# Hold-up and Strategic Investment in International Transport Networks: Gas Pipelines in North Western Europe.

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**Abstract**

We propose a variant of the incomplete contract framework to analyze strategic investment in international transport networks, where investment is observable and some, but not all, players cannot make long-term commitments regarding access to their transport infrastructure. Those players who can commit may exchange access rights and ownership titles and coordinate their investment. All others may only join specific pipeline consortia based on cost sharing. Quasi rents at the final production stage are shared through bargaining. The North-Western corridor for Russian natural gas offers a nice example for such heterogeneity among players and a rare opportunity to calibrate an incomplete contract model to obtain quantitative results. In line with recent empirical developments in this network, we predict large overinvestment in expensive offshore pipelines (*Nord Stream*) which crowds out any investment in more cost efficient onshore alternatives.

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# 1 Introduction

In 2005 Russian Gazprom and German energy companies E.ON-Ruhrgas and Wintershall agreed to build a new offshore gas pipeline through the Baltic sea, later called Nord Stream (figure 1). The twin pipeline will increase transport capacities to North Western Europe by almost two thirds. The sheer size of Nord Stream raises the question of where the additional gas should originate. Russia after all, has been very slow to develop fields, which would allow for such an increase of supply any time soon.[1] Nord Stream is also by far the most expensive option to increase the transport capacity for Russian gas. It would be much cheaper to upgrade the aging system in Ukraine - mainly by modernizing compressor stations. If new pipelines were needed, these would benefit from existing infrastructure if laid along the Yamal track through Belarus and Poland, where preparations for a second pipeline were already made when Yamal 1 was built. However, with the decision to go offshore, all plans to invest in these more cost efficient options have been shelved. Apparently, the North Western Europe gas corridor fell victim to the well known "hold-up" problem (Klein & Crawford & Alchian (1978), Williamson (1979)) where some players, i.e. Russia and the Western importers, invest too little in cost efficient pipelines and too much in expensive alternatives in order to gain bargaining leverage over transit countries such as Ukraine and Belarus.

In this paper we propose a variant of the incomplete contract framework to analyze strategic investment in international transport networks, where investment is observable, but some players cannot make long-term commitments regarding access to their transport infrastructure. Although motivated by and applied to our particular pipeline example, we hope to develop a general framework that can be adapted to other networks. Our starting point is the canonical setting of the hold-up problem, which rests on two assumptions: (i) investment is idiosyncratic and non-contractible and (ii) contracts sharing the joint surplus remain incomplete due to verification problems or complexity. Analytically these features are captured in a two stage game. First, players non-cooperatively choose their investments; second, rent is shared according to some bargaining game. At the margin, every player compares the full private cost of investing to the share of the joint surplus expecteed from bargaining at the second stage. Hence, a typical outcome would be insufficient investment in assets, which enhance the joint surplus, possibly combined with ex-

[1] For a critical assessment of Russia's ability to sustain its gas exports at current levels, not to speak of a large scale increase, see Stern (1995) and Observatoire Mediterraneen de L'Energie (2002). Rather than developing its own production, Russia is rapidly increasing imports from central Asia.

Figure 1: Transit Options to North-Western Europe


cessive investment in outside options, enhancing the bargaining power of individual players.

We suggest two modifications to the standard setting as to account for the particularities of international gas transport infrastructure. First, in the case of pipelines, contractual incompleteness is not a result of difficulties to write comprehensive contracts as such, but of the inability of some partners to make credible long-term commitments regarding pipelines access.[2] Some players are likely to renege on an agreement if they stand to gain from recontracting because there are no institutions to enforce the contract. In Belarus for example, there is no independent judicial system, which could uphold a contract against a political move by the government.

[2]In an attempt to formalize transaction costs the theoretical literature has considered a number of reasons for contractual incompleteness. Grossman & Hart (1986) and Hart & Moore (1990) assume that some contingencies cannot be clearly described or verified. Anderlini & Felli (1994, 1999), Battigalli & Maggi (2002), Al Najjar & Anderlini & Felli (2006) and Hart & Moore (2008) refer to cost of complexity or limits on language to explain why incomplete contracts are chosen even if complete contracts are feasible. Tirole (2009) and Bolton & Faure-Grimaud (2010) invoke bounded rationality in form of cost of cognition and time cost of deliberating decisions, respectively. However, none of these issues appear to be of major relevance in the case of gas transport. Gas pipelines have little alternative usage and operating costs are negligible in comparison to capacity costs. Thus under almost any contingency, they should be used at full capacity. By indexing the gas price to energy-prices (mostly oil) the producer carries the resource price risk, while the pipeline operator usually gets a fixed fee. Not surprisingly, comprehensive long-term "take-or-pay" contracts, regulating quantity, price, and pipeline usage, have been common since the early years of the industry (Energy Charter Secretariat (2007)).

Belarus is also not a part of a larger structure, like the EU, which might insure compliance. If there are some players in the network who cannot commit, recontracting at the production stage will be anticipated — as in the standard model. However, even though the contractual governance of the system as a whole remains incomplete, those players who have adequate internal or external institutions in place, can still use comprehensive long-term contracts to enhance their interests. We capture this ability by allowing these players to establish a strategic alliance, which maximizes the joint surplus of its members by coordinating their investment and by exchanging access rights and ownership titles. The latter implies that the structure of access and property rights is determined endogenously, but not in an attempt to improve overall efficiency as in Grossman & Hart (1986), Hart & Moore (1990), or Rajan & Zingales (1998). Instead, the alliance tries to maximize the bargaining power of its members. In this respect, our analysis is related to the literature on pre-coalitions in bargaining games (Owen (1977), Hart & Kurz (1983), and Segal (2003)).

Second, investment in pipeline capacity is easy to verify. Hence the assumption of non-contractible investment appears too restrictive. We allow the players who could gain from a pipeline to establish a consortium and share the cost for this pipeline, even if they are not able to make long term commitments.[3] The consortium chooses investment to maximize the joint payoff of its members. In this respect consortia can overcome the classical "hold-up" problem, where complementary players contribute too little because, at the margin, they face the full cost while receiving only part of the benefit.[4] Nevertheless, coordination remains imperfect as we rule out agreements and side payments between different consortia. Essentially, we assume that consortia, rather than single players, invest non-cooperatively.

With these modifications, the investment phase consists of three sub-stages. First, those players who are able to commit may establish a strategic alliance to maximize

[3]International consortia among heterogeneous countries are a common phenomenon in the gas industry. During the Cold War the Soviet Union and Western Europe constructed a large pipeline network stretching from Siberia to West Germany and Austria. More recently, Turkmenistan, Kazakhstan, and China built the Central Asian - China gas pipeline. In both cases, there were no international institutions to enforce the deals and some players could not ensure independent protection of contracts.

[4]To illustrate the difference, suppose we have only two parties in a pipeline project with no alternative options. Not being able to commit, both parties anticipate recontracting after investment is sunk, from which each expects to receive half of the surplus. In our model they will set up a consortium at the investment stage, share investment cost, e.g. fifty-fifty, and build a pipeline with the efficient capacity. In contrast to the canonical set-up, we would not expect underinvestment in this simple case.

their joint profit. Second, for each pipeline option a consortium is created and all consortia invest non-cooperatively in transport capacity. Third, the members of the strategic alliance exchange long-term access rights and ownership titles. Then, in the final production phase, capacities are used efficiently and rent is shared according to bargaining power.

After explaining this framework in more detail in section 2, we assess its usefulness by analyzing the investments in a stylized model of the North-Western gas corridor mentioned earlier. We start with a qualitative analysis, reflecting only the geography of the network and our assumptions on institutional structure, i.e. the players' ability to commit (section 3). We characterize the equilibrium structure of access and property rights and show that there are incentives for excessive investment in all pipelines. If neither Ukraine nor Belarus can make long term commitments regarding pipeline access, the distortion is particularly strong for investment in North Stream.

In a second step (section 4), we calibrate the model using data from Hubert & Ikonnikova (2011). Solving the model numerically, we find that, unless Ukraine or Belarus can credibly assure pipeline access, Nord Stream will be built in spite of its high cost. In fact, our theoretical prediction for the equilibrium capacity of this pipeline comes reasonably close to the investment, which is currently under way. Also in line with the empirical evidence, we find that Nord Stream's large capacity crowds out any investment in other pipelines. Nord Stream's strategic importance overshadows the potential role for consortia. Only if we take the off-shore pipeline out of the picture do we find that consortia can be established who invest in their pipelines, even though they include players who cannot make long term commitments. Again our quantitative findings come close to the capacities of projects in Ukraine and Belarus, which have been intensively discussed around 2001/2, but have been abandoned with the decision to go offshore. In the concluding section 5, we discuss some limitations and possible extensions of the model.

## 2 The Analytical Framework

### Overview and Notation

The transport network consists of a set of pipelines, $L$, each linking the gas fields to the market. The vector of capacities at the different links is $K$ and $K_l$ denotes the capacity at link $l \in L$. A pipeline runs through the territory of one or more players. The set of all players involved in the network is $N$. Let $M \subset N$ be the subset of players, who can credibly commit to make payments and grant access to pipelines in the production stage (for the sequencing see figure 2). These players may form a strategic coalition, or alliance, $A \subseteq M$ at the first stage. Its members plan capacities and exchange access rights in order to maximize their joint profit. Below, we consider a network with four players, of whom at least one cannot commit. So at most one alliance of two or more players can form, imposing a unique coalition structure, or partition, $P_A$ on $N$, in which all outsiders remain singletons.

In order to build pipelines, the players form consortia who share the cost of investment in a particular pipeline. Even players who cannot make long term commitments may join a consortium. We denote the set of members of consortia $C_l,\ l \in L$. The cost of capacity at link $l$ is denoted $c_l(K_l)$ and $c(K)$ is the corresponding vector of cost for all pipelines. Player $i$'s share of the investment cost in link $l$ is denoted by $\alpha_l^i$ and his total capital expenditure is $\alpha^i c(K)$ with $\alpha^i = (.., \alpha_l^i, ..)$.

