Strategic Investment in International Gas-Transport Systems
A Dynamic Analysis of the Hold-up Problem

preliminary draft, not for quotation: March 2006

Franz Hubert
Humboldt–Universität zu Berlin
hubert@wiwi.hu-berlin.de

Irina Suleymanova
Humboldt–Universität zu Berlin

Franz Hubert, Irina Suleymanova

Humboldt Universität zu Berlin

Strategic Investment in International Gas-Transport Systems
A Dynamic Analysis of the Hold-up Problem

Abstract

We develop a dynamic model of strategic investment in the Eurasian transport system for natural gas. In the absence of international contract enforcement, countries may distort investment in order to increase their bargaining power, resulting in underinvestment in cheap and/or overinvestment in expensive pipelines. With repeated interaction, however, there is a potential to increase efficiency through dynamic collusion. In the theoretical part we establish a fundamental asymmetry: it is easier to avoid overinvestment than underinvestment. Calibrating the model to fit the Eurasian pipeline system, we find that the potential to improve efficiency through dynamic cooperation is large. In reality, however, only modest improvements over the non–cooperative solution have been achieved.

Keywords: multilateral bargaining, hold up, networks, dynamic collusion;
JEL: L95, L14, C71

1 Introduction

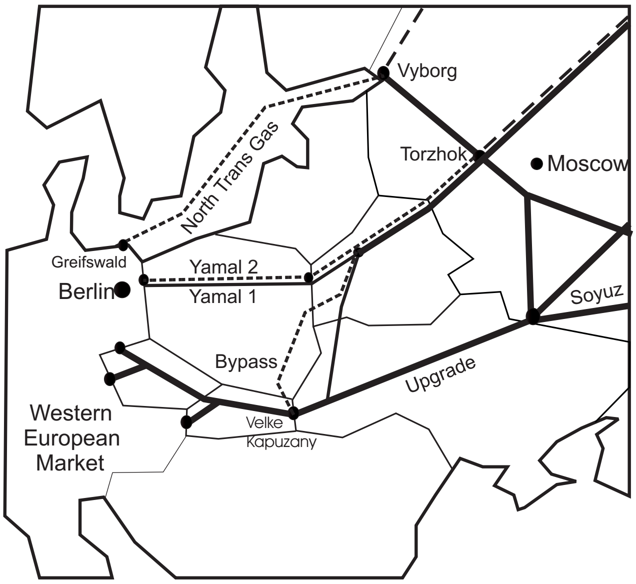
In late 2005, Russia and Germany singed a treaty to build a huge new offshore pipeline through the Baltic Sea, the *North European Gas Pipeline* (*NEGP*). The project will enable Russia to maintain its position as major supplier of natural gas to Western Europe.[1] Plans for an offshore pipeline to Western Europe have been around for a quite awhile under names like *Baltic Ring*, and *North Trans Gas*. However, for a long time Russia's western partners have dragged their feet, mainly because of all possible ways to increase the transport capacity for natural gas from Russia to Western Europe, this variant is the most expensive. It looks as if history is repeating itself with *NEGP*. In the late nineties a new pipeline through Byelorussia and Poland, *Yamal I*, has been built, although it would have been much cheaper to upgrade and renovate old pipelines in the south, running through Ukraine into Slovakia and the Czech Republic. (See figure 1 for an illustration of the network.) With *Yamal I* already in place and the southern system still in decay, there are a number of commercially more attractive and technologically less demanding alternatives to *NEGP*: upgrading the old system, adding a second pipeline to *Yamal I*, even building new pipelines in the south. However, cost and technological risk are only part of the picture. As the hostile reactions from Poland, the Baltic States and Ukraine suggest, *NEGP* will alter the balance of power in the region.

Production and transportation of natural gas are characterized by large initial investment in specialized facilities with a long lifetime and low operating costs. Most of the expenditures on project identification, investment planning and construction are sunk. Once installed, capacities generate large quasi–rents. Hence, it is essential that the players can credibly commit to grant access to pipelines on agreed terms. Currently, there are no international institutions which could enforce multilateral contracts in case of a dispute. If some countries cannot commit ex-ante to share the rents in long term contracts, recontracting after completion of the investment is anticipated. As a result, investment may be distorted to gain leverage in the bargaining process.

