantage and information is complete.

The rest of the paper is organized as follows. The next section describes the main features of the Eurasian supply system for natural gas. In section III we develop and motivate the analytical approach and calibrate the model. The numerical results are presented and interpreted in section IV. In section V we test the model against empirical evidence. Section VI concludes.

[4]For a review of game theoretic notions in supply chain analysis see Cachon and Netessine [2004]

[5]The European pipeline system was developed under long–term agreements with so called 'take–or–pay' provisions. Contracts stipulate prices *and* quantities to ensure the efficient usage of the capacities and to avoid double marginalization (see Energy Charter Secretariat [2007] for details). Contracts with transit countries also cover tariffs *and* quantities.

II. THE SUPPLY CHAIN FOR RUSSIAN GAS

Gas from the Russian Federation is supplied through a network of pipelines stretching from field in Eastern Siberia and central Asia to Western and Southern Europe. For an illustration of the part, which is relevant for this study, see figure 1. The network's backbone, labeled 'Southern System', was already built in Soviet times. When the Soviet empire disintegrated, Russia emerged as a central player owning most of the gas fields and essential pipelines but it also became depended on three newly independent transit countries, Slovakia, Czech Republic and Ukraine.[6]

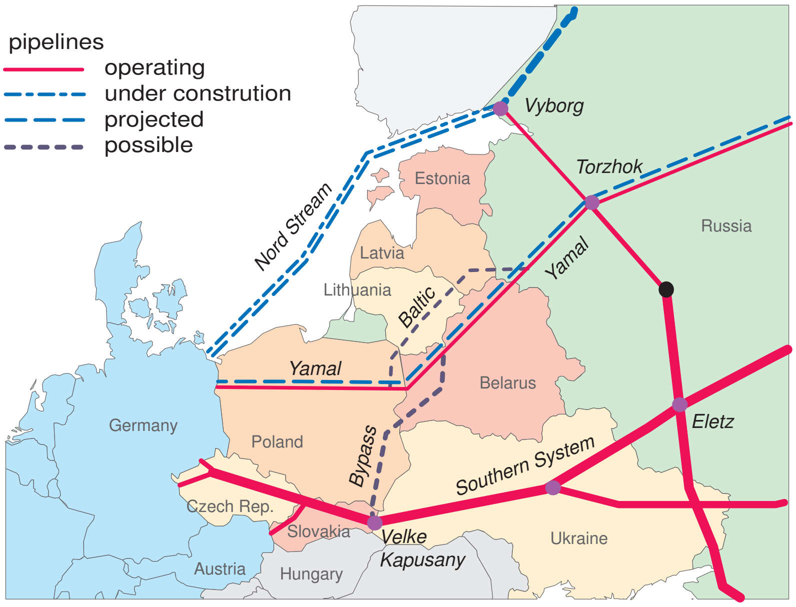
Slovakia and Czech Republic privatized their sections of the pipelines and sold them to western importers. In the following, both countries developed stable commercial gas relations with Russia and transit never became an issue. Ukraine and Russia, in contrast, failed to find a lasting solution for their gas relationship. Ukraine consolidated its pipeline system in a state owned national monopoly, Naftogas, an opaque structure, which is in charge of domestic supply and international transit. Throughout the nineties both sides constantly quarreled over fees for transit service, which were paid in barter (gas), the price for Ukraine's additional gas imports, payment arrears, Ukraine's re-exports of Russian gas etc. In this decade the gas conflict was only a part of the broader problems of disentanglement and was also overshadowed by the collapse of the socialist economic system.[7]

With the economic environment improving and many of the political issues resolved, the two countries made a new attempt to lay down principles for their gas relations in 2001. A number of agreements addressed transit fees, prices and quantities for Ukraine's own gas imports from Russia, and the settlement of controversial debts resulting from payment arrears. In section V we will use these agreements to assess Ukraine's bargaining power empirically. Although the implementation proved to be cumbersome, the two countries went on to tackle problems of maintenance and repairs in summer 2004. A Russian-Ukrainian consortium, RosUkrEnergo, was set up to handle all Ukrainian imports and to operate and refurbish the transit system in co–operation with Western partners. The agreements even raised hopes for a large scale expansion of the Southern system including new pipelines, which would benefit from the established infrastructure. However, Ukraine failed to transfer the pipelines to the consortium, and after the Orange Revolution brought a regime change in December 2004, the other parts of the deals quickly unraveled. On the background of soaring international gas prices and deteriorating bilateral relations, the countries failed to reach an agreement on prices for Ukraine's imports and in January 2006 the Russian curtailed supplies by the amount earmarked for Ukraine's own consumption. When Ukraine syphoned gas from transit pipelines, Russia quickly bowed to pressure from Western importers not to taint its reputation as a reli-

[6]For the ease of reference we often use the names of the countries instead of companies, whenever there is no risk of misunderstanding. Hence we speak of Russia rather than Gazprom, Ukraine instead of Naftogaz etc.

[7]For detailed and balanced accounts of the conflicts see Stern [1999] and Stern [2005].

Figure 1: Transit Options to North-Western Europe



able supplier. But the conflict lingered on and erupted again three years later, leading to the events described in the introduction.

The protracted conflict with Ukraine led Russia to search for alternative transit routes since the early nineties. Initially, efforts were directed to a new export corridor through Belarus and Poland. In 1993 Belarus agreed on a 99–year lease of land for the new pipelines which would be owned by Gazprom and operated by Belarus' national company BelTransGaz. For the section in Poland a joint stock company, EuroPolGaz, was established in which Polish PGNiG and Russian Gazprom hold equal shares. The first pipeline, now commonly referred to as *Yamal 1*, went into operation in 1998. Due to delayed investment in compressor stations it reached its planned capacity of 28 bcm/a only in 2006. The second pipeline, *Yamal 2*, with a potential of another 28 bcm/a, has been already laid at major river crossings, but its completion seems to be very unlikely by now. In the late nineties, Russia also pushed plans for a twin–pipeline with a capacity of 60 bcm/a running north–south through Belarus, Poland and Slovakia. The pipeline, to which we will refer to as *Bypass*, would have used existing capacities in Slovakia and Czech Republic, hence, not increased increased transmission capacities westwards.[8] Apparently, the project has been instru-

[8]To add credibility to the plans, a consortium was set up for the sections in Poland and Slovakia including among others Gazprom (18%), PGNiG (10%), SNAM (29%), Ruhrgas (22%), Gas du France (12%), and Wintershall (5%). Gazprom would have been in charge of the section in Belarus.

mental in preparing the ground for the 2001 deal between Russia and Ukraine and it was shelved shortly afterwards.

By the beginning of the new decade relations between Russia and Belarus had already cooled considerably. Like Ukraine, Belarus leveraged its newly gained strategic position in the export chain to gain concessions for its own gas imports. In April 2002 Gazprom agreed to deliver gas at Russia's domestic price and to swap accumulated payment arrears for a controlling stake in BelTransGaz. However, the second part of the deal, which would have given Gazprom more effective control over its export routes, never materialized. In January 2004 Gazprom stopped deliveries to Belarus because no agreement on prices could be reached. When Belarus started to divert gas from the export pipeline, Russia shut down all supplies through Belarus, deliberately cutting off Poland, Germany, and its own enclave Kaliningrad. The crisis was solved before costumers in the West were affected, but as a consequence Russia redirected its efforts to avoid transit countries altogether.

Plans for a direct offshore connection between Vybourg (Russia) and Germany have been discussed since the late nineties, but Russia's Western partners dragged their feet due to high cost. In late 2005 the project took a surprising turn, when a German–Russian consortium involving E.ON-Ruhrgas, Wintershall, and Gazprom announced the construction of a twin pipeline, later named *Nord Stream*, with a capacity of 60 bcm/a. Preparations for the onshore connection on the Russian side started soon after the announcement, though progress on the essential offshore part was slow. The Baltic states and Poland mustered their influence in the EU to lobby against the project and *Nord Stream* became one of the major obstacles for the development of a common EU energy policy.

In principle, Belarus can also be bypassed onshore through Latvia and Lithuania. We will refer to this option as *Baltic*. Such a pipeline could use existing capacities of *Yamal 1* in Poland and Russia without involving Belarus. With additional capacities in Poland and Russia, it could also be part of a revised *Yamal 2* project.[9]

We conclude the section with a number of observations. First, in marked contrast to the EU-members Poland, Slovakia, and Czech Republic, the non-EU-members Belarus and Ukraine failed to find a stable long-term solution for their gas relations with Russia. Instead they engaged in continuous bargaining over prices and transit fees. Second, in spite of sharp conflicts, interruptions of supply have been rare and, with one notable exception, short lived. In a sense, instantaneous cooperation was largely successful, but attempts to settle for a lasting division of surplus failed. Third, in order to gain leverage over transit countries, Russia has pushed various projects, such as *Yamal*, *Bypass* and lately *Nord Stream*. While the cost of establishing alternative supply routes are well known, the strategic gains are difficult to discern, even by order of magnitude. In the next section we develop a formal model of how network architecture and investment options determine the power of the different players and the sharing

[9]So far, this possibility has attracted little public attention. Only recently, in their attempts to stall progress on *Nord Stream*, the EU members Poland, Latvia, Lithuania, and Estonia proposed a similar pipeline, called Amber, which would also pass through Estonia.

of profits from gas exports.