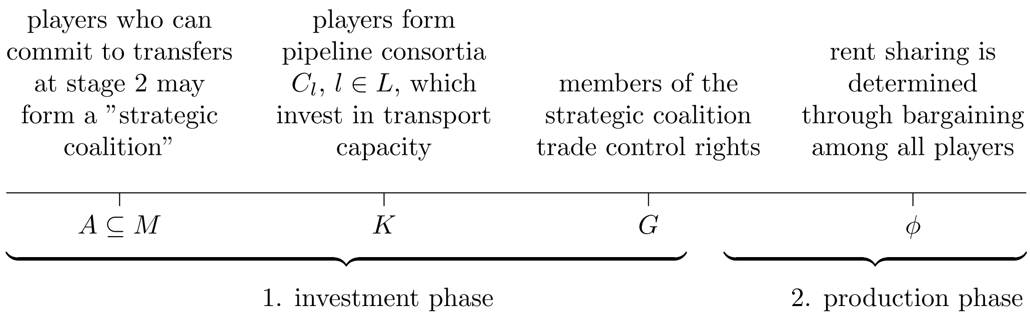
Bargaining power at the production stage depends on command over pipelines. Let $S \subseteq N$ be a subset of players and $\mathbb{S}$ denote the set of all subsets of $N$. We describe the access or control structure by a function $G : \mathbb{S} \times \mathbb{R}^{|K|} \rightarrow \mathbb{R}^{|K|}$. For any $S \in \mathbb{S}$ and installed pipeline capacities $K$, $G$ gives the capacities which are at the disposal of $S$. Under the initial or natural control regime $G^o$ each player enjoys exclusive access to the pipeline sections on his territory. Hence a group of players can use a pipeline only when all players owning sections of the pipeline are included. The members of the strategic alliance, however, can modify the control structure by trading access rights or ownership titles. Since entitlements may be traded after investments are made, we require the final access regime $G$ to be renegotiation proof.

At the production stage, $K$ and $G$ are given and all players enter a bargaining game to share the rent. We allow the members of the alliance $A$ to act independently at this stage. Should they prefer to speak with "one voice", they can designate one proxy player by making him the sole owner of all transport capacities. The payoffs from bargaining over rent are denoted by $\phi^i$, where $i \in N$ and $\phi^S = \sum_{i \in S} \phi^i$.

For player $i \notin A$, the payoff in the overall game is given by $\Pi^i = \phi^i - \alpha^i c(K)$. For the alliance $A$, the payoff is $\Pi^A = \phi^A - \alpha^A c(K)$. As the focus of this paper is on strategic investment, we only briefly discuss how the members of $A$ might share the surplus to establish a stable coalition.

As usual, the analysis proceeds backwards. First, we consider the rent sharing game for given $(G, K)$ and determine $\phi^i(G, K)$, $i \in N$. Then we characterize the strategic choice of (renegotiation proof) control rights $G^{A,K}$. Next we discuss how investment consortia determine capacities $K^A$. Finally, we ask which strategic alliance $A$ is

Figure 2: Sequencing




likely to form in equilibrium.

### Production and Rent–Sharing

The players have to cooperate to make use of the network. The value $v$ of a coalition $S$ depends on its command over transport capacities.[5] Let $\tilde{K} = G(S, K)$ denote the capacities at the disposal of $S$ under access structure $G$, then the operating profit, or rent, is given as:

$$\pi(\tilde{K}) = \max_q \left[p(Q)Q - c^o(q)\right], \quad \text{s.t. } q \leq \tilde{K}, \tag{1}$$

where $p$ denotes the price of gas, $c^o$ the operating cost, $q$ the vector of quantities delivered through the links of the transport system, and $Q$ is the total supply. We assume that $\pi$ is concave with $\partial\pi/\partial K_l \geq 0$ and $\partial^2\pi/\partial K_l \partial K_h \leq 0$ for capacities at any two links $l, h \in L$. With control regime $G$ and installed capacities $K$ the value of coalition $S$ is given as:

$$v^G(S; K) = \pi(G(S, K)). \tag{2}$$

In principle, the value of a coalition may depend on whether outside players $i, j \notin S$ form coalitions or not. Such externalities, however, do not arise if one player (in our case Russia) is essential. A group of players, which includes the essential player, is not affected by others because these cannot form a complete link and compete. A coalition not including the essential player receives no profit whatever the others do. Below we will introduce restrictions on $G$, which prevent externalities at the

[5] It is important not to confound a *strategic alliance* $A$, which is a lasting coalition formed at the first stage, with notional coalitions $S$ used to characterize the bargaining game at the production stage.

production stage and allow us to analyze rent sharing as a game in characteristic function form $(N, v^G)$.

We use the first difference $\Delta_i v^G(S;K) = v^G(S \cup i;K) - v^G(S \backslash i;K)$ to denote $i$'s marginal contribution to coalition $S$ and assume that the bargaining game $(N, v^G)$ is solved with the Shapley value:

$$\phi^i(G,K) = \sum_{S:i \notin S} p_S \Delta_i v^G(S;K), \tag{3}$$

where $p_S$ is the probability of coalition $S$ under random order bargaining if all orderings of players have equal probability.[6]

**Control Rights**

Our starting point is the "natural" regime of control, $G^o$. Here, each player enjoys unrestricted ownership, i.e. *exclusive access* to those parts of the network which are in his territory. It is instructive to decompose any change of the control regime into a series of bilateral contracts. We follow Segal (2003) in the distinction of contracts over *access* and *exclusion*. A bilateral inclusive contract $I_i^j$ grants player $i$ access to $j$'s resources without preventing $j$ from using them on his own. It results in a new control regime $G = I_i^j(G^o)$. With an exclusive contract $E_i^j$, player $i$ obtains the right to exclude all players from $j$'s resources. A transfer of ownership can then be represented by a composition of two contracts: $T_i^j = E_i^j I_i^j$. The inclusive contract gives $i$ access to the resources of $j$. The exclusive contract prevents others from using these resources. With such a contract, $j$ becomes redundant in the bargaining game. A transfer of ownership has the same effect as if the players unite or merge and $i$ acts as a proxy player. All these contracts weaken player $j$'s bargaining power. Such contracts are, therefore, only feasible, when (i) player $j$ can commit to grant $i$ access and/or veto-power to resources on his territory, and (ii) player $i$ can commit to compensate $j$ at the production stage, i.e. $i, j \in A$.

We impose two more restrictions on feasible contracts. First, while emphasizing the distinction between access and ownership, we want to rule out that a player has the right to exclude all others from a resource without having access himself. If "stand alone" exclusive contracts were possible, the game could be changed by

[6] The Shapley value is commonly used in the theoretical literature on non-contractible investment and hold-up to solve multilateral bargaining games (Grossman & Hart (1986), Hart & Moore (1990), Rajan & Zingales (1998)). It always exists, is unique and easy to calculate. Furthermore, the limited empirical evidence on surplus sharing in North-European gas supply chain favours the Shapley value over competing solutions such as the nucleolus and the core (Hubert & Ikonnikova (2011)).

adding a player who initially has no relation to the physical network (e.g. Australia). Second, to ensure that the game at the production stage can be represented in value function form, we also rule out contracts, where the essential player (e.g. Russia) grants access to (parts of) its resources.[7]

Let $\mathbb{G}_A$ denote the set of all control structures which can be implemented by a strategic coalition, $A$, using only contracts of the types $I_i^j$ and $T_i^j$ or their compositions, where $i, j \in A$ and $j$ is non-essential. The members of $A$ will choose control rights so as to maximize the sum of their payoffs, $\phi^A$, which is equivalent to minimizing the share of outsiders, because, with physical capacities fixed, the size of the pie is already determined. Then the renegotiation proof control regime $G^{A,K}$ is given as

$$G^{A,K} = \arg\max_{G \in \mathbb{G}_A} \phi^A(G, K) = \arg\min_{G \in \mathbb{G}_A} \phi^{N \setminus A}(G, K) \tag{4}$$

**Investment**

At the investment stage, the strategic alliance $A$ acts as a single player vis-à-vis outsiders. So the set of independent players is given by the elements of the coalition structure $P_A$. As argued in the introduction, strategic issues in international gas networks arise from the inability of at least some players to make long-term commitments, not from difficulties to observe or verify investments in pipelines. Hence all players who gain from investing in pipeline $l$, can set up a pipeline consortium $C_l$ and share the cost of investment. As a minimum, a consortium has to include all countries which the pipeline will cross. A player can join several consortia. The consortium structure is denoted $C = \{..C_l..\}$, $l \in L$.

Each consortium $C_l$ chooses capacity $K_l$ to maximize the joint profit of its members, taken the capacities on other pipelines as given. For a given alliance $A$, consortium structure $C$, and already existing capacity $K^o$, the network capacity $K^A$ is given as the Nash-equilibrium:

$$K_l^A = \arg\max_{K_l \geq K_l^o} \left[ \phi^{C_l}(G^{A,K}; K) - c_l(K_l) \right], \ \ \forall l \ \in L, \tag{5}$$

Consortia are imperfect means to achieve cooperation. First, we rule out that a player, who is hurt by the expansion of a link, joins the consortium and compensates the others for investing less. For a player $i \in P_A$ to join $C_l$, we require that $\phi^i$ is non-

[7]Alternatively, one can assume that Russia cannot credibly commit to grant access to its resources. Russia may nevertheless enter a strategic coalition, because given the architecture of the network and the cost of new investments, it will not be in its interest to recontract.

decreasing in the capacity of link $l$.[8] Second, we do not allow for transfer payments across consortia and restrict payments within the consortium to simple cost sharing, such that $\alpha_l^i \in [0,1]$ and $\sum_{i \in C_l} \alpha_l^i = 1$. If all players could join a consortium and more general upfront transfers were possible, the inability to make long-term commitments would become irrelevant. All players could first select the capacity which maximizes industry profits and neutralize the effects on future bargaining power through compensating up front payments.

We are left with the question of which consortium structure $C$ and cost sharing system $\alpha$ will be established in equilibrium. Here we look at a game of coalition formation with multiple memberships and externalities. We are not aware of a generally accepted solution for such games. We will only check on a case by case basis, whether a coalition structure can be supported by a simple cost sharing rule, which makes profitable deviations impossible.