The Eurasian pipeline system offers a unique opportunity to investigate multilateral bargaining and its impact on investment both theoretically and quantitatively. Hubert & Ikonnikova (2003) quantify the strategic value of different investment options by measuring their impact on the profit shares of the countries involved in the supply chain under Shapley bargaining. In Hubert & Ikonnikova (2004) a two stage multilateral bargaining

[1] Throughout this paper we will refer to 'Western Europe' as the market consisting of the old EU-countries excluding Greece, which are connected through a dense network of pipelines. For ease of reference, we use the names of the countries instead of companies when there is no risk of confusion. Hence we speak of Russia rather than Gazprom, Ukraine instead of Naftogaz, etc.

Figure 1: Transport Network for Russian Gas



game is developed in order to investigate strategic distortions of investment. At the first stage, the players form strategic coalitions by negotiating contracts over access rights and jointly investing in transport capacities. At the second stage, investment cost are sunk, capacities are given and the players bargain onthe sharing of the rents from previous investment. Two stage games are a standard tool in the theoretical analysis of the hold–up problem. However, as the numerical results in Hubert & Ikonnikova (2004) show, the strategic effect is overestimated if confronted with historical data. One possible reason for the discrepancy is that two stage models rule out the use of credible threats to support cooperation.

In the present paper, we develop a dynamic model of investment and multilateral bargaining and calibrate it to the Eurasian supply chain for natural gas. In every period, the players bargain onthe sharing of rents from previous investment. At the same time, however, they can form new coalitions for new investment. Additional transport capacities have a long lasting impact on bargaining power, but they become available only with some delay. In this dynamic, infinite horizon setup, we investigate how dynamic cooperation based on trigger–like strategies can improve the efficiency of investment. As in Hubert & Ikonnikova (2004), the distinction between short–term and long–term cooperation is crucial. Short–term cooperation refers to the coordinated use of the existing transport capacities in any given period. It also includes the sharing of current profits if this has not been done previously in a long–term agreement. In spite of heavy disputes between Russia and the transit countries, incidents of interruption of gas transport have been extremely rare and had virtually no impact on the gas supply in Western Europe.[2] Therefore, we assume that all players are able to cooperate in the use of existing capacities. Long term cooperation revolves around the joint determination of transport capacities, ownership or secured access rights, and long term rent sharing. It requires commitment over time spans of up to forty years. In principal, these commitments can be based on contracts, which are enforced by external institutions and/or credible concerns for reputation. From the experience of the Eurasian gas network, we conclude that in the absence of external contract enforcement at least some countries are not able to make credible long term commitments. With repeated interaction, however, long term cooperation can also be based on dynamic strategies, which support cooperation by the mutual threat of switching to non–cooperation. This, feature is absent in Hubert & Ikonnikova (2004).

In the non–cooperative situation, the players share profits according to their current bargaining power, as determined by the existing capacities along the various tracks. At the same time, they invest non-cooperatively, taking into account the impact on future profit sharing. In the cooperative situation, in contrast, they agree on profit sharing and investment policy, which deviates from current bargaining power and economizes on total investment cost. However, in the absence of external enforcement, these agreements have to be dynamically incentive compatible.

We identify two mechanisms by which strategic investment in capacities effects cooperation. The first, direct effect operates through the gains from deviating from cooperation. Players may invest in alternative, though expensive, routes in order to reduce the gains from deviation. This effect is similar to the strategic reasoning in a two stage model, but less pronounced. The second, indirect effect is completely new. It works through the impact on payoffs in case of punishment. Earlier investments create capacities, which in turn would affect investments at a later stage if cooperation were to brake down.

The theoretical model predicts that overinvestment is reduced compared to a two period setup. Since investment can be delayed, investing less in expensive capacities today creates a rational threat in case cooperation breaks down. However, reducing underinvestment turns out to be more difficult. This is due to the fact that investment, by permanently strengthening the bargaining power of a player, makes deviation from cooperation more attractive.

[2]Since the collapse of the Soviet Union, gas supplies have been interrupted only twice. The first incident was in February of 2004 for two days, when Russia stopped supplies along the Yamal pipeline after Bjelorussia diverted gas towards own consumption. The second time was for two days in January of 2006, when Ukraine diverted gas earmarked for Western Europe after Russia turned off supply to the country in a conflict over prices.

Using a similar calibration of the model as in previous literature, we obtain quantitative results for equilibrium capacities in the Eurasian pipeline system, both for the non–cooperative and the best cooperative outcome compatible with the dynamic incentive constraint. We show that the potential for avoiding over- and underinvestment through dynamic cooperation is large. For some variants, even the first best can be achieved. However, comparison with real–world data suggests that countries have failed to fully exploit this potential. Nevertheless, dynamic strategies seem to matter in the Eurasian transport system. Empirical distortions are smaller than those prevailing in the non–cooperative equilibrium.