III. THE MODEL

III (i). *The Analytical Approach*

We represent the interdependencies among the players by a game in value function form (N, v), where N denotes the set of players and the value (or characteristic) function $v : 2^{|N|} \to R_+$ gives the payoff, which a subset of players $S \subseteq N$ can achieve. The value function captures the essential economic and institutional features, such as the geography of the network, different cost of alternative pipelines, demand for gas, production cost, etc. A potential difficulty with the value function approach is that a coalition's payoff may depend on what outside players do. Fortunately, this problem does not arise in our setting, because one player, Russia, is essential in the game. Coalitions, which do not include Russia, cannot form a complete supply chain and, therefore, neither receive any income from exporting gas nor compete with the coalition which includes Russia.

As mentioned in the introduction, we will consider different value functions to reflect various assumptions about the scope of the game. In the 'status quo' game (N, v^s) existing capacities cannot be changed. The value v^s of a coalition depends on its command over existing pipelines. In the 'all options' scenario (N, v^a) a coalition may invest in new pipelines to maximize the net-present value of its profits. Hence the value v^a reflects investment options, the differences in investment cost of various pipelines, capital cost etc. However, we assume that the decision to invest in new capacities becomes effective without delay — as if, investment options were ready for execution at any time. Finally, we consider the general game $(N, \bar{v})$, which also accounts for inertia resulting from delay in implementation. We consider a stationary environment with respect to technology, demand, etc, so that optimal investment is independent of the delay.[10] With this simplification we can approximate $\bar{v}$ as a weighted average of v^s and v^a. Suppose, it takes τ periods before investment can be realized and new capacities become available, which then last forever. During the first τ periods the coalition's payoff will be given by v^s and thereafter by v^a. For a given discount rate r, we calculate the annuity $\bar{v}$ from the present value of this sequence as:

$$\bar{v}/r = \sum_{t=1}^{\tau} \frac{v^s}{(1+r)^t} + \frac{v^a}{r(1+r)^\tau}$$

Rearranging we obtain the value function as a weighted average:

$$\bar{v} = (1-\alpha)v^s + \alpha v^a; \quad \alpha = (1+r)^{-\tau}. \tag{1}$$

[10] Delay is not the same as the time it takes to build a pipeline. Inertia may encompass many other conditions. For example, the decision to built *Nord Stream* was taken end of 2005, but political obstacles prevented the start of construction for a long time.

As τ approaches infinity, inertia becomes overwhelming and we approach the status quo game. As τ approaches zero, inertia disappears and we obtain the all option game. Alternatively, for a given delay, the more forward looking and patient the players are, the smaller will be r, and the more weight will be put on the options.[11]

Cooperative game theory has developed a number of solutions for games in value function form. In the following we emphasize the Shapley value, ϕ_i, $i \in N$, which is the player i's expected contribution to possible coalitions:

$$\phi_i = \sum_{S:i \notin S} P(S) \left[v(S \cup \{i\}) - v(S) \right] \tag{2}$$

where $P(S) = |S|!\,(|N| - |S| - 1)!/|N|!$ is the probability of coalition S. The Shapley value is the only efficient allocation of surplus featuring *symmetry*, the *dummy player property*, and *linearity* (Shapley [1953]).[12] Moreover, it is the unique rule with so called *balanced contributions*: For any two players i and j it is true that i loses as much if j withdrew from the game, as j loses if i withdrew. Hence, if a player objects the Shapley allocation by pointing out the damage he can impose on another player through a boycott of cooperation, his opponent can always counter the argument (Myerson [1980]).

The Shapley value is also supported as the equilibrium of a number of non–cooperative models of structured bargaining processes (the so called 'Nash-program'). Stole and Zwiebel [1996a] and Stole and Zwiebel [1996b] analyze a scenario, which captures structural features of bargaining in the Eurasian gas network particularly well. They show that the Shapley value is the unique equilibrium outcome of a non-cooperative bargain game, if an essential player negotiates bilateral agreements with the others players, which can be renegotiated before any plans are executed.[13] In our case Russia is an essential player, without whom nothing can be achieved and negotiations with transit countries are usually bilateral. As a rule, there are many rounds of negotiations, resulting in letters of intent, preliminary agreements, etc., which will be renegotiated several times before investments and payments are made.

Besides the Shapley value we consider two alternative solutions: the core, which is motivated by the stability of cooperation, and the nucleolus, which emphasizes equality among coalitions. Let ψ with $\sum_{i \in N} \psi_i = v(N)$ denote a vector of feasible and efficient payoffs (an imputation), and $\gamma(S, \psi) = \sum_{i \in S} \psi_i - v(S)$ be the surplus which a coalition receives in excess of its value. The core is given by the set of allocations, which leave no coalition with a negative surplus $\psi^c = \{\psi : \gamma(S, \psi) \geq 0, \forall S \subseteq N\}$. Hence no coalition can possibly make all its

[11]This interpretation implies that players may use different discount rates when assessing power structures and investment projects. We keep the cost of capital used to derive optimal investment constant.

[12]Linearity ensures that $\phi(\bar{v}) = (1 - \alpha)\phi(v^s) + \alpha\phi(v^a)$, i.e. it allows us to calculate the solution of the general game as a weighted average of the two extremes. *Linearity* and *dummy player property* can be replaced with *monotonicity* (Young [1985a]).

[13]For other non–cooperative foundations of the Shapley value see Gul [1989], Evans [1996]), and Inderst and Wey [2001].

members better off by withdrawing from cooperation with the other players. The nucleolus ψ^n maximizes the surplus of those coalitions, whose gains are smallest using a lexicographic order (Schmeidler [1969]).[14] If the core is empty, hence all feasible ψ impose a loss on at least one coalition, the nucleolus minimizes the discontent of the coalitions, which lose most. If the core is not empty, the nucleolus selects an allocation from the core, which can be considered to be the most 'equitable' in terms of coalitions' surplus.[15]

III (ii). *Calibration*

In the following we outline the main steps of the calibration. Details are given in the appendix. Since our focus is on the power structure within the supply chain for Russian gas, we abstract from strategic interaction between Russia and competing suppliers (e.g. Norway, Algeria) or large importers. The main players are *Russia*, *Ukraine*, *Poland*, and *Belarus*. In addition, we include *Slovakia*, *Latvia*, and *Lithuania*, which are involved in attempts to bypass Ukraine or Belarus. Using capital initials of the countries, the set of players is $N = \{R, U, P, B, S, La, Li\}$. As to pipelines, we consider the old system through Ukraine, which we will refer to as *South*, the possibility to upgrade and extend it (referred to as *Upgrade*), the *Yamal 1* pipeline and its possible extension *Yamal 2*, *Bypass*, *Baltic*, and finally *Nord Stream*.[16]

Besides geography, a coalition's command over resources also reflects institutional features. For this reason, we will not consider the sections of the southern system, which are located in Slovakia and Czech Republic. In these countries transit pipelines have been sold to Western gas importers, whose property rights are constitutionally protected. The situation is similar in Poland. The country cannot obstruct the use of the existing pipeline *Yamal 1*. Long term agreements and constitutional rights effectively assure Russia's access.[17] However, we assume that all countries can veto any new pipeline on their territory. Hence, without Poland neither *Baltic* nor *Yamal 2* can be built. Without Slovakia the *Bypass* is unfeasible.

All pipeline options establish a complete link between Russia and its customers, but there are important differences in transportation cost. We estimate transportation cost for each link and obtain a simple hierarchy. By far the cheapest are *Yamal 1* with a capacity of 28 bcm/a and *South* with app. 70 bcm/a, for which investment cost are sunk. Up to a limit of about 15 bcm/a, the cheapest option for creating new capacities is the modernization of the

[14]Schmeidler [1969] defines the nucleolus using the so called excess function e, that is the gain which a coalition can assure by vetoing ψ, hence $e = -\gamma$.

[15]In general, neither the core nor the nucleolus are monotonic (or linear) in the value (Young [1985a]). However, when calibrating the model, we obtain the special case of a 'Big Boss Game' (Muto et. al. [1988]), for which both solutions are linear.

[16]We do not consider the recently proposed *Amber* pipeline because it is not cheaper than *Baltic* and involves an additional player, Estonia. The added complexity would not change our results.