### Strategic Alliance

Finally, we have to establish which strategic alliance will form. Here we consider a coalition game between those players who can commit, $M$, as they are the only ones to form an alliance. At this stage of the game, we again expect externalities, i.e. the payoff of a player/coalition depends on whether other players form a coalition or not. Hence, the game has to be casted in in partition function form (Thrall & Lucas (1963)). Let $\mathbb{P}$ denote the set of feasible coalition structures, or partitions, and the partition function $\Pi$ be a mapping which associates to each coalition structure $P \in \mathbb{P}$ a vector in $\mathbb{R}^{|P|}$, representing the worth of all elements in $P$. We use superscripts to refer to payoffs of single elements of $P$, e.g. $\Pi^i(P)$, $i \in P$. The stage game in partition function form is denoted $(M, \Pi)$.

Unfortunately, none of the accepted solutions for characteristic function form games extends easily to games with externalities. Several notions have been proposed to determine which coalitions form and how coalitional profits are shared (for an overview see Yi (2003)). Ray & Vohra (1999) and Maskin (2003) propose sequential bargaining, to solve the game in a fashion which resembles the non-cooperative foundations of the Shapley value. Others use different extensions of the core to identify stable coalition structures (Aumann & Peleg (1960), Shenoy (1963), Aumann (1967), Hart

[8] The alliance $A$ may be composed of some elementary players, who, individually, would gain from capacities at a particular pipeline $l$, and others, who are harmed. If the alliance as a group gains, then it may decide to join $C_l$. Only in this case, the consortium can take into account the interest of an elementary player, who is hurt by its investment.

& Kurz (1983), d'Aspremont et al. (1983)). The variants differ in their assumptions on possible adjustments in the partition after a player or group of players leaves a coalition. Since, none of the solutions has gained widespread acceptance, we assess the stability of a possible alliance against all possible realignments, but we abstain from making a definite prediction on surplus sharing.

# 3 Qualitative Analysis

We now use the framework outlined in the previous section to analyze a stylized model of the network, delivering Russian natural gas to North-Western Europe (figure 1). In this section, we focus on the insights that can be derived without a numerical calibration of the model. The main agents in the network are Russia, Poland, Belarus, and Ukraine to which we refer with upper case initials $N = \{R, P, B, U\}$. The transport network consists of three possible links *Nord Stream*, *Yamal*, and *South*. We use lower case initials for the capacities at these links, $K = \{n, y, s\}$.

To accommodate different assumptions about the institutional environment, we consider various scenarios with respect to the ability to make credible long-term commitments. The benchmark cases assume (i) that all players can commit, $M = N$ and (ii) that no player can commit, $M = \emptyset$. In our standard case, we assume that Poland, being a member of the European Union, can commit to long-term rent sharing, guaranteed access to its pipelines, etc. Given our restrictions on feasible contracts, Russia cannot gain from recontracting, hence, the alliance $\{R, P\}$ may form. Finally we consider two, admittedly, unrealistic variants. In one scenario we assume that in addition to Poland, Belarus can commit. In this case, three more alliances can form $\{R, B, P\}$, $\{P, B\}$, and $\{R, B\}$. Alternatively, we envisage a situation in which Ukraine is able to commit, which would allow for $\{R, U\}$, $\{R, P, U\}$, and $\{P, U\}$.

In the next subsection we ask, which access regime $G^{A,K} \in \mathbb{G}_A$ is selected, then we discuss the implications for the Shapley value, and finally we turn to the issue of strategic investment.

## 3.1 Access Rights and Ownership

Recall from (4) that the purpose of contracting over access rights within a strategic alliance is to weaken the bargaining power of outsiders. The effect of a contract on a third player, $k$, depends on how it affects his marginal contribution $\Delta_k v(S)$.

The impact of $j$'s resources on the marginal contribution of $k$ is given by the second difference: $\Delta^2_{kj}v(S) = \Delta_k v(S \cup j) - \Delta_k v(S \backslash j)$. We use the following insights from Segal (2003) to derive optimal access and ownership structures for all strategic coalitions, which are relevant in our four scenarios:

1. An inclusive contract $I_i^j$ harms a third player $k$ if the included player $j$ is substitutable to $k$ in the presence of $i$, i.e. $\Delta^2_{kj}v(S) \leq 0$, $\forall S : i \in S$.
2. An exclusive contract $E_i^j$ harms a third player $k$ if the excluded player $j$ is complementary to $j$ in the absence of $i$, i.e. $\Delta^2_{kj}v(S) \geq 0$, $\forall S : i \notin S$.

A transfer of ownership is obtained by a composition of two contracts: $T_i^j = E_i^j I_i^j$. Its effect on $k$ depends on the third difference $\Delta^3_{ijk}v(S) = \Delta^2_{kj}v(S) - \Delta^2_{kj}(S \backslash i)$.

3. Transferring ownership between $j$ and $i$ harms a third player $k$ if $k$'s presence increases the substitutability (decreases the complementarity) between the contracting players $i$ and $j$, i.e. $\Delta^3_{ijk}v(S) \leq 0$, $\forall S : i \notin S$.

It turns out that installed capacities, $K$, have no effect on the structure of access rights. Whether a player is granted or denied access to a pipeline depends only on the geography of the network. To simplify notation, we omit $K$ and write $G^A$ for the optimal control structure.

**Proposition 1** *For all capacities $K$:*

*(i) Alliances, which include only two out of three complementary players, will not change the natural access regime: $G^{\{R,P\}} = G^{\{R,B\}} = G^{\{P,B\}} = G^o$.*

*(ii) Alliances, which are composed of all complementary players of a link, grant the essential player (Russia) access rights to the sections of the others: $G^{\{R,P,B\}} = I_R^P I_R^B(G^o)$ and $G^{\{R,U\}} = I_R^U(G^o)$.*

*(iii) If two substitutable players from different links form a coalition, then one of them acquires ownership of the other's section: $G^{\{P,U\}} \in \{T_P^U(G^o), T_U^P(G^o)\}$.*

*(iv) An alliance, which includes all complementary players and a substitutable player, grant the essential player access rights: $G^{\{R,P,U\}} = I_R^U(G^o)$.*

Proof see appendix.

The proposition largely follows from applying the principles 1-3 to the network at hand. If all players which are complementary in a link are in the alliance, then all outside players belong to substitutable links and are hurt by inclusive contracts. There are three such cases. The alliance $\{R, B, P\}$ weakens the bargaining power of Ukraine, the only player outside the coalition, by granting Russia access rights to the sections of *Yamal* in Poland and Belarus. The alliance $\{R, P, U\}$ harms $B$, and $\{R, U\}$ harms $B$ and $P$, by granting Russia access to *South*.

If (non-essential) players from substitutable links form an alliance, then one of them obtains ownership of the other resources. The right to exclude enables Poland and Ukraine to eliminate competition between *Yamal* and *South* and strengthens their bargaining power vis-à-vis Russia and Belarus.

Somewhat surprisingly, alliances, which do not include all complementary players, do not change the natural access regime. While an inclusive contract would harm the substitutable outside player, it also benefits the complementary outside player. We find that in our network, regardless of capacities, the latter effect dominates the former.[9]

### 3.2 The Shapley Values

Based on proposition 1 we can calculate the value functions (see appendix) and the resulting Shapley values. As an example, consider the natural access regime $G^o$. Straightforward application of the Shapley formula yields for Russia:

$$\phi^R = \frac{5}{12}v(\{R\}) + \frac{1}{12}v(\{R, P, B\}) + \frac{1}{4}v(\{R, U\}) + \frac{1}{4}v(\{R, P, B, U\}).$$

Rewriting it in terms of operating profit $\pi$ and accessible capacities, we obtain:

$$\phi^R(G^o, (n, y, s)) = \frac{5}{12}\pi(n, 0, 0) + \frac{1}{12}\pi(n, y, 0) + \frac{1}{4}\pi(n, 0, s) + \frac{1}{4}\pi(n, y, s)$$

Russia's payoff from bargaining over rent under the natural access regime is given by a weighted sum. The first term, weighted with 5/12, is the operating profit from using only the capacity at *Nord Stream*. The second, weighted with 1/12, is obtained by using *Nord Stream* and *Yamal*. The third and forth term, both with a weight of 1/4, reflect the joint usage of *Nord Stream* and *South*, and the usage of all capacities, respectively. The Shapley values of the other players can also be expressed as a weighted sum of these terms. The weights reflect the strategic role of a player under a given access regime. Table 1 gives the weights for the calculation of the Shapley values under the four access regimes derived in proposition 1.

[9] Take the example of $\{R, P\}$, an inclusive contract $I_R^P$ would reduce Ukraine's contribution to $\{R, B\}$, because the capacities at *Yamal* would be already available. But Ukraine's loss is smaller than the increase of Belarus' contribution to $\{R\}$. In addition, Belarus' contribution to $\{R, U\}$ is also increased.