The paper is obviously related to the large body of literature on hold–up and second sourcing. In most of this literature, it is assumed that contracts are incomplete due to information problems, which limit external enforcement by a third party. Possible remedies arise from the fact that an enforcing agency may observe at least some relevant features, which then can be incorporated into the contract as a substitute to improve efficiency. However, investment in transport capacity for natural gas is verifiable, and so are most contract violations during the operating stage. Hence, from the technical side, there is little reason to assume that contractual incompleteness and the resulting hold–up problem are of particular relevance in gas transportation. This hypothesis is supported by the fact that, historically, the Eurasian transmission system was developed under long–term agreements. Such cooperation is fragile since the players are sovereign nations or firms strongly connected to their respective governments. In some countries, the separation of business and politics has not been firmly established and there is no truly independent legal system. As there is also no international arbitration system, legal remedies are hardly available even if it is plainly clear who is breaching the contract. In this aspect, this paper is related to the literature on lack of investor protection and tax competition among sovereign states (e.g. Janeba (2000)). It differs, however, in its focus on multilateral bargaining among heterogeneous players, the dynamic set up, and the quantitative application. While there is a small literature exploring the strategic implication of Shapley bargaining for choice of technology and merger in general models (Inderst & Wey (2001), Jeon (2002)), we are not aware of previous use of a dynamic version in applied quantitative studies of industrial organization.

Finally, our work can be related to the literature on the gas–industry. Grais & Zheng (1996) and Chollet & Meinhart & von Hirschhausen & Opitz (2001b) provide a quantitative analysis of the strategic interaction in transmission systems for gas. None of them derives the bargaining power endogenously from the architecture of the transmission system. Instead, they assume that Russia has all the bargaining power but is restricted to set simple linear prices while transit countries determine quantities. Due to double marginalization, the quantities supplied to the markets in Western Europe may be inefficiently low.

In section 2 we develop the analytical framework and establish a basic asymmetry: it is easier to avoiding overinvestment through dynamic cooperation than underinvestment. In section 3 we show how geography and access rights interact to determine the payoff from bargaining over rents. We explain the calibration of the model in section 4 and present and discuss the results of the numerical calculation in section 5. The appendix contains the proofs and some technical background information.

2 The Model

Let N denote the set of players consisting of Russia, Poland, Byelorussia, and Ukraine, to which we will refer later with their initials R,P,B, and U. Essentially, these players control three links: North European Gas Pipeline *NEGP*, *Yamal*, and the old system of pipelines in the south, to which we will refer as *South*.[3] For a realistic assessment, it is necessary to further distinguish among (i) existing capacities, which can be made available immediately at zero cost; (ii) the upgrading of existing pipelines, which can be achieved with little delay and low marginal cost by adding compressor stations; and (iii) completely new pipelines, which require a long time for planning and construction. For the analysis in this section, it is sufficient to distinguish a vector K of existing capacities and new investment k. As there is little danger of confusion, we will occasionally denote the set of links also with K and refer to a single pipeline l as $l \in K$. In any period, K can be used to generate operating profit $\pi(K)$. All investment costs are sunk so we refer to π also as "rent". Transport capacities can be left idle and all links are substitutes. Hence $\partial\pi/\partial l \geq 0$ and $\partial^2\pi/\partial l\partial h \leq 0$ for any $l,\ h \in K$. In order to focus on the dynamics of strategic interaction, we assume that the economic environment is stationary, i.e. we abstract from growth of demand, depletion of gas fields, technical progress, etc.

Suppose a decision is made in $t = 0$ to increase the capacity by k. Planning, preparations, and construction cause a delay of δ periods before the capacity increases to $K + k$ in $t = \delta + 1$. The unit costs of capacity are assumed to be constant but specific for each investment option. Their present value in $t = \delta$, i.e. one period before the new capacity becomes available, is denoted c. We abstract from depreciation and assume that capacity is permanent. With discount rate r we obtain the annualized cost of investment for $t > \delta$

[3]In Hubert & Ikonnikova (2003) it is shown that other possible connections, bypassing Ukraine or Bjelorussia, have little strategic value. To simplify the analysis we omit them in this paper.

as $r \cdot c \cdot k$.

Non-cooperative Stage Game

As a first step we analyze the equilibrium in which the players fail to use dynamic strategies to achieve long term cooperation. In simple models of repeated interaction, this equilibrium is given by the non-cooperative Nash equilibrium of the one shot game. In our context, however, we allow for limited, short term, cooperation. We first address the use of existing pipelines and then turn to investment in new capacities.