[17]It worth noting that in 2007, Polish courts protected Russian Gazprom against attempts by the owner of the Polish section EuroPolGas (in which Gazprom has a 48% stake) to increase transit rates by a meager 2%.

southern system, *Upgrade*. Beyond that threshold *Yamal 2* comes second, with capital cost, which are at least two times larger. Here investment would benefit from preparations made during the construction of *Yamal 1*. Building new pipelines along the southern track, that is extending *Upgrade* beyond 15 bcm/a, is slightly more expensive than *Yamal 2*. By far the most expensive option is *Nord Stream*, which requires at least another doubling of capital expenditures per unit of capacity. *Bypass* and *Baltic* are special cases. Up to a capacity of 70 bcm/a *Bypass* costs about 20 percent less than *Yamal 2*, but only if *South* is not used. Similarly, up to 28 bcm/a *Baltic* is about 40 percent cheaper than *Yamal 2* provided that *Yamal 1* is not used. Beyond that threshold the costs are comparable to those of *Yamal 2*.

Finally, we have to make assumptions on demand for Russian gas in 'North-Western Europe' and the cost of producing gas and transporting it to Russia's Western border. For simplicity, we take linear specifications for demand and marginal cost of supply and make assumptions for the slope and intercept parameters, which capture the situation in the first years of the new century (for details see the appendix). Most importantly, the parameters have been chosen so that the grand coalition would maximize its profit by using existing capacities at *South* and *Yamal 1* while abstaining from investments in new capacities. Only sub-coalitions, which are restricted in their access to existing pipelines, may want to increase capacities along the tracks, which are under their control.

The main results of the calibration are reported in table 1. The first column shows the smallest coalition necessary to implement the transport network characterized in the next seven columns. The figures indicate for all pipelines available capacity and optimal investment: '-' means that the link is not available to the coalition, by virtue of geography, as in the upper part of the table, or by assumption, as in the lower part; '0' indicates that a link is available, but the coalition chooses not to install capacities. Positive figures indicate usage of existing or investment in new capacities. The last column shows the resulting payoff, or value, of the coalition expressed in per cent of the profit of the grand coalition. We focus on relative payoffs, because they reflect geography and differences in transportation cost, whereas absolute figures are sensitive to our assumptions on demand and cost of production.[18]

On its own, Russia would choose *Nord Stream*, the only option for which it does not need partners, and install a capacity of 72 bcm/a. This would give Russia an annual payoff equivalent to 57% of the profit of the grand coalition. Russia and Ukraine together forego investment in *Nord Stream* and invest in *Upgrade*, the renovation of the existing system *South* instead. By avoiding the large cost of *Nord Stream* this coalition would achieve a relative payoff of 96%. Given that Russia's access to the Polish section of *Yamal 1* is secured, the coalition of Russia and Belarus would use the existing 28 bcm/a of *Yamal 1* and install a capacity of 45 bcm/a at *Nord Stream*, thereby earning a relative value of 72%. If Poland joined that coalition, investment would shift to *Yamal*

[18]Most coalitions, not reported in table 1, either have equivalent investment opportunities, hence equal payoffs, or they cannot establish a complete supply link and have zero profit.

Table 1: Coalitions, Capacities, and Value

coalition	capacity on links [bcm/a]							value
	South	*Upgrade*	*Yamal 1*	*Yamal 2*	*Bypass*	*Baltic*	*Nord Stream*	%
all options (v^a)								
R	-	-	-	-	-	-	72	57
R, U	70	15	-	-	-	-	0	96
R, B	-	-	28	-	-	-	45	72
R, B, P	-	-	28	60	-	-	0	89
R, B, U	70	0	28	-	-	-	0	100
R, B, P, S	-	-	28	0	60	-	0	92
R, P, Li, La	-	-	-	-	-	88	0	85
all players	70	0	28	0	0	0	0	100
status quo (v^s)								
R, U	70	-	-	-	-	-	-	92
R, B	-	-	28	-	-	-	-	51

R: Russia, B: Belarus, P: Poland, U: Ukraine, S: Slovakia, La: Latvia, Li: Lithuania

2, with a capacity of 60 bcm/a, yielding a payoff of 89%. The coalition of the three major players, Russia, Ukraine, and Belarus would achieve the value of the grand coalition simply by using the existing capacities.

Bypass would enable Belarus, Poland, and Slovakia to replace the most important transit country, Ukraine, using existing capacities through Slovakia and Czech Republic. By including Slovakia, the coalition $\{R, B, P\}$ could increase its worth by 4 percentage points to 93%. The difference is modest, but it requires only one additional player. The link through the Baltic countries Latvia and Lithuania consists of two parts: a short pipeline with a capacity of 28 bcm/a, which replaces Belarus in using *Yamal 1*, and a second one with another 60 bcm/a, which is a variant of *Yamal 2*. These investments would enable the coalition $\{R, P, Li, La\}$ to achieve a payoff of 85%. Compared to what Russia can achieve alone, this is an increase by 28 points. The difference is large, but it takes three additional players to achieve it.

IV. THE POWER STRUCTURE

In table 2 we present the players' relative power, calculated from their Shapley values for various assumptions on the scope of the game. We will refer to the figures as shares of profit (in percent), or simply as power index. In the left column of the upper part, under the heading 'status quo', we report the results for the case, in which the existing network cannot be changed. In this situation Russia completely depends on Belarus and Ukraine for transit.[19] The

[19]By assumption Poland cannot obstruct the use of *Yamal 1*, hence, it cannot derive any power from threatening to do so. Our model does not account for the share Poland has secured in negotiations before this pipeline was build.

Table 2: Relative Shapley Value [%]

	status quo[a]	adding one option at a time					
		Upgrade	*Yamal 2*	*Bypass*	*Baltic*	*North*	
Russia	57.1	57.8	60.3	59.2	58.7	79.7	
Ukraine	31.8	32.5	22.2	23.5	29.1	15.1	
Belarus	11.1	9.6	14.3	13.2	7.5	5.2	
Poland	0	0	3.2	2.1	1.6	0	
Slovakia	0	0	0	2.1	0	0	
Lithuania	0	0	0	0	1.6	0	
Latvia	0	0	0	0	1.6	0	
	all options	excluding one option at a time					general game
		Upgrade	*Yamal 2*	*Bypass*	*Baltic*	*North*	
Russia	82.4	81.9	81.9	82.3	82.0	62.6	74.5
Ukraine	10.1	9.5	10.9	10.7	11.0	19.5	16.8
Belarus	4.3	5.0	3.7	4.1	5.3	10.1	6.5
Poland	2.0	2.2	1.5	1.9	1.6	4.8	1.4
Slovakia	0.2	0.2	1.0	0	0.2	0.2	0.2
Lithuania	0.5	0.6	0.5	0.5	0	1.4	0.3
Latvia	0.5	0.6	0.5	0.5	0	1.4	0.3

[a] Capacities are 70 bcm/a at *South* and 28 at *Yamal 1*, which are optimal given our assumptions on transportation cost, demand, and production cost. Figures do not add up due to rounding errors.

two countries compete for transport service, but as capacities are limited, the competition is weak. With 57%, Russia's share is just 7 points above what it would obtain if facing a monopolistic transit country. The unequal shares of Ukraine and Belarus, 32% and 11% respectively, reflect the differences in capacities at *South* and *Yamal 1*.

If we take into account the various possibilities to change the transport grid, the picture changes dramatically. The results for the 'all options' game are in the lower part of table 2. With more than 82%, Russia now obtains the lion's share of the profit. Recall, that, given our assumption on demand and supply, none of the additional investment options would be used. It is the mere possibility to build pipelines through the Baltic Sea, to increase capacities on *Yamal* and on *South*, and to bypass Ukraine and Belarus, that increases Russia's share by more than a quarter of the total payoff. Ukraine's share is slashed by two thirds, from 32% down to 10%. With a loss of almost 7 points Belarus is also hard hit. Poland, in contrast, is strengthened and receives a share of 2%. Latvia and Lithuania as well as Slovakia derive their power from making it possible to bypass Belarus and Ukraine, respectively. Their payoffs are tiny compared to those of the established transit countries. However, given their much smaller population, the benefits are still very substantial. If measured in per capita terms, the benefits of Lithuania and Latvia fall in between those of Poland and Ukraine.

To single out the strategic value of particular options, we look at them in isolation, adding one link at a time to the 'status quo' (see upper part of table 2). Alternatively, we evaluate them in the context of the other options, withdrawing one link at a time from the benchmark case 'all options' (see lower part of table 2). For small additions to the capacity, *Upgrade* is the cheapest option, but its impact on the power structure is small, whether it is evaluated alone or on the background of all other options, because the existing capacities at *South* are already large. If *Yamal 2* were the only possibility to increase capacity, its strategic impact would be substantial. It would cut Ukraine's share by more than 9 points, almost a third of the share in 'status quo'. If seen in the context of the other options, however, *Yamal 2* is of modest relevance. Comparison of the third and the first columns in the lower part of table 2 shows that Russia, Belarus, and Poland each gains half a percentage point, while Ukraine and Slovakia lose. Slovakia's loss indicates that the strategic value of *Yamal 2* is related to *Bypass*, the only pipeline which involves this country. Like *Yamal 2*, *Bypass* looks important only in isolation. Assessed in the context of all other options, its impact on Russia is negligible and Slovakia gains little. This is due to the fact that all coalitions, which can realize *Bypass*, can also realize *Yamal 2*, which is just marginally less profitable. *Nord Stream*, though the most expensive option, has the strongest impact on the power structure. In isolation, it raises Russia's index from 57% to almost 80%. Even when assessed on the background of all other options, *Nord Stream* pushes Russia's share from nearly 63% up to more than 82%. Hence, the direct access is more important than all other options together.