Table 1: Factors for Calculating the Shapley Value

| $G^*$ | $\phi$ | $\pi(n,0,0)$ | $\pi(n,y,0)$ | $\pi(n,0,s)$ | $\pi(n,y,s)$ |
|---|---|---|---|---|---|
| $G^o$ | $\phi^R$ | $+\frac{5}{12}$ | $+\frac{1}{12}$ | $+\frac{1}{4}$ | $+\frac{1}{4}$ |
| | $\phi^P$ | $-\frac{1}{12}$ | $+\frac{1}{12}$ | $-\frac{1}{4}$ | $+\frac{1}{4}$ |
| | $\phi^B$ | $-\frac{1}{12}$ | $+\frac{1}{12}$ | $-\frac{1}{4}$ | $+\frac{1}{4}$ |
| | $\phi^U$ | $-\frac{1}{4}$ | $-\frac{1}{4}$ | $+\frac{1}{4}$ | $+\frac{1}{4}$ |
| $I_R^B I_R^P(G^o)$ | $\phi^{\{R,P,B\}}$ | 0 | $+\frac{1}{2}$ | 0 | $+\frac{1}{2}$ |
| | $\phi^U$ | 0 | $-\frac{1}{2}$ | 0 | $+\frac{1}{2}$ |
| $I_R^U(G^o)$ | $\phi^{\{R,U\}}$ | 0 | 0 | $+\frac{2}{3}$ | $+\frac{1}{3}$ |
| | $\phi^P$ | 0 | 0 | $-\frac{1}{3}$ | $+\frac{1}{3}$ |
| | $\phi^B$ | 0 | 0 | $-\frac{1}{3}$ | $+\frac{1}{3}$ |
| $T_P^U(G^o)$ | $\phi^{\{P,U\}}$ | $-\frac{1}{2}$ | 0 | $+\frac{1}{6}$ | $+\frac{1}{3}$ |
| | $\phi^R$ | $+\frac{1}{2}$ | 0 | $+\frac{1}{6}$ | $+\frac{1}{3}$ |
| | $\phi^B$ | 0 | 0 | $-\frac{1}{3}$ | $+\frac{1}{3}$ |
| | $\phi^{\{R,P,B,U\}}$ | 0 | 0 | 0 | 1 |

If Belarus and Ukraine cannot commit, the natural access regime, $G^o$, will prevail and we can calculate the Shapley value $\phi^i$ for all players separately (see top panel). If the strategic alliance $\{R, P\}$ is established, we simply add up the corresponding Shapley values. Similarly, we calculate the Shapley value for a consortium by summing up the values for its members. If Belarus can also commit and forms the alliance $\{R, P, B\}$ (panel two), we calculate only $\phi^{\{R,P,B\}}$ and $\phi^U$, taking into account Russia's access rights to *Yamal* (second panel). If Ukraine and Poland can commit, we have two cases depending on whether the alliance $A = \{R, P, U\}$ or $A = \{P, U\}$ forms. In the first case (panel three) we calculate $\phi^{\{R,U\}}$, $\phi^P$ and $\phi^B$, taking Russia's acquired access rights to *South* ($I_R^U(G^o)$) into account. The alliance maximizes $\phi^{\{R,U\}} + \phi^P$. In the second case we calculate $\phi^{\{P,U\}}$, $\phi^R$ and $\phi^B$ accounting for the transfer of ownership between Poland and Ukraine.

### 3.3 Strategic Investment

For a given alliance, $A$ and coalition structure $P_A$, we have to establish who benefits from additional capacities in a particular pipeline, $l$, i.e. those $i \in P_A$ for which $\phi^i(G^A, K)$ is (weakly) increasing in $K_l$. These players can set up a consortium, $C_l$.

Then we calculate the equilibrium investment and the resulting division of rents during production for all possible consortium structures. Finally, we ask whether investment costs can be shared, so that a consortium structure is stable.

Strategic alliances affect consortia and investment through access rights and membership. Consider the consortium for *Yamal*. In order to add capacities to this track, Russia, Poland and Belarus have to join $C_y$. If there is no strategic alliance, $A = \emptyset$, the consortium requires the consent of three independent players $C_y = \{R, P, B\}$. There is a chance that they might fail to find a cost sharing scheme, which makes this consortium part of a stable structure. If established, $C_y$ evaluates the sum of the countries' Shapley values under the natural access regime $G^o$ as $\phi^R + \phi^P + \phi^B = \frac{1}{4}\pi(n, 0, 0) + \frac{1}{4}\pi(n, y, 0) - \frac{1}{4}\pi(n, 0, s) + \frac{3}{4}\pi(n, y, s)$. If the alliance $A = \{R, P, B\}$ had been formed at the first stage, the consortium $C_y = \{\{R, P, B\}\}$ consists only of one player. The member countries evaluate the sum of their Shapley values under $I_R^B I_R^P(G^o)$ as $\phi^{\{R,P,B\}} = \frac{1}{2}\pi(n, y, 0) + \frac{1}{2}\pi(n, y, s)$.

Now suppose that the alliance $A = \{R, U\}$ had been formed instead, then investment in *Yamal* requires that a consortium of three independent players is established, which encompasses all four countries $C_y = \{\{R, U\}, P, B\}$.[10] The access regime under this alliance is $I_R^U(G^o)$, but for $C_y$ it would not matter because $\phi^{\{R,U\}} + \phi^P + \phi^B = \pi(n, y, s)$. This example shows how a strategic alliance can account for the interests of a country, here Ukraine, which is individually hurt by the capacity of a pipeline, provided that the country can commit and joins a strategic alliance.

In our simple representation of the North-European gas network, any consortium which can invest in a pipeline includes all players which might benefit from investment. If certain players are not included, these outsiders are necessarily hurt by the investment. The marginal returns to investment for the consortium will therefore be larger than the social returns. Given our assumptions on limited coordination among consortia, there is an inclination to overinvest:

Let $K_l^*(K)$ denote the investment in $l$, which maximizes the joint profit of all players $\Pi^N$ for any given capacity $K$ on the other links and let $\hat{K}_l(K)$ be the investment, which maximizes profits of the consortium $C_l$.

**Proposition 2** *If established, a consortium never underinvests,* $\hat{K}_l(K) \geq K_l^*(K)$ $l \in L$.

Proposition 2 does not imply that capacities on all links end up larger than in the

[10]To simplify notation, we usually drop brackets for single players.

first best case, $K^*$. Firstly, a consortium may fail to form, in which case there will be no investment in the pipeline at all. Secondly, even if it is established, investment in other pipelines may be so large, that investment in this particular pipeline may fall short of what would characterize an efficient solution. In this case, strategic overinvestment in (expensive) links crowds out investment in (cheap) links. Compared to efficient investment, there would be "underinvestment" in a particular link as a byproduct of overinvestment in other links.

**Example.** As an example we consider the case where Poland can commit and forms a coalition with Russia, resulting in the coalition structure $P_{\{R,P\}} = \{\{R,P\}, B, U\}$. To simplify notation, we use subscripts to denote partial derivatives: $\phi^i_{K_l} := \partial\phi^i/\partial K_l$ and $\pi_{K_l} := \partial\pi/\partial\tilde{K}_l \cdot \partial G/\partial K_l$, with $\tilde{K} = G(S,K)$. From Proposition 1 we know that $G^{\{R,P\}} = G^o$ and from Table 1 we obtain:

$$\begin{aligned}
\phi^R + \phi^P &= +\frac{1}{3}\pi(n,0,0) + \frac{1}{6}\pi(n,y,0) + \frac{1}{2}\pi(n,y,s) \\
\phi^B &= -\frac{1}{12}\pi(n,0,0) + \frac{1}{12}\pi(n,y,0) - \frac{1}{4}\pi(n,0,s) + \frac{1}{4}\pi(n,y,s) \\
\phi^U &= -\frac{1}{4}\pi(n,0,0) - \frac{1}{4}\pi(n,y,0) + \frac{1}{4}\pi(n,0,s) + \frac{1}{4}\pi(n,y,s)
\end{aligned}$$

To find the equilibrium capacity denoted $K^{\{R,P\}} = (n^{\{R,P\}}, y^{\{R,P\}}, s^{\{R,P\}})$ we first consider the consortium for each link.

*Nord Stream*: Ukraine will not contribute to investment in $n$, because

$$\phi^U_n = \frac{1}{4}(\pi_n(n,0,s) - \pi_n(n,0,0) + \pi_n(n,y,s) - \pi_n(n,y,0)) \leq 0$$

and the same holds true for Belarus, hence, $C_n = \{\{R,P\}\}$.

*Yamal*: Again $\phi^U_y \leq 0$, but

$$\phi^B_y = \frac{1}{12}\pi_y(n,y,0) + \frac{1}{4}\pi_y(n,y,s) \geq 0$$

and

$$\phi^{\{R,P\}}_y = \frac{1}{6}\pi_y(n,y,0) + \frac{1}{2}\pi_y(n,y,s) \geq 0,$$

so that $C_y = \{\{R,P\}, B\}$.

*South*: Here $\phi^B_s \leq 0$, but $\phi^{\{R,P\}}_s \geq 0$ and $\phi^U_s \geq 0$ so that both can agree on cost sharing and $C_s = \{\{R,P\}, U\}$.

If all three consortia form, $C = \{C_n, C_y, C_s\}$, then $K^{\{R,P\}}$ is found as the solution of:

$$n^{\{R,P\}} = \arg\max_{n \geq n^o}[\phi^{\{R,P\}}(n,y,s) - c_n(n)] \tag{6}$$

$$y^{\{R,P\}} = \arg\max_{y \geq y^o} [\phi^{\{R,P\}}(n, y, s) + \phi^B(n, y, s) - c_y(y)] \quad (7)$$

$$s^{\{R,P\}} = \arg\max_{s \geq s^o} [\phi^{\{R,P\}}(n, y, s) + \phi^U(n, y, s) - c_s(s)]. \quad (8)$$

If $C_s$ fails to form for some reason, then $K^{\{R,P\}}$ solves (6), (7) and $s^{\{R,P\}} = s^o$. If $C_y$ is not established, then $K^{\{R,P\}}$ solves (6), (8) and $y^{\{R,P\}} = y^o$. Since $C_n$ consists of only one player, it cannot fail to form.

Finally, we look at incentives for excessive investment. For all players together, marginal returns to investment in link $l$ are: $\phi_l^N = \pi_l(n, y, s),\ l \in \{n, y, s\}$. For each consortium, the returns are excessive:

$$\begin{aligned}
\phi_n^{\{R,P\}} - \phi_n^N &= \frac{1}{3}\pi_n(n, 0, 0) + \frac{1}{6}\pi_n(n, y, 0) - \frac{1}{2}\pi_n(n, y, s) \geq 0 \\
\phi_y^{\{R,P\}} + \phi_y^B - \phi_y^N &= \frac{1}{4}\pi_y(n, y, 0) - \frac{1}{4}\pi_y(n, y, s) \geq 0 \\
\phi_s^{\{R,P\}} + \phi_s^U - \phi_s^N &= \frac{1}{4}\pi_s(n, 0, s) - \frac{1}{4}\pi_s(n, y, s) \geq 0
\end{aligned}$$

The incentives for excessive investment appear to be particularly strong for *Nord Stream*. With a weight of 1/3, the marginal returns of investing in *Nord Stream* are assessed as if there were no capacities on the other links and with a weight of 1/6, the capacity of *South* is ignored. In contrast, consortia for investment in *Yamal* and *South* always account for capacity at *Nord Stream* and ignore capacity on the other competing link only with a weight of 1/4. This observation suggests that investment in *Nord Stream* might crowd out investment in other links, but the question cannot be answered without a numerical calibration of the model.