As players control only sections of the transportation links, they have to form coalitions $S \subseteq N$ in order to generate revenues. We represent the strategic interaction as a game in characteristic function form, with $v(S)$ denoting the profit, or 'value', of coalition S. In deriving the value function, we have to account for capacities and access rights. Let capacities along the various tracks be given by $K = \{n, y, s\}$, where lower case initials n, y, s denote *NEGP*, *Yamal* and *South*, respectively. If every country has access only to sections within its own territory, the value of the coalition of Russia and Ukraine is given as $v(\{R, U\}) = \pi(n, 0, s)$. Both together can use whatever is available on *NEGP* and *South*. The value for Ukraine and Poland is $v(\{P, U\}) = \pi(0, 0, 0) = 0$, because they are not able to establish a complete link.[4] Since v is superadditive, the assumption of efficient short term cooperation requires that the players are able to form the grand coalition N in this game.

In the absence of a long term agreement, profits are shared through some form of bargaining process. We follow Hubert & Ikonnikova (2004) in solving the rent-division game with the well–known Shapley value. The Shapley value assigns a unique payoff ϕ_i to every player $i \in N$. The payoff is equal to the player's expected contribution to all possible coalitions, assuming that coalitions are formed by adding players at random.

$$\phi_i = \sum_{S:i \notin S} \frac{|S|!\,(|N| - |S| - 1)!}{|N|!} \cdot [v(S \cup i) - v(S)]\,. \tag{1}$$

The first factor in the summand gives the probability of a particular coalition S assuming that all possible orderings of players are equally likely. The second is the marginal contribution of the player i. Using the Shapley value we derive the 'strength' of a player endogenously from his role in gas production and transmission. We say that investment,

[4] 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 here because one player, Russia, is essential in this 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 including Russia. For a full characterization of the value function, see appendix.

or any other change of the value function, increases the bargaining power of a player if it increases his share of the payoff.

Besides using the current transportation network, the players have to decide on investment. In the non-cooperative equilibrium, each player i selects a vector of investments k_i to maximize his expected payoffs from future bargaining net of initial investment cost given the equilibrium strategies of the other players. We rule out that players install incompatible capacities on their respective sections of a pipeline. Whoever invests in a pipeline will make sure that the capacity is increased along the whole track and that the sections are connected. It is in the interest of all players involved in a pipeline to cooperate in the technical implementation of a project even if they do not want to contribute financially or cannot commit to grant each other access rights.[5] As a result, investments of different players on the same track are perfect *substitutes* and we can write $k = \sum_{i \in N} k_i$ and define the equilibrium as follows:[6]

Definition 1 (Equilibrium non-cooperative stage game) *Given capacity K, the equilibrium in the non–cooperative stage game is characterized by a set of payoffs and investment plans $(\phi_i(K), \hat{k}_i(K))$ for all $i \in N$, so that:*[7]

$$\hat{k}_i(K) = \underset{k_i \geq 0}{\text{argmax}} \quad \phi_i(K + \sum_{N \setminus i} \hat{k}_j + k_i) - r \cdot c \cdot k_i \tag{2}$$

The payoffs ϕ are unique; the equilibrium investments not necessarily so. From (2) follows the first order condition for positive investment in link l by player i as $\partial \phi_i / \partial l = r \cdot c$. Players for which this is achieved at the largest capacity l 'crowd out' all others. If there is more than one player with maximal marginal returns to investment, the division of

[5] Alternatively, one could assume that the players invest only on their section of a link. In this case, investments would be perfect *complements* and total capacity would be limited by the smallest investment along the track. However, this would require that (out of equilibrium) players spend huge sums over several years on pipeline projects which have no connection on other players' territory and are therefore completely worthless.

[6] Note that we can rule out staggered investment strategies. With efficient implementation and constant marginal cost, all investment is done immediately. To see this, consider a link $l \in K$ and a player i such that $\partial \phi_i / \partial l > 0$, as is necessary for positive investment. From $\partial^2 \pi / \partial l \partial h \leq 0$, and the definitions of v and ϕ it follows that $\partial^2 \phi_i / \partial l \partial h \leq 0$, $\forall \, h \in K$. Since capacities can only increase over time, the marginal returns to investment can only decrease. Hence, whatever the strategies of the other players are, player i will invest immediately or never.