How do geography and cost interact in determining bargaining power? To develop the intuition, we focus on the four main countries, Russia, Belarus, Poland and Ukraine. Suppose that all pipelines had equal cost, so that total profit would be the same, whatever connection is used. If the only possible transport route were through Ukraine, then Russia and Ukraine would share 1/2 : 1/2. If we add an equally efficient route through Belarus and Poland, Russia would obtain 7/12 of the profit, Ukraine 1/4, and Belarus and Poland would share the rest equally, obtaining 1/12 each.[20] Ukraine suffers a lot from the competing route, but Russia has to share the gain with the two transit countries. Finally, if we allow Russia to establish a direct offshore link on its own, it can capture the whole profit, as there is no need to cooperate with anyone.

Now, assume that all options are available, but pipelines differ in their cost, either because of different conditions (offshore vs. onshore) or because investment costs are already sunk. Loosely speaking, Russia would start with the profit, obtained if the expensive direct link were the only possible connection to Western Europe. While *Nord Stream* looks inefficient in comparison to the other options, standing alone, it would be a highly profitable project. Given our calibration, it already yields 57% of the profit of the most efficient trans-

[20] With payoffs normalized to one, the value function would be: $v(\{R, B, P\}) = v(\{R, U\}) = v(\{R, P, U\}) = v(\{R, B, U\}) = v(\{R, B, P, U\}) = 1$ and zero in all other cases, yielding Shapley values of $\phi_R = 7/12$, $\phi_B = \phi_P = 1/12$, and $\phi_U = 1/4$.

portation network. In addition, Russia receives 7/12 of the increase in profit obtained by switching from the offshore to the cheaper onshore option, *Yamal*. Finally, Russia would enjoy 1/2 of the increment achieved by using the most efficient solution, which includes the system in the south. Summing up we obtain $\phi_R = v(\{R\}) + \frac{7}{12}(v(\{R,B,P\}) - v(\{R\})) + \frac{1}{2}(v(\{R,B,P,U\}) - v(\{R,B,P\}))$, which yields a share of 81% when evaluated using the figures from table 1. This result is close to the figure from the more complex model reported in table 2. Enriching the analysis with more players and pipeline options makes the model more realistic, but the quantitative results change only marginally.

Finally, we consider the role of inertia and impatience. Being linear in the value function, the Shapley value of the general game it is easily computed using the weights from equation (1). It may take from two to six years from the decision to invest until capacities become available. Unfortunately, we have little clues as to the discount rates countries use to evaluate international negotiations, but a range of 5 % to 15 % should be a reasonable guess. We use four years and 10 % for our baseline case, reported in in the last column of the lower panel of table 2. Not surprisingly, delay reduces Russia's power index and increases the power of those countries, which can disrupt the flow in the existing network. We made a number of robustness tests, some of which are reported in a separate appendix, available in the online version. Overall the Shapley values are reasonably robust with respect to our assumptions on demand and cost. However, given the large discrepancy between the power indices for status quo and the all options games, somewhat speculative assumptions on delay in the exercise of options and the discount rate applied in international negotiations have a strong impact on the results.

IV (i). *Other Solutions: Core and Nucleolus*

Our calibration simplifies the calculation of the core and the nucleolus considerably. The geography of the transport network (figure 1) implies that some transit countries are complementary, eg. Poland and Belarus with respect to *Yamal*, while others are substitutes, e.g. Belarus and Ukraine with pipelines *Yamal* and *South*, respectively. Hence, the joint contribution $v(S) - v(S\backslash M)$ of a subset transit countries M to a coalition S, may be smaller (complements) or larger (substitutes) than the sum of their individual contributions $\sum_{i \in M}(v(S) - v(S\backslash\{i\}))$. However, with our calibration Poland's contribution to the grand coalition N is zero: (i) it cannot obstruct the use of the existing capacities at *Yamal 1* for institutional reasons, and (ii) the grand coalition would not like to invest in *Yamal 2* for lack of demand. As a result, the joint contribution of Poland and Belarus equals Belarus' contribution, which makes them *weak* substitutes with respect to the grand coalition. By similar reasoning it can be shown that $v(N) - v(N\backslash M) \geq \sum_{i \in M}(v(N) - v(N\backslash\{i\}))$ forall $M \subseteq N\backslash\{R\}$, so that the games (N, v^s), (N, v^a) are 'Big Boss Games' as defined in Muto et. al. [1988]. For this class of games, both solutions are linear in the value. More specifically, the nucleolus is in the very center of the core and gives every non-essential player exactly half of his marginal contribution to the

Table 3: Core ψ^c, Nucleolus ψ^n, and Shapley Value ϕ

	status quo			all options			general		
	ψ^c min-max	ψ^n	ϕ	ψ^c min-max	ψ^n	ϕ	ψ^c min-max	ψ^n	ϕ
Russia	43 - 100	71.5	57	88 - 100	94	82	75 - 100	87.5	74.5
Ukraine	0 - 49	24.5	32	0 - 8	4	10	0 - 20	10	16.8
Belarus	0 - 8	4	11	0 - 4	2	4	0 - 5	2.5	6.5
Poland	0 - 0	0	0	0 - 0	0	2	0 - 0	0	1.4
others	0 - 0	0	0	0 - 0	0	1	0 - 0	0	0.8
	$v^s(\{R,U\}) = 92$ $v^s(\{R,B\}) = 51$			$v^a(\{R,U\}) = 96$ $v^a(\{R,B,P,S\}) = 92$			$\bar{v}(\{R,U\}) \approx 95$ $\bar{v}(\{R,B,P,S\}) \approx 80$		

Grand coalition $\psi_i^n = (v(N) - v(N\backslash\{i\}))/2$.

How does the Shapley value compares to other possible solutions? In table 3 we report the range of possible values in the core, ψ^c, the nucleolus ψ^n, and, for ease of comparison, again the Shapley value ϕ for all three games. Both, the nucleolus and the core will allocate all the power to Russia, Belarus, and Ukraine, and none to any other players. The core and the nucleolus depend on the values of the coalitions $\{R, U\}$ and $\{R, B, P, S\}$.[21] Neither coalition would invest in *Nord Stream* or *Yamal 2* (see table 1). As a result these two pipelines would be strategically irrelevant if bargaining power were determined by the core or the nucleolus. Since $\{R, U\}$ invests in *Upgrade* and $\{R, B, P, S\}$ in *Bypass*, exactly those options, which carry little strategic weight under the Shapley value, turn out to be decisive for the nucleolus and the core.

For all three solutions there is a consistent pattern across games. As we move from status quo to all options, Russia's share increases, while those of Ukraine and Belarus decline. But the focus on different coalitions and their options has a large impact for the predicted power index. The essential player Russia appears much stronger when assessed with the nucleolus. In the general game, the difference between the nucleolus (or the center of the core) and the Shapley value is almost 13 points and of a similar magnitude in the other games.

[21] We briefly explain the steps for the all option game, (v^a, N). Russia, Belarus, and Ukraine together can achieve the full payoff, $v(\{R, B, U\}) = 100$, while the others achieve nothing, $v(S) = 0$ for $S \subseteq N\backslash\{R, B, U\}$, hence, $\psi_i^c = \psi_i^n = 0$ for $i \in N\backslash\{R, B, U\}$. Second, from $v(\{R, U\}) = 96$, we obtain the maximum, which the core can possibly assign to Belarus, $\psi_B^c \leq 4$. The nucleolus splits this gain evenly among the coalitions $\{R, U\}$ and $\{B\}$, hence $\psi_B^n = 2$. Third, from $v(\{R, B, P, S\}) = 92$, the highest value for a coalition not including Ukraine, we obtain $\psi_U^c \leq 8$. Again, by even split Ukraine receives $\psi_U^n = 4$, which leaves Russia with $\psi_R^n = 94$. The nucleolus of the game (v^a, N) features the following lexicographical order of coalitions with respect to their surplus $\gamma(S, \psi^n) = \sum_{i \in S} \psi_i^n - v(S)$:

1. $\gamma(\{R, B, U\}) = \gamma(\{P\}) = \gamma(\{S\}) = \gamma(\{Li\}) = \gamma(\{La\}) = 0$;
2. $\gamma(\{R, U\}) = \gamma(\{B\}) = 2$;
3. $\gamma(\{R, B, P, S\}) = \gamma(\{U\}) = 4$;
4. $\gamma(\{B, U\}) = 6$;
5. $\gamma(\{R, B, P\}) = 7$;
6. $\gamma(\{R, P, Li, La\}) = 9$;
7. $\gamma(\{R\}) = 37$

Finally, if the whole profit is allocated to Russia, no subset of players can veto this allocation, because Russia is an essential player in this game, hence, $\psi_R^c \in [88, 100]$.