# 4 Quantitative Analysis

## 4.1 Calibration

We use the same calibration as in Hubert & Ikonnikova (2011), which reflects the situation around the years 2000/1 (for details see the appendix). At that time, gas for Northern-Europe was supplied through *Yamal 1* with a capacity of 28 bcm/a and through pipelines in the Ukraine, here called *South*, with app. 70 bcm/a. For both links 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 southern system, which we refer to as *Upgrade*. Beyond that threshold, *Yamal 2* comes second, with at least double capacity cost. Building new pipelines along the southern track, that is extending *Upgrade* beyond 15 bcm/a, is slightly more expensive than *Yamal*

*2*. The most expensive option by far is the off-shore project, *Nord Stream*, which requires at least another doubling of capital expenditures per unit of capacity.[11]

Besides transportation cost, for which reliable information is available, 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. In our first scenario, assumptions on the slope and intercept parameters reflect low demand in the first years of the new century. As a result, the grand coalition would maximize its profit by using existing capacities at *South* and *Yamal 1* while abstaining from investments in new capacities. With this calibration, any investment is excessive compared to the profit maximizing one. At the end of this section we consider a second scenario in which demand is high enough to warrant modest new investment.

## 4.2 Gaining leverage through strategic capacities

In Table 2 we summarize our main results for different assumptions on which players can make long-term commitments and hence, may form strategic coalitions. When calculating the table it was assumed that all consortia are established.

We start the interpretation by looking at the reference case, in which all players can commit and no recontracting occurs (top of panel 0). With efficient contracting, a comprehensive agreement would allow capacities to maximize industry profits. Due to our calibration of demand, the existing capacities are optimal, $K^* = (70, 28, 0)$ and yield a profit of \$ 7.0 bn/a, which is set equivalent to 100 to ease comparison. Since there is no second stage, we solve the game with the Shapley value, taking into account all investment options under the natural access regime. Russia obtains 80.3 out of a total of 100, while Poland and Belarus each get 3.6 and Ukraine 12.6. Russia's share is so large because it has many options to add transport capacities to the existing pipelines, either alone or in coalitions.[12] Now, suppose capacities are fixed at their first best level but transit countries do renegotiate. Belarus and Poland would increase their payoffs by more than two thirds up to 6.2 each and Ukraine could almost triple its share to 35.4. As a result, Russia would obtain only 52.2, hardly more than the 50 which it could obtain when dealing with a transit monopoly.

[11] In Hubert & Ikonnikova (2011) we consider some more options to bypass transit countries. But as these turn out to be of little strategic relevance, we neglect them here.

[12] When assessing bargaining power this way, we do not account for the time needed to build the alternative pipelines. As a result we tend to overestimate Russia's power. For more detail see Hubert & Ikonnikova (2011).

Table 2: Coalition structure, Investments, and Payoffs

| partition[a] payoffs | | | | total profit | control regime | capacities: old+new[b] *South* | *Yamal* | *Nord Stream* |
|---|---|---|---|---|---|---|---|---|
| *0. All can commit (first best)*[c] | | | | | | | | |
| $\{\{R,$ | $P,$ | $B,$ | $U\}\}$ | 100.0 | — | 70 | 28 | 0 |
| (80.3 | 3.6 | 3.6 | 12.6) | | | | | |
| *renegotiating*[d] | | | | | | | | |
| *(52.2* | *6.2* | *6.2* | *35.4)* | *100.0* | $G^o$ | | | |
| *1. No player can commit* | | | | | | | | |
| $\{\{R\},$ | $\{P\},$ | $\{B\},$ | $\{U\}\}$ | 77.8 | $G^o$ | 70 | 28 | 0+47 |
| (65.9, | 2.2, | 2.2, | 7.5) | | | | | |
| *2. Poland can commit* | | | | | | | | |
| $\{\{R,P\},$ | | $\{B\},$ | $\{U\}\}$ | 81.0 | $G^o$ | 70 | 28 | 0+41 |
| (68.1, | | 2.5, | 9.8) | | | | | |
| *3. Poland, Belarus can commit* | | | | | | | | |
| | | $\{\{R,P,B\},$ | $\{U\}\}$ | 89.3 | $I_R^P I_R^B(G^o)$ | 70 | 28+49 | 0 |
| | | (88.7, | 0.6) | | | | | |
| $\{\{R,B\},$ | | $\{P\},$ | $\{U\}\}$ | 81.0 | $G^o$ | 70 | 28 | 0+41 |
| (68.1, | | 2.5, | 9.8) | | | | | |
| $\{\{R\},$ | $\{P,B\},$ | | $\{U\}\}$ | 77.8 | $G^o$ | 70 | 28 | 0+47 |
| (65.9, | 4.4, | | 7.5) | | | | | |
| *4. Poland, Ukraine can commit* | | | | | | | | |
| | | $\{\{R,P,U\},$ | $\{B\}\}$ | 98.9 | $I_R^U(G^o)$ | 70+10 | 28 | 0 |
| | | (97.8, | 1.1) | | | | | |
| $\{\{R,U\},$ | | $\{P\},$ | $\{B\}\}$ | 98.3 | $I_R^U(G^o)$ | 70+15 | 28 | 0 |
| (97.1, | | 0.6, | 0.6) | | | | | |
| $\{\{R\},$ | $\{P,U\},$ | | $\{B\}\}$ | 75.8 | $T_P^U(G^o)$ | 70 | 28 | 0+51 |
| (64.2, | 11.1, | | 0.5) | | | | | |

[a]Figures are for the low demand scenario $p(Q) = 160 - 0.33Q$. A profit of 100 is equivalent to \$ 6.97 bn/a. The complete partition functions are given in the appendix.

[b]All capacities are measured in bcm/a. We assume that for all pipelines consortia are established. Hence, zero investment implies that, given the equilibrium investment of the other consortia, it is not in the interest of the consortium to invest.

[c]Individual payoffs are ex-ante Shapley values, which account for all investment options.

[d]The payoffs would be achieved when recontracting takes place with capacities fixed at their first best level.

With capacities fixed at their optimal level, Russia has little leverage over transit countries because competition between alternative transit routes is curtailed by small capacities.

As recontracting is anticipated, investment is distorted for strategic reasons. In panel 1 of Table 2 we report the results for the case when no player can commit. As no strategic coalition is formed, the partition is given by the singletons and bargaining over rents will take place under the natural access regime, $G^o$. Even if no player can commit, three consortia $C_y = \{R, P, B\}$, $C_s = \{R, U\}$ and, trivially, $C_n = \{R\}$ can form to invest in *Yamal*, *South*, and *Nord Stream*, respectively. In equilibrium, however, only the latter will invest. Russia builds a staggering 47 bcm/a on *Nord Stream* to gain leverage over transit countries. The investment expenditures reduce overall profit by more than a fifth, down to 77.8, but Russia can appropriate 65.9 while Poland and Belarus obtain 2.2 each and Ukraine is reduced to 7.5.

Now we turn to the case we consider the most realistic: Poland can commit and may form a strategic alliance $\{R, P\}$ with Russia. If the alliance is established (panel 2), then the two players jointly enter the investment consortia. As there is no need to gain leverage over Poland, the incentives of $C_n = \{\{R, P\}\}$ to invest in *Nord Stream* are diminished. Nevertheless, a capacity of 41 bcm/a is installed, which is still large enough to prevent investment in any other pipeline. Compared to the previous case, the reduction of investment expenditures increases total profit to 81.0, but lower capacities also strengthen the bargaining power of Belarus and Ukraine, who increase their shares to 2.5 and 9.8, respectively. These positive externalities cast doubts on whether the alliance $\{R, P\}$ will actually form. The loss in bargaining power practically offsets the cost saving, so that the surplus of the alliance is negligible.

### 4.3 Consortia

Before we turn to panels 3 and 4, which reflect different assumptions on commitment, we address the issue of consortia. At first glance, our assumption that players who cannot commit might nevertheless join consortia based on cost sharing, appears to have no impact on investment what so ever. In equilibrium, there is no investment in pipelines without assured access. Investment in a pipeline occurs only if all involved players can commit and form a strategic alliance — not just a consortium. However, these results reflect particular features in the North-European gas network and obscure the potential of consortia. For the sake of argument, suppose Poland does not enter a strategic alliance with Russia but instead, uses its political leverage

Table 3: Consortium Structure and Investments with *Nord-Stream* removed

| consortia[a] | | total profit | rent sharing[b] $\phi^R$ | $\phi^P$ | $\phi^B$ | $\phi^U$ | capacity: old+new (*Investment Cost*) *South* | *Yamal* |
|---|---|---|---|---|---|---|---|---|
| $C_s$ | $C_y$ | | | | | | | |
| $\{R, U\}$ | $\{R, P, B\}$ | 92.0 | 56.7 | 7.6 | 7.6 | 28.2 | 70+15 (*1.7*) | 28+29 (*6.3*) |
| — | $\{R, P, B\}$ | 93.7 | 55.1 | 9.1 | 9.1 | 26.7 | 70 (*0*) | 28+29 (*6.3*) |
| $\{R, U\}$ | — | 98.3 | 53.8 | 4.7 | 4.7 | 36.9 | 70+15 (*1.7*) | 28 (*0*) |
| — | — | 100.0 | 52.2 | 6.2 | 6.2 | 35.4 | 70 | 28 |

[a]demand: 160 - 0.33 x; Coalition structure $\{\{R\}, \{P\}, \{B\}, \{U\}\}$

[b]Scaled so that 100 is equivalent to \$ 6.97 bn/a.

in the EU to obstruct the construction of *Nord Stream*.[13] If the efforts are successful and the option *Nord Stream* is removed for political reasons, then the ability to form consortia would become relevant (for the results see table 3).

If the remaining two consortia are formed, $C_y = \{R, P, B\}$ would add a capacity of 29 bc/a at *Yamal* to gain leverage over Ukraine and $C_s = \{R, U\}$ would install 15 bc/a at *South* to weaken Belarus and Poland.[14] This constellation resembles the situation around the year 2000, when Russia, in cooperation with European importers, simultaneously pushed both options — *Yamal 2* and the upgrading of the Ukrainian system.