[7] We choose the notation $\phi_i(K)$ to emphasize the role of capacities which are used to calculate the value function. The value function also reflects the current access regime. However, borrowing insights regarding access rights from Hubert & Ikonnikova (2004) it is convenient to omit this dependency in the notation. We also extend the definition of ϕ to sets of players and write $\phi_S = \sum_{i \in S} \phi_i$.

investment is undetermined and there exists a continuum of equilibria. However, when we apply this framework to the specific features of the Eurasian gas network, the problem of multiple equilibria will play no role. Therefore, in the following we assume that the equilibrium investment is unique.

We now turn to the level of investment. As a benchmark, assume that all players could commit to a long term sharing rule. Then, the decisions how to share and how to invest can be separated. The grand coalition of all players would choose investment $k^* \geq 0$ to maximize $v(N)|_{K+k^*} - r \cdot c \cdot k$. Writing $K^*(K) = K + k^*$ and using $v(N) = \phi_N$ we obtain the first order condition for an interior solution for link $l \in K$ as

$$\frac{\partial}{\partial l}\phi_N(K^*(K)) = r \cdot c_l. \tag{3}$$

In the non-cooperative stage game, every player (or coalition of players) anticipates the impact which capacities have on bargaining power in the future. Using $\phi_i = \phi_N - \phi_{N\backslash i}$ we obtain the first order condition for an interior solution at link $l \in K$ evaluated at equilibrium capacities $\hat{K}(K) = K + \hat{k}$ from equation (2) as:

$$\frac{\partial}{\partial l}\phi_N(\hat{K}(K)) - \frac{\partial}{\partial l}\phi_{N\backslash i}(\hat{K}(K)) = r \cdot c_l. \tag{4}$$

The second term on the left hand side reflects the strategic role of investment and is responsible for the differences between non-cooperative capacities $\hat{K}$ and efficient capacities K^*. For the sake of the argument, suppose that investment is efficient in all links except for one link l in which the marginal player i contemplates investing. If investment increases the bargaining power of the other players ($\partial\phi_{N\backslash i}/\partial l > 0$), then for player i the gains from investment are decreased and we obtain *underinvestment* compared to the first best. In the opposite case, if investment decreases the bargaining power of others, the result is *overinvestment*. For $\partial\phi_{N\backslash i}/\partial l > 0$ and c_l sufficiently small, we even obtain excess capacity, i.e., capacity for which $(\partial/\partial l)\phi_N(\hat{K}(K)) = 0$, so that part of it remains idle. We summarize:[8]

Proposition 1 *For strategic reasons investment may be distorted. Compared to the first best, we may obtain underinvestment, or overinvestment, and even excess capacity, which will remain idle.*

The possibility of underinvestment is a variant of the well known 'hold up' problem. If the returns on investment are ex-ante not contractible but shared according to some bargaining

[8]This result has been derived in Hubert & Ikonnikova (2004).

rule, the incentives to invest are decreased accordingly. The possibility of overinvestment is central in the literature on second sourcing, or in strategic investment in international production facilities in the absence of tax commitment Janeba (2000).

Dynamic cooperation

Now we turn to the central question of this paper. Can the inefficiencies associated with strategic investment be alleviated through dynamic collusion? We envisage a tacit agreement on a system of transfers $\tilde{T}_i$ and investments $\tilde{k}_i$ for all players $i \in N$ which is supported by the following strategy:

$$\{T_i, k_i\} = \begin{cases} \{\tilde{T}_i, \tilde{k}_i\} & \text{if} \quad \{\tilde{T}_j, \tilde{k}_j\} \quad \forall j \in N \backslash i \\ \{\phi_i, \hat{k}_i\} & \text{else} \end{cases}$$

Cooperation breaks down if one player starts bargaining for an increase of his assigned share or if one player deviates from the agreed investment schedule. The former is obvious. It is not possible to increase the share of one party without renegotiating all payments. The latter is due to the fact that investment in transport capacity is easily observable. Upon observing that a player deviates from cooperative investment, all others anticipate that cooperation will fail once the capacities become available. Backward induction leads them to defect immediately. While cooperation breaks down immediately, the full impact is to be felt only with delay. Initially, non-cooperative payments reflect the bargaining power of the players at given capacities, i.e. $\phi(K)$. This is the time when the deviating party might earn profits. Once capacities increase to $\hat{K}(K) = K + \hat{k}$ in $t = \delta + 1$, payments adjusts to $\phi(\hat{K})$. This corresponds to the punishment phase.[9]