Russia's strength is mirrored by the weakness of Belarus and Ukraine, whose power indices are reduced from 6.5 and 16.8, respectively, when assessed with the Shapley value down to 2.5 and 10, when assessed with the nucleolus.

V. EMPIRICAL EVIDENCE

The theoretical analysis of the previous section revealed that the analysis of the power structure depends critically on (i) how we account for investment options and the delay in their implementation and (ii) the choice of the solution concept (nucleolus, core, and Shapley value). Compared to these determinants, assumptions on the parameters of demand, cost etc. are of minor importance. In this section we make an attempt to provide empirical evidence on these issues. In particular we ask: (i) whether the empirical power structure is mainly derived from the control of existing pipelines or whether it also reflects options to change the system, and (ii) which solution gives a better prediction.

We start by estimating how the countries shared the gains from gas exports in real world bargaining around 2001/2. For practical reasons we confine the analysis to the most important transit countries, Ukraine and Belarus. This evidence is then contrasted with the theoretical predictions. Unfortunately, empirical evidence in a strict sense would require observations from a world with and a world without gas exports to Western Europe. As we have only the former, our empirical evidence depends on assumptions about counterfactuals, some of which involve a substantial degree of judgement.

We base our assessment only on measurable *economic* benefits. This approach would be misleading, if Russia pursued political goals by granting favorable gas deals. In our opinion, this is not very likely for the time and the countries in question. By 2001/2, the Putin administration had adopted a rather sober and commercial attitude towards the major transit countries (for similar views see Stern [2005], Bruce [2005]). Previous attempts to pull the neighbors closer, either in the framework of CIS or bilaterally, had failed to yield discernible results. In particular, several plans to establish a monetary or even political union with Belarus never went beyond the stage of declarations. There was also little move in the opposite direction. Neither the Lukashenko regime in Minsk nor the Kuchma government in Kiev showed ambitions towards closer cooperation with EU or NATO, what might have produced concerns in Moscow. Thus, for the first years of the decade we do not see the kind of political concessions on the part of Belarus or Ukraine, which could have motivated Russia to forego substantial economic benefits.

V (i). *Data and Estimation*

We consider two types of economic benefits, which the transit countries obtain from their strategic position in the transport network: explicit payments for transit services either in cash or barter, and price discounts for the transit countries' own gas imports. As described in section II, negotiations about import prices have always been intermingled with transit issues. Price discounts, which are related to the strategic position in the gas network have to be added to direct transit fees to obtain a comprehensive measure of benefits. In order to quantify the value of price discounts, we have to chose an appropriate benchmark price, the import price for gas, which would be paid in the absence of gas transit. To calculate a power index all benefits have to be measured on a common scale. Since the gas, which Ukraine receives explicitly for its transit service is by far the largest single item in our calculation, it is convenient to convert all figures into gas equivalents at the assumed benchmark price. Formally we calculate a transit country's share as $(F_i + D_i)/(T_i + F_U + D_U + F_B + D_B - C)$, $i \in \{U, B\}$, with F: transit fee, D: benefit from price discount, T: relevant total transit volume, C: cost, and the subscripts referring to Ukraine and Belarus, respectively. We base our estimation on the transit and gas agreements of the years 2001 and 2002 and the subsequent developments, which are documented in Bruce [2005], and Stern [2005].[22]

Explicit compensations. Following the agreement of 2001 Ukraine received an average 25 bcm/a of gas as an explicit compensation for its transit service during 2001-2005. For Belarus the intergovernmental agreement of 2002 set a fee of $ 0.46 per tcm/100km for transit to Western Europe through Yamal and $ 0.53 per tcm/100km for transit to Poland through Northern Lights (Yafimava and Stern [2007]). From export volumes of 18 bcm/a and 8 bcm/a and a distance of 575 km, we estimate the annual revenue of Belarus at app. $ 72 mln/a, which will be converted to gas equivalents below.

Price discounts. As to the appropriate benchmark price we consider two variants. The lower bound is given by the price, which Itera and other independent suppliers charged in 2001 for deliveries to CIS countries, approximately 40 $/tcm. Arguably, this benchmark is too low, because gas from independent Russian companies or central Asia used to be cheaper, exactly because Gazprom prevented it from being sold anywhere except to selected CIS countries. We use 60 $/tcm as an upper bound for the benchmark price in 2001. We do not consider European prices as a relevant benchmark, as these are indexed prices for gas delivered under long term contracts and reflect to a large extent the recent hikes in oil prices. It is unlikely that Ukraine and Belarus had settled for European prices in the absence of gas exports. For example Latvia and Lithuania paid Gazprom around 50 $/tcm in late 2001, more than Ukraine and Belarus, but a far cry from European prices of 100 – 120 $/tcm.

The agreement of the year 2001 entitled Ukraine to 30 bcm/a of gas shipments through Russian pipelines in excess to those which where used as a transit fee. Since Russia officially insisted on Western prices for its own gas, Ukraine attempted to secure supplies from central Asia, mainly Turkmenistan — paying prices around 40 $/tcm.[23] For the low benchmark we find no price discount

[22] The agreements contain debt settlements, which originate from payment arrears carried over from the nineties. They also include provisions for strengthening Gazprom's control over pipelines in the transit countries, which failed to materialize afterwards. We ignore both aspects in our evaluation.

[23] Unfortunately, we cannot reconstruct the exact amounts and prices from the meager information on these deals. Apparently, Russia continued to deliver gas even when Ukraine

Table 4: Estimated Sharing of Profit in 2001/2

	explicit compensation for transit only		incl. discounts on imported gas	
	low price	high price	low price	high price
	absolute benefits in gas equivalents [bcm/a]			
Ukraine	25.0	25.0	25.0	35.0
Belarus	1.8	1.2	5.9	7.4
	relative shares in total gas volume [%] [a]			
	not accounting for cost			
Ukraine	13.9	14.0	13.6	17.9
Belarus	1.4	1.0	4.5	5.2
	medium cost (worth 1/5 of the gas)			
Ukraine	17.4	17.5	17.0	22.4
Belarus	1.8	1.2	5.7	6.5
	high cost (worth 1/3 of the gas)			
Ukraine	20.9	21.0	20.4	26.9
Belarus	2.1	1.4	6.8	7.8

[a] The total volume is obtained by adding the gas equivalent of the benefits to the base quantity, which is 153 bcm/a in case of Ukraine and 100 bcm/a in case of Belarus.

for Ukraine. However, for the upper benchmark of 60 \$/tcm we obtain a cash benefit worth \$ 600 mln/a (20 \$/tcm $\times$ 30 bcm/a), which converts into a gas equivalent of 10 bcm/a.

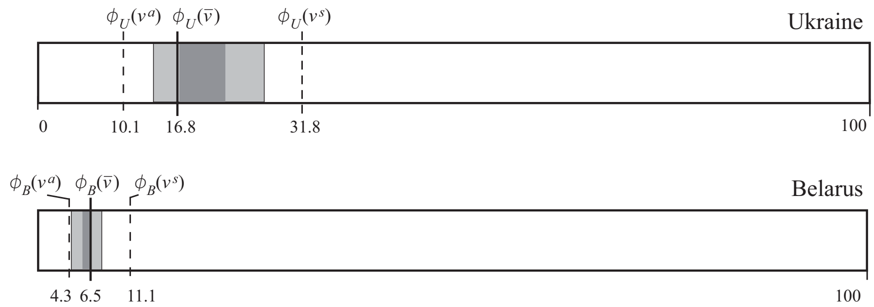
For Belarus the agreement of 2002 stated that it would receive 10.3 bcm/a at Russia's internal price. Standing at app. 24 \$/tcm, the internal price implied a very substantial discount compared to the price of independent suppliers.[24] Even for the low benchmark the benefit was worth a gas equivalent of 4.1 bcm/a, which has to be added to the 1.8 bcm/a gas equivalent of direct transit fees (\$ 72 mln/a). For the high benchmark price of 60\$/tcm the equivalent of the price discount increases to 6.2 bcm/a but we obtain a lower gas equivalent of 1.2 bcm/a for cash transit fees. The results are given in the upper part of table 4.

Shares. As the next step we relate the benefits to the total amount of gas, which is composed of gas exports and gas used to compensate for transit. During 2001-2005 the average volume of total transit through Belarus and Ukraine amounted to 153 bcm/a (Stern [2005], p. 86). This figure includes transits to Eastern and Southern Europe and is larger than exports to the Northwest of Europe on which the theoretical model is built. Since we cannot separate the compensation, which Ukraine received for transit to countries such as Romania, Bulgaria, we have to use this figure as a basis for comparison. For Belarus, how-

failed to secure sufficient quantities in direct deals, without receiving European prices for these shipments. In the end, Ukraine obtained about 30 bcm/a paying approximately the lower benchmark price (for details see Stern [2005] and Stern [2006]).

[24] In the following Russia's internal prices steadily increased, but the prices of independent suppliers rose even faster. So by 2003 the figures were closer to 30 \$/tcm and 50 \$/tcm, respectively (Stern [2005]).