Provided Russia contributes at least $0.4 = 6.3 - 2(7.6 - 4.7)$ to *Yamal* and at least $0.2 = 1.7 - (28.2 - 26.7)$ to *South*, this consortium structure would be stable because no transit country could gain from leaving the consortium. Compared to investing in *Nord Stream*, the total profit goes up by 14 points, from 77.8 to 92. The highest payoff Russia can hope for without endangering the stability of the

[13]In fact, the Polish government made great efforts to stall *Nord Stream* in the years 2005-2009. It went into a serious row with Germany over the project and blocked any progress in the EU-Russian energy dialog using its veto power.

[14]One may note that the investment of $C_s$ is independent of the capacity choice by $C_y$. Recall that the profit of a consortium consists of a weighted sum of $\pi(n, 0, 0)$, $\pi(n, y, 0)$, $\pi(n, 0, s)$ and $\pi(n, y, s)$. Only the last term depends on both the capacity on Yamal and South. With our calibration of demand and supply, however, it is optimal to use exactly the already existing capacities at these two links and the marginal return on increasing any one of them is zero.

consortium structure is 56.1. This is much lower than the 65.9 which it could expect when investing in *Nord Stream*, either alone or in a strategic alliance with Poland. Poland, in contrast, would more than double its payoff from 2.2 to at least 4.7, which may explain its very hostile reaction to *Nord Stream*.[15]

### 4.4 Commitment

Now we return to the issue of commitment, asking first what would change if in addition to Poland, Belarus could make credible long term commitments. The results are presented in panel 3 of table 2. We have three more possible coalition structures, depending on whether the alliance $\{R, P, B\}$, $\{R, B\}$ or $\{P, B\}$ forms. Of these, only the first yields new results. Investment is shifted to *Yamal* and Russia obtains access rights to the sections in the transit countries. Since a strategic alliance acts as one player at the investment stage, the consortia for *Yamal* and *Nord-Stream*, both consist of the alliance $C_y = C_n = \{\{R, P, B\}\}$. Under the access regime $I_R^P I_R^B(G^o)$ the rent for the alliance is $\phi^{\{R,P,B\}} = \frac{1}{2}\pi(n, y, 0) + \frac{1}{2}\pi(n, y, s)$. In both terms, capacities at *Yamal* and *Nord Stream* are evaluated together but capacity cost and operating cost are lower for *Yamal*. Investment is therefore concentrated on *Yamal*, where an additional 49 bcm/a would be installed. The capacity is slightly larger than if Russia would invest in *Nord Stream*, but the total profit increases due to decreased capital expenditures. The formation of a strategic alliance $\{R, P, B\}$ is the worst case scenario for Ukraine, reducing its payoff to a meager 0.6. It is harmed through large capacities at *Yamal* and the change in access rights.[16]

It is also interesting to compare these results with the previous subsection in which *Yamal*-consortium invested an additional capacity of only 29 bcm/a. In both cases, the *Yamal*-consortium consists of the same players — Russia, Poland and Belarus — which invest to gain leverage over the only outside player, Ukraine. The strategic alliance also modifies the access regime to its advantage, while the simple consortium, by contrast, can expect recontracting under the natural access

[15] In both consortia, the transit countries could, in principle, 'bribe' Russia to abandon the competing project by offering to carry a larger share of the investment cost. However, even if Russia contributes nothing, it can obtain at most 55.1 when withdrawing from *South* and a maximum of 53.8 when abandoning *Yamal*. So we consider it likely that, without *Nord Stream*, viable consortia for *Yamal* and *South* would be established.

[16] The formation of $\{R, P, B\}$ appears to be very likely once Poland and Belarus can commit. Apart from virtually driving Ukraine out of the game, the total profit is increased to 89.3. The coalition offers a surplus of more than 20 over the payoffs, which single players or a coalition of players can assure when braking away, whatever the final partition may be.

regime. With access assured, the marginal return to investment for the alliance is $\frac{1}{2}\pi_y(0,y,0)+\frac{1}{2}\pi_y(0,y,s)$, which is larger than the marginal return for the consortium without commitment, which is $\frac{1}{4}\pi_y(0,y,0)-\frac{3}{4}\pi_y(0,y,s)$.[17] This comparison demonstrates that the ability to make long-term commitments matters a lot even when investment is observable and consortia can be established on the basis of cost sharing.

Finally, we consider the case of Ukraine and Poland, but not Belarus being able to commit (panel 4, table 2). Compared to panel 1 and 2, we have additional possible coalition structures, depending on whether the alliance $\{R,P,U\}$, $\{R,U\}$ or $\{P,U\}$ forms. If Poland and Ukraine establish a coalition, they effectively create a monopoly for land based transit (and all existing capacities). Russia would respond by investing into an offshore pipeline with huge dimensions, 51 bcm/a. The alliance $\{P,U\}$ imposes a substantial negative externality on the outside players $R$ and $B$ and even reduces the overall efficiency compared to a situation in which all players remain singletons. If by contrast, Russia and Ukraine form an alliance, Russia obtains access rights to Ukraine's sections, investment would be decreased substantially and shift to *South*, enhancing overall profits to 98.3. If Poland joins this coalition, investment is further reduced as there is less need to gain leverage over outside players.[18]

### 4.5 Higher Demand

Finally, we consider the impact of an increase in demand. In the high demand scenario, industry profits are maximized when low cost measures are being taken to increase capacity at *South* by another 15 bcm/a (for the results, see table 4). With higher demand, investments increase in all variants, but the overall pattern remains the same. It is the ability to make long-term commitments which dictates the direction of strategic investment, not the ability to form consortia. In equilibrium, there is investments only in links, for which the involved players can form a strategic alliance and assure access. If Belarus cannot commit, investment is directed towards *Nord Stream*. Investment is only shifted to *Yamal* if an alliance of all three involved players $\{R,P,B\}$ forms (panel 3). In both cases, the additional capacities are so large

[17] For $G^o$ we obtain the rent of $\{R,P,B\}$ by summing up in table 1 first panel as $\phi^{\{R,P,B\}} = \frac{1}{4}\pi(n,0,0)+\frac{1}{4}\pi(n,y,0)-\frac{1}{4}\pi(n,0,s)+\frac{3}{4}\pi(n,y,s)$ .

[18] Again it is easy to check the stability of these coalition structures. Russia can easily lure Ukraine away from Poland and once $\{R,U\}$ is established, even Poland can be motivated to join. The structure $\{\{R,P,U\},B\}$ is stable against any other final partition, provided Ukraine gets at least 10.5, Poland 2.2 and Russia 65.9, which leave a comfortable surplus of 20.3 to be distributed among the three players.

Table 4: Coalition structure, Investments, and Payoffs for a High Demand Scenario

| partition[a] payoffs | total profit | control regime | capacities: old+new[b] South | Yamal | Nord Stream |
|---|---|---|---|---|---|
| *0. All can commit (first best)*[c] | | | | | |
| $\{\{R, P, B, U\}\}$ | 100.0 | — | 70+15 | 28 | 0 |
| (83.2  4.2  4.2  8.4) | | | | | |
| *renegotiating*[d] | | | | | |
| *(51.6  5.8  5.8  37.8)* | | $G^o$ | | | |
| *1. No player can commit* | | | | | |
| $\{\{R\}, \{P\}, \{B\}, \{U\}\}$ | 79.8 | $G^o$ | 70 | 28 | 0+72 |
| (71.9, 1.5, 1.5, 4.9) | | | | | |
| *2. Poland can commit* | | | | | |
| $\{\{R,P\}, \{B\}, \{U\}\}$ | 80.9 | $G^o$ | 70 | 28 | 0+68 |
| (73.4, 1.6, 5.9) | | | | | |
| *3. Poland, Belarus can commit* | | | | | |
| $\{\{R,P,B\}, \{U\}\}$ | 91.6 | $I_R^P I_R^B(G^o)$ | 70 | 28+76 | 0 |
| (91.5, 0.1) | | | | | |
| $\{\{R,B\}, \{P\}, \{U\}\}$ | 80.9 | $G^o$ | 70 | 28 | 0+68 |
| (73.4, 1.6, 5.9) | | | | | |
| $\{\{R\}, \{P,B\}, \{U\}\}$ | 79.8 | $G^o$ | 70 | 28 | 0+72 |
| (71.9, 3.0, 4.9) | | | | | |
| *4. Poland, Ukraine can commit* | | | | | |
| $\{\{R,P,U\}, \{B\}\}$ | 99.5 | $I_R^U(G^o)$ | 70+23 | 28 | 0 |
| (97.4, 2.1) | | | | | |
| $\{\{R,U\}, \{P\}, \{B\}\}$ | 97.7 | $I_R^U(G^o)$ | 70+37 | 28 | 0 |
| (96.3, 0.7, 0.7) | | | | | |
| $\{\{R\}, \{P,U\}, \{B\}\}$ | 78.3 | $T_P^U(G^o)$ | 70 | 28 | 0+77 |
| (70.9, 7.0, 0.4) | | | | | |

[a] Figures are for the high demand scenario $p(Q) = 200 - 0.33Q$. A profit of 100 is equivalent to \$ 11.17 bn/a.

[b] All capacities are measured in bcm/a. We assume that for all pipelines consortia are established. Hence, zero investment implies that, given the equilibrium investment of the other consortia, it is not in the interest of the consortium to invest.

[c] Individual payoffs are ex-ante Shapley values, which account for all investment options.

[d] Ex post rents obtained when recontracting takes place with capacities fixed at their first best level. Investment cost of *1.0* are sunk at this stage, so the figures add up to *101.0*.

that they crowd out the more cost efficient upgrading of the system in the south. In this sense, we have "underinvestment" in this particular link as a byproduct of massive overinvestment in more expensive pipelines. Investment in *South* requires an alliance including Russia and Ukraine (panel 4). Such an alliance would then again overinvest, though the effect is smaller, because capacities at *South* are already large.

## 5 Concluding Remarks

This paper starts from the observation that in the North European supply chain for natural gas, the players failed to implement the least cost solution for long distance gas transport. Since investment in pipelines is easily observable, we find it difficult to explain this evidence as an example of the standard "hold-up" problem. Instead, we propose a modification of the model with observable investment where some players are unable to make long-term commitments regarding access and rent sharing. All players gaining from investment in a pipeline can establish a consortium and share investment cost, but only those players who are able to make long-term commitments can exchange access rights and agree on rent sharing. Such consortia can overcome the classical "hold-up" problem of underinvestment, where complementary players contribute too little because at the margin they face the full cost while receiving only part of the benefit. However, they cannot prevent excessive investment into competing projects. The result is a tendency towards over-investment.