Definition 2 (Cooperative dynamic equilibrium) *A cooperative equilibrium is characterized by $(\tilde{T}_i, \tilde{k}_i)$ for all $i \in N$, so that:*

$$\frac{\tilde{T}_i}{r} \geq \phi_i(\tilde{K}) \sum_{t=1}^{\delta} \frac{1}{(1+r)^t} + \frac{\phi_i(\hat{K}(\tilde{K}))}{r} \frac{1}{(1+r)^\delta} - c \cdot \hat{k}_i(\tilde{K}) \frac{1}{(1+r)^\delta}, \tag{5}$$

$$\tilde{T}_i \geq \phi_i(\hat{K}(K)) \tag{6}$$

In order to sustain cooperation, the present value of future income from cooperation (given by the left hand side of expression (5)) must not be less than what can be obtained by defecting (the right hand side). The first term on the right hand side reflects the payments

[9] This is a slight variation of the usual story in which the deviating party chooses the best response against the others, which still play cooperatively.

resulting from bargaining at existing capacities. The second term is the present value of the income given non–cooperative capacities, which become available in $\delta+1$, and the last term stands for the cost of adding capacities. Finally, the player must not be worse off than by repeatedly playing the non–cooperative stage game from the very beginning on (condition (6)).

In order to gain from cooperation, the players have to decrease the strategic distortion of investment. Whether they are able to do so depends on the effect of investment on the dynamic incentive constraint. To develop some general insights, we assume that equilibrium investment is characterized by the first order conditions for an interior solution. Suppose that player i is selected to orchestrate the cooperation to his advantage. To simplify the argument, assume that the other players will not invest in case cooperation were to break down. From the dynamic incentive constraint (5) we derive the minimum transfer to player $j \in N\backslash i$ as

$$T_j = \phi_j(\tilde{K})\left(1 - \frac{1}{(1+r)^\delta}\right) + \phi_j(\hat{K}(\tilde{K}))\frac{1}{(1+r)^\delta} \quad .$$

Player i proposes a compensation scheme $\tilde{T}$ and capacities $\tilde{K}$ to maximize $\phi_N(\tilde{K}(K)) - \sum_{N\backslash i}\tilde{T}_j - r \cdot c \cdot \tilde{k}$.[10] Substituting for T we obtain the following first order condition:

$$\frac{\partial}{\partial l}\phi_N(\tilde{K}(K)) - \frac{\partial}{\partial l}\phi_{N\backslash i}(\tilde{K}(K)) + \frac{1}{(1+r)^\delta}\,D \;=\; r \cdot c_l \tag{7}$$

with

$$D \;\equiv\; \frac{\partial}{\partial l}\phi_{N\backslash i}(\tilde{K}(K)) - \frac{\partial}{\partial l}\phi_{N\backslash i}(\hat{K}(\tilde{K}))\frac{\partial}{\partial l}\hat{l}(\tilde{K}) - \sum_{h \in K\backslash l}\frac{\partial}{\partial h}\phi_{N\backslash i}(\hat{K}(\tilde{K})) \cdot \frac{\partial}{\partial l}\hat{h}(\tilde{K}). \tag{8}$$

D captures the difference which dynamic cooperation makes for strategic investment. Long lasting investment has two effects on the ability to support cooperation in equilibrium. It has a direct impact on the short term gains from defection (the first term of D). In addition, it may have an indirect effect on the long term payoffs after deviating from cooperation, which depends on how non-cooperative capacities $\hat{K}$ relate to cooperative capacities $\tilde{K}$. This effect on the ability to 'punish' deviations can be decomposed into two components: the link's effect on its own non–cooperative capacity, and the effect on other links (second and third term of D).

Now we consider two special cases. Pure overinvestment requires that there exists at least one link $l \in K$ so that $l^* < \hat{l}$ and there is no $h \in K$ for which $h^* > \hat{h}$. Similarly, pure

[10] Since the dynamic incentive constraints are fulfilled, cooperation will continue and player i's own cost of investment in case of deviation does not matter.

underinvestment requires that $\exists\, l \in K$ so that $l^* > \hat{l}$ and $\nexists\, h \in K$ for which $h^* < \hat{h}$. The next proposition (2) establishes a fundamental asymmetry in the possibility to improve efficiency through dynamic cooperation.