Figure 2: Empirical Shares and Theoretical Predictions based on Shapley Value



ever, we use only exports to Western Europe including Poland, app. 100 bcm/a. In both cases we add the gas equivalent of the benefits to obtain the overall amount of gas to be shared. Note that the latter depends on the benchmark price used for converting cash benefits into gas equivalents.

As the last step, we account for the cost of supplying gas to Europe, which are borne by Russia only. A fraction of the gas is used in compressor stations. Depending on the distance and the pipelines the loss will range from 10% to 15% of the gas supplied. Measuring and converting other operating cost into gas equivalents is difficult. Again we make a bold assumption and consider two variants with gas equivalents of one fifth and one third. The results are given in the lower part of table 4.

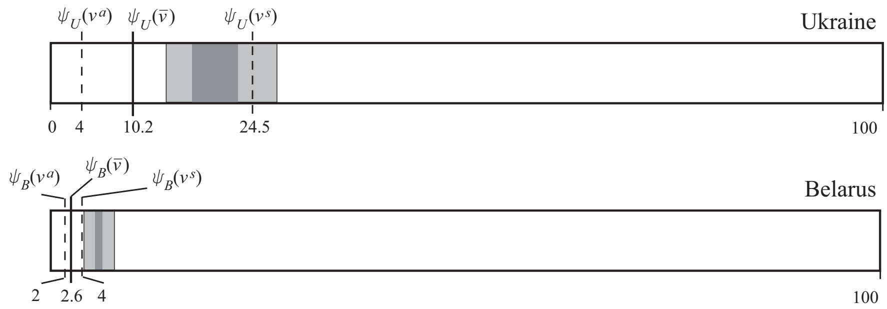
The estimation of surplus sharing from empirical data involves as much judgement as the calibration of the theoretical model. As the benchmark price or Russia's cost increases, the estimated shares of the two major transit countries increase. We choose the medium cost variant as our most reasonable guess. That leaves us with an estimated share for Ukraine in the range of 17.0 – 22.4, depending on the benchmark price. For Belarus we obtain a range of 5.7 – 6.5, of which less than one third can be attributed to direct transit fees and the rest to price discounts.

V (ii). *Comparison with Theoretical Results*

To facilitate the argument we illustrate the power indices in figure 2. The lightly shaded areas indicate the maximal range of our empirical estimates. The lower bounds are obtained from the zero cost / low price scenario from table 4 and the upper bounds from the high cost / high price scenario. The darkly shaded areas indicate what we consider as our most reasonable empirical estimate.

First, we compare the empirical results with the range spanned by the Shapley values of the all-options and the status-quo game, $\phi(v^a)$ and $\phi(v^s)$, respectively. For Ukraine, these are 10.1 and 31.8 (see table 2). As can be seen from figure 2 (or by comparison with table 4), our empirical estimates fall within the

Figure 3: Empirical Shares and Theoretical Predictions based on the Nucleolus



boundaries. Even the upper bound of the empirical estimation is smaller than what Ukraine could expect under status quo bargaining. On the other side, even the smallest figure in the empirical range is larger than the Shapley value of the all option game. This observation leads us to the conclusion that options do matter, but so does inertia. In case of Belarus the Shapley indices are 4.3 and 11.1. Again, our empirical estimations in the range of 5.7 – 6.5 are well within the limits.

Second, we ask whether the Shapley value $\phi(\bar{v})$ of the calibrated general game matches the empirical estimates well. In the baseline variant (see table 2), the Shapley indices were 6.5 and 16.8 for Belarus and Ukraine, respectively. As illustrated in figure 2 both are well within the corresponding empirical ranges. However, in case of Ukraine the theoretical prediction is just at the lower bound of the range, which we consider as most plausible empirical estimate, while in case of Belarus it is at the upper bound. Ukraine appears to be somewhat stronger in 'real life' than in our theoretical baseline model, while the opposite is true for Belarus.

We suggest two reasons for this minor divergence. The first is related to the calibration of the theoretical model. Here we assumed that *Yamal 1* is available with its planned capacity of 28 bcm/a. The pipeline went into operation in 1998 but due to slow installment of compressors it reached full capacity only in 2006. In 2001/2002, when the deals were made, from which we obtained our empirical estimates, the capacity was closer to 18–20 bcm/a. For this reason, our theoretical model is slightly biased towards underestimating the power of Ukraine and overestimating the power of Belarus. The second is related to our focus on exports to North-Western Europe. This area can be reached by all pipeline options, which we took into consideration, but it accounts only for two thirds of the total exports delivered through the Ukrainian network. For destinations in central and South-Eastern Europe, such as Hungary, Serbia, Romania, and Bulgaria it is more difficult to avoid transit through Ukraine.

As can be seen from figure 3, theoretical predictions based on the nucleolus tend to underestimate the power of transit countries. In the case of Belarus, the whole range spanned by the all options and the status quo game is below the lower bound of our empirical values. For Ukraine, only the status quo game yields a prediction, which matches empirical estimates well. In defense of the nucleolus one might argue that the players in the Eurasian gas supply chain were guided by a short-term assessment of bargaining power. The agreements of 2001/2 had be shaped by the power to obstruct and divert flows in the existing system. However, contrary to the events some years later, there is no evidence that threats to cut flows played a role in the negotiations at that time. Quite to the contrary, the discussions clearly centered on investment plans both for alternative pipelines and for improving existing ones. In particular, shelving the plans for *Bypass*, was one of the concessions Russia made to Ukraine.

Finally, we turn to the core to shed some light on the stability of cooperation. From comparing the figures from tables 3 and 4 follows that our empirical estimates are somewhat large to be safely in the core of the general game. The core would allocate a maximum of 20 to Ukraine and 5 to Belarus, which leaves a large part, in case of Belarus even all, of our most reasonable range outside. This fact may explain, why Russia, Ukraine, and Belarus found it so difficult to settle for a lasting long-term solution of the gas transit issues in the past. The observed shares of Ukraine and Belarus are too large to be firmly established in a stable long-term arrangement. At the same time the whole range of empirical estimates is well within the core of the status quo game, for which the upper limits are 49 and 8, for Ukraine and Belarus, respectively. No coalition can unilaterally improve over the currently observed profit sharing by exploiting its short-term potential to obstruct flows in the existing system.

VI. CONCLUSIONS

In this paper we used cooperative game theory to develop and calibrate a model of bargaining power in the supply chain for Russian gas. The power structure thus obtained reflects in an intuitive way the architecture of the current system, the cost of various options for its extension, and the delays in bringing about a change. We contrasted the theoretical results with empirical evidence obtained from transit and import agreements for Ukraine and Belarus, and found that the Shapley value yields better predictions than other solutions, such as core and nucleolus. Nevertheless, the paper is only a first step towards the analysis of strategic issues in international gas transport. We see three major limitations, which merit further investigation.

Calculating the value function, we assumed that coalitions use all pipeline options, which do not cross the territory of outsiders, in order to maximize their joint profit. Given the sunk cost nature of pipeline investment, efficiency within a coalition requires that its members can make long-term commitments to grant access to pipelines and share rents in a particular way. However, if international institutions lack the power to enforce such contracts and if the country's legal system is weak, a national players may lack the ability to credibly commit. In this case contracts remain incomplete and recontracting will be anticipated. To account for contractual incompleteness, Hubert and Ikonnikova [2004] blend the cooperative approach with non-cooperative elements in a two stage game. At the first stage, only those players, who can credibly commit, form 'strategic' coalitions, by agreeing on access rights, long-term sharing of rents, and investments. These pre-coalitions cooperate internally but act non-cooperatively with respect to outsiders. At the second stage all players bargain over the sharing of rents in the framework of the access regime inherited from the first stage. Hubert and Ikonnikova [2004] show that in the Russian gas network contractual incompleteness creates strong incentives to overinvest in some expensive pipelines (e.g. *Nord Stream*) and underinvest in cheap pipelines (e.g. *Upgrade*).

The present paper accounts for inertia, i.e. the time it takes between the decision to invest and new capacities becoming available, but we do not consider the possibility to deliberately delay the decision itself. If contracts are incomplete, then cooperation may be enhanced through dynamic strategies, which make future investment dependent on past rent sharing (e.g. trigger or tit-for-tat). Hubert and Suleymanova [2008] consider an infinite sequence of games, in which players, at any stage, share the rents from previous investments and possibly invest in new capacities, which become available with some delay. The non-cooperative one shot game replicates Hubert and Ikonnikova [2004], players would share rents according to the status quo game, and 'strategic coalitions' invest to maximize discounted future rents. In the collusive equilibrium, in contrast 'strategic coalitions' delay inefficient investments, creating thereby a credible threat to do so later, while outsiders compromise on their bargaining power under status quo. Hubert and Suleymanova [2008] show that with repeated interaction there is substantial scope for cooperation (collusion) in the network for Russian gas even if contracts are incomplete.