The North Western gas corridor offers a unique opportunity to put theoretical results to an empirical test. The various investment options and the associated cost are sufficiently clear to allow for a quantitative specification of the parameters and to confront the results with the historical evidence. Using the calibration of Hubert & Ikonnikova (2011), we show that excessive investment in the offshore pipeline Nord Stream is a consequence of weak institutional protection of property rights in Belarus and Ukraine. At the same time the capacity at Nord Stream crowds out alternative projects, like Yamal 2 or the renovation of existing pipelines in the Ukraine-corridor. These cheaper options would stand a chance only if Nord Stream had been prevented for political reasons. Our qualitative and quantitative analysis show that in spite of large capacity cost, overinvestment and excess capacity are not a mere theoretical possibility in the Eurasian transport system for natural gas. Given the particular geography of this network, and the inability to make credible long-term commitments or large up–front payments on part of Belarus and Ukraine, there is in fact much to gain from creating countervailing power.

Overall, our quantitative results compare reasonably well to the empirical facts, both for current investment in Nord Stream as well as for earlier plans for the alternative projects. However, we tend to overestimate the distortion if compared to real world investment. While investment in the Ukraine-corridor was in fact close to zero, *Nord Stream's* planned capacity of 56 bcm/a is smaller than the 68-72 bcm/a which we predict in our second demand scenario. The discrepancy, which is not to be resolved by reasonable changes in the numerical values of our parameters, leads us to a structural deficiency of our approach. By assuming that investment can take place only once, we consider an essentially static environment. In reality bargaining over rents is not only influenced by capacities established in the past, but also by options to extend the system in the future (Hubert & Ikonnikova (2011)). A credible threat of investing in the future should enhance bargaining power and make it less necessary to actually invest in excessive transport capacities. To develop a better understanding of strategic investment in a dynamic context the sequence modeled in the present paper should, therefore, be embedded as a stage game in a model of repeated interaction (see Hubert & Suleymanova (2008) for a first attempt along this line).

Another limitation of the model is its narrow geographical scope. With Russia being the only exporter, and hence essential player, we ensure that the game can be modeled in characteristic function form at the production stage. It would be interesting to include other pipeline projects such as Nabucco, in South Eastern Europe and competing gas suppliers such as the Caspian region, Norway or northern Africa. However, with competing supply chains selling into a common market, the final production phase cannot be modeled as a game in characteristic function form. We see two alternatives: either the common market assumption is maintained and a game in partition function form is solved at the final stage (Ikonnikova (2006)), or the market is segmented into different customers, each acting as a strategic player.

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**Appendix 1: The Value Function**

The natural access regime; $G^o$:

$$\begin{aligned}
v(\{U\}) = v(\{P\}) = v(\{B\}) = v(\{U,P\}) = v(\{U,B\}) = v(\{B,P\}) &= 0 \\
v(\{R\}) = v(\{R,B\}) = v(\{R,P\}) &= \pi(n,0,0) \\
v(\{R,U\}) = v(\{R,B,U\}) = v(\{R,P,U\}) &= \pi(n,0,s) \\
v(\{R,B,P\}) &= \pi(n,y,0) \\
v(\{R,B,P,U\}) &= \pi(n,y,s)
\end{aligned}$$

Russia having access to sections of *Yamal* in Belarus and Poland; $I_R^P I_R^B(G^o)$:

$$\begin{aligned}
v(\{U\}) = v(\{P\}) = v(\{B\}) = v(\{U,P\}) = v(\{U,B\}) = v(\{B,P\}) &= 0 \\
v(\{R\}) = v(\{R,B\}) = v(\{R,P\}) &= \pi(n,y,0) \\
v(\{R,U\}) = v(\{R,B,U\}) = v(\{R,P,U\}) &= \pi(n,y,s) \\
v(\{R,B,P\}) &= \pi(n,y,0) \\
v(\{R,B,P,U\}) &= \pi(n,y,s)
\end{aligned}$$

Russia having access to *South*; $I_R^U(G^o)$:

$$\begin{aligned}
v(\{U\}) = v(\{P\}) = v(\{B\}) = v(\{U,P\}) = v(\{U,B\}) = v(\{B,P\}) &= 0 \\
v(\{R\}) = v(\{R,B\}) = v(\{R,P\}) &= \pi(n,0,s) \\
v(\{R,U\}) = v(\{R,B,U\}) = v(\{R,P,U\}) &= \pi(n,0,s) \\
v(\{R,B,P\}) &= \pi(n,y,s) \\
v(\{R,B,P,U\}) &= \pi(n,y,s)
\end{aligned}$$

Poland owning section of *South* in Ukraine; $T_P^U(G^o)$:

$$\begin{aligned}
v(\{U\}) = v(\{P\}) = v(\{B\}) = v(\{U,P\}) = v(\{U,B\}) = v(\{B,P\}) &= 0 \\
v(\{R\}) = v(\{R,B\}) = v(\{R,U\}) = v(\{R,B,U\}) &= \pi(n,0,0) \\
v(\{R,P\}) = v(\{R,P,U\}) &= \pi(n,0,s) \\
v(\{R,B,P\}) = v(\{R,B,P,U\}) &= \pi(n,y,s)
\end{aligned}$$

**Appendix 2: Proof of proposition 1**

Let $\Delta_{I_i^j}(k) = \phi^k(I_i^j(G^o); K) - \phi^k(G^o; K)$ denote the effect which an inclusive contract $I_i^j$ exerts on a third player $k$ under Shapley bargaining. Similarly, $\Delta_{E_i^j}(k)$ and $\Delta_{T_i^j}(k)$ denote the effects of exclusive contracts and ownership transfers, respectively.

Since $I_i^j$ grants player $i$ access to $j$'s resources without preventing $j$ from using them on his own, it only affects the value of those subsets $S$, which include $i$ but do not include $j$. Hence, the effect of the inclusive contract on the Shapley payoff of a third player $k$ is given by $\Delta_{I_i^j}(k) = \sum_{S:i\in S, j\notin S} p_S \Delta^2_{kj} v(S)$, which is non-positive if $\Delta^2_{kj} v(S \cup i) \leq 0$, $\forall S$. With an exclusive contract $E_i^j$ player $i$ obtains the right to exclude all players from $j$'s resources. It matters only for subsets $S$ which include $j$ but not $i$. The effect on a third player $k$ is $\Delta_{E_i^j}(k) = \sum_{S:i\notin S, j\in S} -p_S \Delta^2_{kj} v(S)$, which is non-positive if $\Delta^2_{kj} v(S \backslash i) \geq 0$, $\forall S$. A transfer of ownership gives $i$ exclusive access to the resources of $j$. As is shown in Segal (2003), the effect on $k$ is given by $\Delta_{T_i^j}(k) = \sum_{S:i\in S, j\notin S} p_S \Delta^3_{ijk} v(S)$, which is non-positive if the third difference $\Delta^3_{ijk} v(S) \leq 0$.

(i)[A]: We start with $\{R, P\}$. There are only two possible contracts: $I_R^P$ and $T_R^P = E_R^P I_R^P$. The latter contract is strategically equivalent to the former, because Russia is essential. Without Russia, the contributions of all other players are zero, hence, $R$'s right to exclude players cannot do any more harm. We ignore the ownership contract and consider only $I_R^P$. This contract weakens $U$ because the included player $P$ is substitutable to outside player $U$ in the presence of $R$ and $B$. It decreases $U$'s marginal contribution to coalition $\{R, B\}$, which has a weight of 1/12 in the Shapley value. The contribution of $U$ to any other coalition is not affected ($\Delta^2_{UP} v(\{R\}) = 0$).

$$\begin{aligned} \Delta_{I_R^P}(U) &= (1/12)\Delta^2_{UP} v(\{R, B\}) \\ &= \frac{1}{12}\left[(v(\{R, P, B, U\}) - v(\{R, P, B\})) - (v(\{R, B, U\}) - v(\{R, B\}))\right] \\ &= \frac{1}{12}\left[(\pi(n, y, s) - \pi(n, y, 0)) - (\pi(n, 0, s) - \pi(n, 0, 0))\right] \leq 0 \end{aligned} \tag{9}$$

The same contract will strengthen $B$'s bargaining power, because $B$ is complementary to $R$ in the presence of $P$. The effect is:

$$\begin{aligned} \Delta_{I_R^P}(B) &= (1/12)\Delta^2_{PB} v(\{R\}) + (1/12)\Delta^2_{PB} v(\{R, U\}) \\ &= \frac{1}{12}(v(\{R, P, B, U\}) - v(\{R, U\})) + \frac{1}{12}(v(\{R, P, B\}) - v(\{R\})) \\ &= \frac{1}{12}\left[(\pi(n, y, s) - \pi(n, 0, s)) + (\pi(n, y, 0) - \pi(n, 0, 0))\right] \geq 0 \end{aligned} \tag{10}$$

The total effect on outsiders is:

$$\Delta_{I_R^P}(U) + \Delta_{I_R^P}(B) = \frac{1}{6}(\pi(n, y, s) - \pi(n, 0, s)) \geq 0,$$

which proves that $G^{\{R,P\}} = G^o$.

(i)[B] Symmetry of $B$ and $P$ implies that $G^{\{R,P\}} = G^{\{R,B\}} = G^o$.

(i)[C] For $\{P, B\}$ the two possible contracts are $I_P^B$ and $T_P^B$.