Proposition 2 *[**pure cases**] In the case of pure overinvestment, dynamic cooperation can increase the efficiency, except if delay is infinitely long ($\delta = \infty$). If capacities become available without delay ($\delta = 0$), even first best can be achieved. In contrast, in the case of pure underinvestment no improvement is possible.*

For the proof see appendix. In the case of pure overinvestment, cooperation allows for lower capacities. There is no lasting impact. If cooperation were to break down at a later stage, the same capacities would be installed as if cooperation would have failed from the very beginning. Without delay, the threat of strategically distorting investment is enough to insure cooperation. This result corresponds to the 'folk theorem' in the theory of repeated games, according to which cooperation can always be supported as an equilibrium, provided the discount rate is small enough. Only if the delay goes to infinity ($\delta \to \infty$), we obtain the non–cooperative solution as a limiting case. In the case of underinvestment, cooperation aims to increase the capacity. Such an increase, however, has a permanent effect. In the pure case, dynamic cooperation cannot bring any improvement over the stage game. This result is not in contradiction to the folk-theorem because investment, being permanent, alters the game over time.[11] Since pure underinvestment is the typical result in the hold–up literature, proposition 2 can also be interpreted as a justification of the dominant modelling strategy in this literature, which relies on a two stage game.[12]

With simultaneous underinvestment on some and overinvestment on other links, the asymmetry can be restated in weaker form.

Proposition 3 *[**mixed case**] If there is both underinvestment and overinvestment in the non–cooperative case, avoiding overinvestment can also help to reduce underinvestment. However, $\delta = 0$ is not sufficient to achieve first best.*

If both distortions would prevail in the non–cooperative case, it is possible to alleviate both. By reducing overinvestment in expensive links a credible threat is created, which

[11] For a similar result for investment on collusion in Cournot Duopoly see Feuerstein & Gersbach (2003).

[12] Castaneda (2005) considers a bilateral hold–up problem in a repeated relationship. The means to encourage proper investment is an option to integrate. With repeated interaction, it is optimal to grant this option without delay. However, as to investment itself, the analysis is basically a variant of the two stage model. Investment can be made only once at the beginning of the cooperation.

allows to increase the capacity in cheap links permanently. What matters is the threat, that is, the difference between non–cooperative capacities and capacities already installed on the expensive links. As this difference decreases, the room for investment in cheap links is reduced.

3 Geography and Access Rights

In order to analyze the scope for dynamic cooperation in the Eurasian pipeline system, we have to calculate the Shapley value ϕ from operating profits π, taking into account capacities and access rights, and relate them to the cost of installing capacities along the different tracks.

A player's bargaining power depends on his command over pipelines. Initially, it is determined by geography and the architecture of the transport grid. However, to the extent that players can make credible long term commitments, they can exchange access rights — modifying the natural access regime to their advantage. As to the ability to make credible long term commitments, we consider four scenarios. As a benchmark case we assume that no country can commit. In this case the natural access regime governs bargaining over rent. For the current situation, it appears most adequate to assume that only Russia and Poland can make long term commitments. In this standard case we allow a coalition $\{R, P\}$ to form, optimally exchange access rights and jointly determine investment. In the third variant, reflecting the situation in the middle nineties, we assume that Byelorussia's independence from Russia was perceived to be restricted, so that opportunistic recontracting was not considered as a threat. In this case, we allow the coalition of $\{R, B, P\}$ to form. Finally, we may envisage a situation in which Ukraine, moving towards the European Union, subjects itself to international arbitration. In this case the coalition $\{R, P, U\}$ can form.

Hubert & Ikonnikova (2004) analyze in some detail how the different coalitions would optimally modify the access regime. Using results from Segal (2003), they prove that the coalition of $\{R, B, P\}$ would grant Russia access rights to the sections of $Yamal$ in Poland and Byelorussia, while the smaller coalition of $\{R, P\}$ would not change the natural access regime.[13] If Ukraine can commit, Russia would obtain access rights to *South*. Hence, regarding the calculation of the Shapley values, we are left with three distinct cases. If Byelorussia and Ukraine cannot commit, we can calculate the Shapley

[13]In principle, Russia and Poland may decide to invest in $Yamal$, even though they anticipate Byelorussia to recontract. Nevertheless they would not grant each other access rights as this would weaken their bargaining power, because Byelorussia is complementary to Poland in the presence of Russia.