Finally, one should extend the geographical coverage of the analysis. Some smaller amendments require only minor adoptions, e.g the onshore pipelines along the Black Sea as well as their offshore alternatives, Blue Stream and South Stream. Including additional producers such as Turkmenistan and Iran, which are linked to pipeline options such as the Transcaspian Gas Pipeline or Nabucco, however, requires profound changes in the analytical approach. With the possibility of competing supply routes, the value of a coalition may depend on whether outside players form other coalitions. To allow for externalities across coalitions, the game has to be described by the partition function. None of the solutions considered in this paper, can be directly applied to this format. For a first attempt to analyze such an extended network see Ikonnikova [2007] who uses a generalization of the Shapley value proposed by Maskin [2003] to solve the game.

APPENDIX A
CALIBRATION

The value of a coalition S is calculated as:

$$v(S) = \max_{\{x_i | i \in L_S\}} [p(x)x - C_0(x) - \sum_{i \in L_S} T_i x_i].$$

where L_S denotes the pipeline options available to S, x_i is the quantity delivered through link i, x is total supply, T_i stands for link specific transportation cost per unit of gas, p is inverse demand for Russian gas, and C_0 denotes production cost.

(i) *Transportation Cost*

The total cost of transporting gas can be decomposed into capacity cost and operating cost, the latter consisting of management & maintenance cost and energy cost. These items are estimated for every possible link separately, to obtain a realistic picture of the differences in transportation cost.

Capacity Cost. For existing pipelines (*South*, *Yamal 1*) capacity cost are sunk and can be ignored in the analysis. As to new projects, like *Nord Stream* and *Yamal 2*, there is considerable variation in published cost estimates, and for others, like *Baltic*, there are no public figures available.[25] Therefore, we complement published figures with our own estimates. Assumed cost for pipes, compressors, and track preparation reflect the situation in 2000.[26] In all cases, we estimate the cost of establishing the capacity for a complete link from a major node in the Russian system to the border of Western Europe.

For new pipelines, the capacity cost are roughly proportional to distance, but there are several types of economies of scale. Some are related to the pipeline itself, others are gains obtained from laying pipelines along the same track. The capacity of a pipeline increases in pipe diameter and the pressure it can withstand. Holding pressure constant, the cost per unit of pipeline capacity decrease in pipe diameter. Capacity economy of scale appears to fade out at a capacity of 20 bcm/year, though this effect is somewhat weaker with offshore pipelines than with onshore pipes.[27] For simplicity we calculate cost for a large increase of capacity and assume the resulting cost per unit to be constant over the relevant range. Since we obtain rather large additional investments for coalitions, which would invest at all, this simplification will be of little consequence. The terrain is another important determinant of cost of new pipelines. Some costs of preparing the ground, building supply roads, etc. can be avoided by using

[25] Public information on investment cost and prices is usually given in \$ or € and sometimes it is not clear to which exact date it refers. The calibration reflect the situation at the beginning of the new century. Between 1.1.1999 and 31.12.2001 the \$ / € rate varied between 0.83 and 1.24 with an average of $1.04 \approx 1$.

[26] We are grateful to engineers from Wintershall AG for helpful discussions about our approach and cross checking of parameter assumptions.

[27] For further information see Oil, Gas and Coal Supply Outlook [1994] and International Energy Agency [1994].

established tracks, which also allows for sharing backup capacity of compressor power (track economics of scale). As new pipelines need about three years for completion, we add 15% of investment cost for interest during construction in these cases.

The figures in the first column of table 5 show, that the capacity cost, thus obtained, vary considerably between the different investment options. For *South* and *Yamal 1* capacity cost are sunk, other projects, such as *Upgrade*, *Bypass*, and *Baltic* have low capacity cost because they can make use of complementary existing infrastructure. The second column of table 5 shows the maximal capacity, for which the cost are valid. As we express all figures on an annual basis, we calculate annualized cost of capacity from project specific initial investment cost per capacity I_i as $C_i = r \cdot I_i/(1-(1+r)^{-T})$, where $T = 25$ denotes the expected lifetime of the facilities and $r = 0.15$ is the assumed interest rate for investment in the gas industry. The rate has to account for the real option nature of the investment and is in line with hurdle rates which are applied in the industry for project evaluation.

Operating Cost. The costs of management & maintenance, m_i are assumed to be proportional to distance and quantity of gas. We assume $m_i = 0.1\$/tcm/100km$ for all pipelines, except the offshore pipeline *Nord Stream*, for which we double the figure. To keep the gas moving, a certain fraction g of it is used to power compressor stations. We assume $g = 0.25\%/100km$ for all pipelines, except for *South*, with its inefficient old compressors, and *Nord Stream*, which needs much higher pressure for its offshore section. Both have $g = 0.5\%$.

Total. With these assumptions link specific transportation cost per unit (net of production cost) are: $T_i = (c_i + m_i + g_i \cdot MC_0)(e^{g_i \cdot l_i} - 1)/g_i$, where l_i denotes the length of the pipeline, $c_i = C_i/l_i$ is the capital cost divided by the total length of link i, and MC_0 denotes the marginal cost of production. The latter affect transportation cost because it determines the value of compressor gas.[28]

(ii) *Demand and Production Cost*

Unfortunately, we cannot base the calibration with respect to demand and production cost on solid data. The bulk of Russian gas is delivered under a small number of long-term 'take-or-pay' contracts, the details of which are confidential. Published information on import prices, which often differ by a wide margin, largely reflects oil price movements on which contract prices are indexed. As a result there is little information on the demand side. Current gas production depends on investment in exploration, wells, and pipelines, which is sunk. The higher the output, the faster established fields deplete and the sooner new fields have to be developed. Hence, the resource cost of Russian gas depends on reserves in old fields, the cost of developing new fields, and the relevant discount

[28]Suppose the total cost of supplying and transporting gas to a point y is $T(y)$. The increase of cost from transporting it a little further is proportional to $c + m + g \cdot T(y)$. Solve $T' = c + m + g \cdot T$, use $T(0) = MC_0$ and deduct the initial value MC_0 to obtain the formula.

Table 5: Transport Links for Russian Gas

project	capacity cost (C_i) [$/tcm]	maximal capacity [bcm/a]	length (l_i) [100km]	compressor gas (g_i) [%/100km]	management & maintenance (m_i) [$/tcm/100km]
South	sunk	70	20	0.50	0.1
	The old southern system of parallel pipelines, gas storages, compressors in poor state of repair. Only accounting for capacities used for export through Czech Republic to Western Europe. Higher energy cost due to old compressors.				
Upgrade	50	15	20	0.25	0.1
	Repairs and replacement of old compressor stations using the existing pipeline capacities of *South*.				
	102	∞	20	0.25	0.1
	Increasing capacity of *South* beyond modernization through new pipelines and compressors.				
Yamal 1	sunk	28	16	0.25	0.1
	Pipeline from Torzok to Germany, operating since 1998.				
Yamal 2	99	∞	16	0.25	0.1
	New pipeline parallel to *Yamal 1* with some preparations already made.				
Bypass	77	70	16	0.25	0.1
	New pipeline from Torzok to Velke Kapusany, replacing *South* in the use of capacities westward through Slovakia.				
Baltic	58	28	16	0.25	0.1
	New pipeline replacing the section of *Yamal 1* in Belarus.				
	99	∞	16	0.25	0.1
	New pipeline from Torzok to Germany, like *Yamal 2* but bypassing Belarus.				
Nord Stream	215	∞	16	0.50	0.2
	New pipeline from Greifswald (Germany) — Vyborg (Russia) 1200 km offshore, then 400 km onshore to Torzhok. Higher maintenance cost due to large offshore section, and higher energy cost due to higher pressure.				

rates, all of which can be estimated only with a considerable margin of error. Given this lack of reliable date, we base the calibration of supply and demand on a number of bold assumptions.

For simplicity we assume demand and production cost to be linear and independent of the transport route. The parameters of the functions have been chosen so that the capacities at *South* and *Yamal 1* are sufficient to maximize the profits of the grand coalition N, given our cost for additional pipeline capacities. At the beginning of the decade, most observers expected a steady increase in demand, but *Yamal 1* was built slowly up to its planned level of 28 bcm/a because capacity was slightly ahead of demand. British Petroleum [2006] reports an average of 125 $/tcm for the prices paid by Western European importers in 2002, which roughly corresponds with figures of 115 $/tcm for revenues net of taxes given in Stern [2005] based on Gazprom's income statements — though International Energy Agency [2003] gives much lower prices of 100 $/tcm. As to the slope of demand, we assume a rather flat schedule. In the short-term, Russia is bound by contractual obligations and cannot raise export prices if some transport links become unavailable. In the long-term, it faces supply competition from other gas producers, such as Algeria Norway, and LNG exporters. Somewhat dated estimates for the price elasticity of gas demand are in the range of $1.5 - 2$ (Pindyck [1979]). To account for contract coverage and competing suppliers our base line parameters for the inverse demand, an intercept of 160 $/tcm and slope of -0.33, imply an elasticity of almost 4 at the profit maximizing quantity. As to the marginal cost of gas at the Russian export node, we assume an intercept of 11 $/tcm reflecting low production cost from old fields such as Urengoy or Zapolyarnoye, for which development cost are sunk. With the low intercept, we need a rather high slope parameter of 0.8 to make the quantities which can be delivered through *South* and *Yamal 1* optimal. Such a steep increase of cost can, in principle, be justified by the very high cost of the development of new fields like Yamal or Shtokman.[29] To sum up, our baseline variant, $p(x) = 160\,[\$/\text{tcm}] - 0.33\,[\$/\text{mcm/a}] \cdot x\,[\text{bcm/a}]$ and $MC_0(x) = 11\,[\$/\text{tcm}] + 0.8\,[\$/\text{mcm/a}] \cdot x\,[\text{bcm/a}]$, yields reasonable figures for prices and elasticities at observed quantities, which would be optimal given our assumptions on capacities and transportation cost.