First, we consider $I_P^B$. The impact on $U$ is (recall $(\Delta^2_{UB} v(\{R\}) = 0)$:

$$
\begin{aligned}
\Delta_{I_P^B}(U) &= (1/12)\Delta^2_{BU} v(\{R,P\}) \\
&= \frac{1}{12}\left[(v(\{R,P,B,U\}) - v(\{R,P,B\})) - (v(\{R,P,U\}) - v(\{R,P\}))\right] \\
&= \frac{1}{12}\left[(\pi(n,y,s) - \pi(n,y,0)) - (\pi(n,0,s) - \pi(n,0,0))\right] \leq 0
\end{aligned}
$$

The impact of $I_P^B$ on $R$'s bargaining power is

$$
\begin{aligned}
\Delta_{I_P^B}(R) &= (1/12)\Delta^2_{BR} v(PU) + (1/12)\Delta^2_{BR} v(\{P\}) \\
&= \frac{1}{12}(v(\{R,P,B,U\}) - v(\{R,P,U\})) + \frac{1}{12}(v(\{R,P,B\}) - v(\{R,P\})) \\
&= \frac{1}{12}\left[(\pi(n,y,s) - \pi(n,0,s)) + (\pi(n,y,0) - \pi(n,0,0))\right] \geq 0
\end{aligned}
$$

Note that $\Delta_{I_P^B}(U) + \Delta_{I_P^B}(R) > 0$. Since the total effect on an outsider is positive, $I_P^B$ is not beneficial.

The contract $T_P^B = E_P^B I_P^B$ is equivalent to $I_P^B$. The right to exclude has no additional effect because $P$ is complementary to $B$.

We conclude $G^{\{P,B\}} = G^o$.

(ii)[A] For $\{R, P, B\}$ the only outside player is $U$. We have established already that $\Delta_{I_R^P}(U) \leq 0$ and by symmetry, $\Delta_{I_R^B}(U) \leq 0$. Separately, $I_R^P$ and $I_R^B$ hurt $U$ by diminishing its contribution to $\{R, B\}$ and $\{R, P\}$, respectively. The effect of $I_R^B I_R^P$ is even stronger, because given $I_R^P$, $I_R^B$ reduces $U$'s contribution also to $\{R\}$.

$$
\begin{aligned}
\Delta_{I_R^B I_R^P}(U) &= (1/12)(\Delta^2_{UP} v(\{R,B\}) + \Delta^2_{UB} v(\{R,P\}) + \Delta^3_{UPB} v(\{R\})) \qquad (11) \\
&= \frac{1}{4}\left[(v(\{R,P,B,U\}) - v(\{R,P,B\})) - (v(\{R,U\}) - v(\{R\}))\right] \\
&= \frac{1}{4}\left[(\pi(n,y,s) - \pi(n,y,0)) - (\pi(n,0,s) - \pi(n,0,0))\right] \leq 0
\end{aligned}
$$

With $I_R^B I_R^P$ in place, all coalitions, which include $R$, have access to $n$ and $y$. Hence, $U$'s contribution cannot be reduced further by any additional contracts and $G^{\{R,P,B\}} = I_R^B I_R^P(G^o)$.

(ii)[B]: The players in $\{R, U\}$ are complements. The effect of an inclusive contract on $B$ is given as:

$$\begin{aligned}
\Delta_{I_R^U}(B) &= (1/12)\Delta^2_{BU}v(\{R,P\}) \qquad (12)\\
&= \frac{1}{12}\left[(v(\{R,P,B,U\}) - v(\{R,P,B\})) - (v(\{R,U\}) - v(\{R\}))\right]\\
&= \frac{1}{12}\left[(\pi(n,y,s) - \pi(n,y,0)) - (\pi(n,0,s) - \pi(n,0,0))\right] \leq 0
\end{aligned}$$

The effect on $P$ is symmetric. $T_R^U$ cannot make $\{R,U\}$ better off, because $R$ is essential, therefore $G^{\{R,U\}} = I_R^U(G^o)$.

(iii) The players in coalition $\{P,U\}$ are substitutes in the presence of the outsiders $R$ and $B$, hence, they would lose from inclusive contracts. If $P$ acquires $U$'s resources, the effect on $B$ is

$$\begin{aligned}
\Delta_{T_P^U}(B) &= (1/12)\Delta^3_{UPB}v(\{R\}) \qquad (13)\\
&= \frac{1}{12}\left[(v(\{R,P,B,U\}) - v(\{R,P,B\})) - (v(\{R,U\}) - v(\{R\}))\right]\\
&= \frac{1}{12}\left[(\pi(n,y,s) - \pi(n,y,0)) - (\pi(n,0,s) - \pi(n,0,0))\right] \leq 0.
\end{aligned}$$

The effect of $T_P^U$ on player $R$ is the same

$$\begin{aligned}
\Delta_{T_P^U}(R) &= (1/12)\Delta^3_{PUR}v(B) + 1/12)\Delta^3_{PUR}v(\emptyset) \qquad (14)\\
&= \frac{1}{12}\left[(v(\{R,P,B,U\}) - v(\{R,P,B\})) - (v(\{R,U\}) - v(\{R\}))\right]\\
&= \frac{1}{12}\left[(\pi(n,y,s) - \pi(n,y,0)) - (\pi(n,0,s) - \pi(n,0,0))\right] \leq 0,
\end{aligned}$$

hence, $\Delta_{T_P^U}$ is beneficial and by symmetry of $T_P^U$ and $T_U^P$ we conclude that $G^{\{P,U\}} \in \{T_P^U(G^o), T_U^P(G^o)\}$.

(iv): For $\{R,P,U\}$ we have to consider $I_R^U$, $T_U^P$, $(T_P^U)$, and the composition $T_U^P I_R^U$. Comparison of (12) and (13) shows that the separate effect of $I_R^U$, $T_U^P$ are of equal magnitude. With $I_R^U$ already in place, $T_U^P$ would reduce $B$'s contribution to $\{R,P\}$ but increase the contribution to $\{R,U\}$ by the same amount.

$$\begin{aligned}
\Delta_{T_U^P I_R^U}(B) &= \frac{1}{12}\Delta^3_{BUP}v(\{R\})\\
&= \frac{1}{12}\left[\Delta_B v(\{R,P,U\}) - \Delta_B v(\{R,P\})\right]\\
&= \frac{1}{12}\left[(\pi(n,y,s) - \pi(n,y,0)) - (\pi(n,0,s) - \pi(n,0,0))\right] < 0
\end{aligned}$$

Since $I_R^U$ requires the smallest amount of transactions, we characterize $G^{\{R,U,P\}} = I_R^U G^o$. ■

**Appendix 3: The Partition Functions**

$M = \{R, P\}$

$A = \emptyset$ : $\Pi^{\{R\}}(P_\emptyset) = 65.9$ $\Pi^{\{P\}}(P_\emptyset) = 2.2$

$A = \{R, P\}$ : $\Pi^{\{R,P\}}(P_{\{R,P\}}) = 68.1$

$M = \{R, P, B\}$

$A = \emptyset$ : $\Pi^{\{R\}}(P_\emptyset) = 65.9$ $\Pi^{\{P\}}(P_\emptyset) = 2.2$ $\Pi^{\{B\}}(P_\emptyset) = 2.2$

$A = \{P, B\}$ : $\Pi^{\{R\}}(P_{\{P,B\}}) = 65.9$ $\Pi^{\{P,B\}}(P_{\{P,B\}}) = 4.4$

$A = \{R, P\}$ : $\Pi^{\{R,P\}}(P_{\{R,P\}}) = 68.1$ $\Pi^{\{B\}}(P_{\{R,P\}}) = 2.5$

$A = \{R, B\}$ : $\Pi^{\{R,B\}}(P_{\{R,B\}}) = 68.1$ $\Pi^{\{P\}}(P_{\{R,B\}}) = 2.5$

$A = \{R, P, B\}$ : $\Pi^{\{R,P,B\}}(P_{\{R,P,B\}}) = 88.7$

$M = \{R, P, U\}$

$A = \emptyset$ : $\Pi^{\{R\}}(P_\emptyset) = 65.9$ $\Pi^{\{P\}}(P_\emptyset) = 2.2$ $\Pi^{\{U\}}(P_\emptyset) = 7.5$

$A = \{P, U\}$ : $\Pi^{\{R\}}(P_{\{P,U\}}) = 64.2$ $\Pi^{\{P,U\}}(P_{\{P,U\}}) = 11.1$

$A = \{R, P\}$ : $\Pi^{\{R,P\}}(P_{\{R,P\}}) = 68.1$ $\Pi^{\{U\}}(P_{\{R,P\}}) = 9.8$

$A = \{R, U\}$ : $\Pi^{\{R,U\}}(P_{\{R,U\}}) = 97.1$ $\Pi^{\{P\}}(P_{\{R,U\}}) = 0.6$

$A = \{R, P, U\}$ : $\Pi^{\{R,P,U\}}(P_{\{R,P,U\}}) = 97.8$

### Appendix 4: calibration

We use essentially the same calibration as in Hubert & Ikonnikova (2011) dropping only some pipeline options which they found to be of minor strategic relevance.

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. To obtain a realistic picture of the differences in transportation cost, these items are estimated for every possible link separately.

*Capacity Cost.* For existing pipelines (*South*, *Yamal 1*) capacity costs are sunk and can be ignored in the analysis. With regard to new projects, like *Nord Stream* and *Yamal 2*, there is considerable variation in published cost estimates.[19] 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 decreases 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.[20] For simplicity, we calculate cost for a large increase of capacity and assume the resulting

[19] 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 $1.04 \approx 1$. We are grateful to engineers from Wintershall AG for helpful discussions about our approach and cross checking of parameter assumptions.

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

cost per unit to be constant over the relevant range. Since we obtain rather large additional investments, this simplification will be of little consequence. 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 costs vary considerably between the different investment options. For *South* and *Yamal 1* capacity cost are sunk, other projects, such as *Upgrade*, and *Yamal 2* 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 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.

### (ii) Demand and Production Cost

Unfortunately, we cannot base the calibration on solid data with respect to demand and production cost. 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 reflect 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 sunc

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 | $\infty$ | 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 | $\infty$ | 16 | 0.25 | 0.1 |
| | New pipeline parallel to *Yamal 1* with some preparations already made. | | | | |
| *Nord Stream* | 215 | $\infty$ | 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. | | | | |

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 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 $N$. At the beginning of the decade, most observers expected a steady increase in demand, but *Yamal 1* was built up slowly 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 to the figure of 115 \$/tcm for revenues net of taxes given in Stern (2005) based on Gazprom's income statements — though Murray (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 inverse demand, an intercept of 160 \$/tcm and slope of $-0.33$, imply an elasticity of almost 4 at the profit maximizing quantity. As for 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.[21] 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.

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