REFERENCES

Billera, L.J.; Heath, D.C. and Rannan, J., 1978, ' Internal Telephone Billing Rates: A Novel Application of Nonatomic Game Theory,' *Operations Research*, 26, pp. 956–965.

Bolton, P. and Scharfstein, D.S., 1996, 'Optimal Debt Structure and the Number of Creditors,' *Journal of Political Economy*, 104(1), pp. 1–25.

Brandenburger, A.M. and Nalebuff, B.J., 1997, *Co–opetition,* (Doubleday Broadway Books, New York).

[29]For long-term perspectives of Russian gas production and its cost see Stern [1995] and Observatoire Mediterraneen de L'Energie [2002].

Brandenburger, A. and Stuart, H., 2007, 'Biform Games,' *Management Science*, 53(4), pp. 537–549.

British Petroleum, 2006, *Quantifying Energy, Statistical Review of World Energy.*

Bruce, Chloë, 2005, 'Fraternal Friction or Fraternal Fiction? The Gas Factor in Russian-Belarussian Relations,' *Oxford Institute for Energy Studies*, NG 8.

Cachon, G.P. and Netessine, S., 2004, 'Game Theory in Supply Chain Analysis,' in Smichi-Levi, D.; Wu, S.D. and Shen, Z. (eds), *Handbook of Quantitative Supply Chain Analysis: modeling in the e-business Era,* (Kluwer Academic Publishers, Boston), pp. 13–66.

Energy Charter Secretariat, 2007, textitPutting a Price on Energy - International Pricing Mechanisms for Oil and Gas, (Energy Charter Secretariat, Brussels, Belgium).

Evans, R. A., 1996, 'Value, Consistency, and Random Coalition Formation,' *Games and Economic Behavior,* 12, pp. 68–80.

Gow, S.H. and Thomas, L.C., 1998, 'Interchange Fees for Bank ATM Networks,' *Naval Research Logistics,* 45:44, pp. 407–417.

Grais, W. and Zheng, K., 1996, 'Strategic interdependence in European east-west gas trade: a hierarchical Stackelberg game approach,' *The Energy Journal*, 17(3), pp. 1-22.

Grossman, S.J. and Hart, O.D., 1986, 'The Cost and Benefits of Ownership: A Theory of Vertical and Lateral Integration,' *The Journal of Political Economy*, 94(4), pp. 691–719.

Gul, F., 1989, 'Bargaining foundations of Shapley value,' *Econometrica,* 57, pp. 81-95.

Hart, O. and Moore, J., 1990, 'Property Rights and the Nature of the Firm,' *Journal of Political Economy,* 98(6), pp. 1119–58.

von Hirschhausen, C.; Meinhart, B. and Pavel, F., 2005, 'Transporting Russian Gas to Western Europe: A simulation Analysis,' *Energy Journal,* 26(2), pp. 49–67.

Hubert, F. and Ikonnikova, S., 2004, 'Hold-Up, Multilateral Bargaining, and Strategic Investment: The Eurasian Supply Chain for Natural Gas,' *Mimeo* (Humboldt University Berlin, Germany).

Hubert, F. and Suleymanova, I., 2008, 'Strategic Investment in International Gas-Transport Systems: A Dynamic Analysis of the Hold-Up Problem,' *DIW Discussion Paper*, 846.

Ikonnikova, S., 2007, 'Multilateral Bargaining and Strategic Investments in the Eurasian Gas Supply Network, *PhD thesis* (Humboldt University Berlin, Germany).

Inderst, R. and Wey, C., 2003, 'Bargaining, Mergers, and Technology Choice in Bilaterally Oligopolistic Industries,' *RAND Journal of Economics,* 34(1), pp. 1–19.

International Energy Agency, 1994, *Natural gas transportation. Organization and regulation.*

International Energy Agency, 1995, *Oil, Gas and Coal supply Outlook 1995,*

edition of the World Energy Outlook.
Murray, I., 2003, 'Russian Energy Developments and IEA Co-operation since the Russia Energy Survey 2002', *International Energy Agency Report*, IEA, Paris, France.
Littlechild, S. C. and Thompson, G. F., 1977, 'Aircraft Landing Fees: A Game Theoretic Approach,' *The Bell Journal,* 8(1), pp. 186–204.
Maskin, E., 2003, 'Bargaining, Coalitions, and Externalities,' *Mimeo* (Institute for Advanced Study, Princeton, USA).
Muto, S.; Nakayama, M.; Potters, J. and Tijs, S., 1988, 'On Big Boss Games,' *The Economics Studies Quarterly,* 39(4), pp. 303–321.
Myerson, R.B., 1980, 'Conference structures and fair allocation rules,' *Int. Journal of Game Theory,* 9(3), pp. 169–182.
Observatoire Mediterraneen de L'Energie, 2002, 'Assessment of internal and external gas supply options for the EU,' *Executive Summary, France.*
Parsons, J. E., 1989, 'Estimating the Strategic Value of Long-Term Forward Purchase Contracts Using Auction Models,' *The Journal of Finance,* XLIV(4), pp. 981–1010.
Pindyck, R.S., 1979, *The structure of World Energy Demand,* (MIT Press, USA).
Pirani, S.; Stern, J. and Yafimava, K., 2009, 'The Russo-Ukrainian gas dispute of January 2009: a comprehensive assessment,' *Oxford Institute for Energy Studies*, NG 27.
Rajan, R.G. and Zingales, L., 1998, 'Power in a Theory of the Firm,' *Quarterly Journal of Economics,* 113, pp. 387–432.
Schmeidler, D., 1969, 'The Nucleolus of a Characteristic Function Game,' *SIAM Journal of Applied Mathematics,* 17(6), pp. 1163–1170
Shapley, L.S., 1953, 'A Value for N-Person Games,' *Annals of Mathematics Study,* 28, pp. 307–17.
Shapley, L.S. and Shubik, M., 1954, 'A Method for Evaluating the Distribution of Power in a Committee System,' *The American Political Science Review,* 48(3), pp. 787–792.
Shubik, M., 1962, 'Incentives, Decentralized Control, the Assignment of Joint Cost and Internal Pricing,' *Management Science,* 8, pp. 325–343.
Stern, J.P., 1995, *The Russian gas bubble,* (The Royal Institute of International Affairs).
Stern, J.P., 1999, 'Soviet and Russian gas: The origins and evolution of Gazprom's export strategy,' in Mabro, R. and Wybrew-Bond, I.(ed.), *Gas to Europe. The strategies of four major suppliers,* (Oxford University Press, England).
Stern, J.P., 2005, *The future of Russian gas and Gazprom* (Oxford University Press, England).
Stern, J.P., 2006, 'The Russian Ukrainian gas crisis of January 2006,' *Oxford Institute for Energy Studies.*
Stern, J.P., 2005, *The future of Russian gas and Gazprom,* (Oxford University Press, England).
Stole, L. and Zwiebel, J., 1996a, 'Intra-firm bargaining under non-binding

contracts,' *Review of Economic Studies,* 63(3), pp. 375-410.

Stole, L. and Zwiebel, J., 1996b, 'Organizational design and technology choice under intra-firm bargaining,' *American Economic Review,* 86, pp. 195–222.

Suzuki, M. and Nakayama, M., 1976, 'The Cost Assignment of Cooperative Water Resource Development — A Game Theoretic Approach,' *Management Science,* 22, pp. 1081–86.

Yafimava, K. and Stern, J.P., 2007, 'The 2007 Russia-Belarus Gas Agreement,' *Oxford Institute for Energy Studies.*

Young, H.P., 1985a, 'Monotonic Solutions of Cooperative Games,' *International Journal of Game Theory,* 14(2), pp. 65–72.

Young, H.P., 1985b, 'Producer Incentives in Cost Allocation,' *Econometrica,* 53(4), pp. 757–765.

Zingales, L., 1994, 'The value of the voting right: a study of the Milan Stock Exchange experience,' *The Review of Financial Studies,* 7, pp. 125–148.

Zwiebel, J., 1995, 'Block Investment and Partial Benefits of Corporate Control,' *The Review of Economic Studies,* 62(2), pp. 161–185.