Table 1: Factors for Calculating the Shapley Value

	$\pi(n,0,0)$	$\pi(n,y,0)$	$\pi(n,0,s)$	$\pi(n,y,s)$
ϕ_R	$+\frac{5}{12}$	$+\frac{1}{12}$	$+\frac{1}{4}$	$+\frac{1}{4}$
ϕ_P	$-\frac{1}{12}$	$+\frac{1}{12}$	$-\frac{1}{4}$	$+\frac{1}{4}$
ϕ_B	$-\frac{1}{12}$	$+\frac{1}{12}$	$-\frac{1}{4}$	$+\frac{1}{4}$
ϕ_U	$-\frac{1}{4}$	$-\frac{1}{4}$	$+\frac{1}{4}$	$+\frac{1}{4}$
$\phi_{\{RPB\}}$	0	$+\frac{1}{2}$	0	$+\frac{1}{2}$
ϕ_U	0	$-\frac{1}{2}$	0	$+\frac{1}{2}$
$\phi_{\{RPU\}}$	0	0	$+\frac{1}{3}$	$+\frac{2}{3}$
ϕ_B	0	0	$-\frac{1}{3}$	$+\frac{1}{3}$
$\phi_{\{RPBU\}}$	0	0	0	1

value ϕ_i for all players separately based on the natural access regime. The coalition of Poland and Russia determines investment to maximize the sum of their Shapley values. If Byelorussia can commit, we calculate only ϕ_{RBP} and ϕ_U, taking into account Russia's acquired access rights to *Yamal*. If Ukraine can commit, we calculate only ϕ_{RPU} and ϕ_B, taking into account Russia's acquired access rights to *South*. (For the value functions see the appendix.)

As an example, consider the benchmark case in which every country acts on its own. Straightforward application of the Shapley formula (1) for Russia yields:

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

Using the operating profit, or rent, π, it can be expressed in terms of capacities:

$$\phi_R(n,y,s) = +\frac{5}{12}\pi(n,0,0) + \frac{1}{12}\pi(n,y,0) + \frac{1}{4}\pi(n,0,s) + \frac{1}{4}\pi(n,y,s)$$

Russia's expected payoff from recontracting under the natural access regime is given by a weighted sum of rents. The first term, weighted with 5/12, is the operating profit from using only the capacity at *NEGP*. The second, weighted with 1/12, is obtained by jointly using *NEGP* and *Yamal*. The third and forth term, both with weight 1/4, reflect the joint usage of *NEGP* and *South*, and the usage of all capacities, respectively. All other Shapley values can also be expressed as a weighted sum of these rents. The weights reflect the role of a player under a given access regime. Table 1 summarizes the information for the calculation of the Shapley value under the three access regimes.

For any given variant of commitment, we first characterize the non–cooperative solution as it depends on existing capacities (n_o, y_o, s_o) using the information of table 1. The Kuhn–Tucker conditions for optimal investment are:

$$\frac{\partial}{\partial l}[\phi_i(n_o + n, y_o + y, s_o + s) - rc_l l] \cdot l = 0, \quad l \geq 0; \quad l \in \{n, y, s\},\ i \in G,$$

where G is the set of independent coalitions.[14] In a second step, we use this information to characterize the optimal investment under dynamic cooperation. The focus of this paper is on the efficiency of investment and not on how players share the gains from dynamic cooperation, so we feel free to assume that Russia (or the coalition which includes Russia) optimizes investment subject to the dynamic incentive constraints of the other players.

To stress the interaction of geography and access rights we neglect the small differences in operating cost of the different links. With operating cost being the same, all existing pipelines are perfect substitutes and only the total capacity matters for the rent. With a slight abuse of notation we may write $\pi(n + y + s)$. We will say a player (or coalition) i strategically prefers a link l over another link h if $\partial\phi_i/\partial l > \partial\phi_i/\partial h$. We will say a player (or coalition) i has a stronger preference for investing in a link l than another player j if $\partial\phi_i/\partial l > \partial\phi_j/\partial l$.

Upon writing down the Shapley values using table 1 it is straightforward to establish that B and U are harmed by all capacities except in y and s, respectively. When only Poland and Russia can make long term commitments (the standard case) they maximize $\phi_R + \phi_P$. The coalition $\{R, P\}$ gains from all links. However, U has a stronger strategic preference for s and would 'crowd out' the coalition. The coalition strategically prefers y over s and n over y. From these observations we can conclude:

Proposition 4 *In the non–cooperative equilibrium the coalition of Russia and Poland may invest in NEGP or Yamal, Byelorussia may invest in Yamal and Ukraine may invest in South.*

Further results require assumptions on operating profits and capacity cost. For example, the coalition will invest in n rather than in y if: $\frac{1}{3}\pi'(n) > r(c_n - c_y)$. We have to relate marginal operating profit, evaluated at the capacity at n, to the difference in capital cost. This leads us to calibrate the model.

[14] If no country can commit $G = N$. If only Ukraine cannot commit $G = \{RPB, U\}$ etc.

4 Calibration of the Model

The total cost of transporting gas can be decomposed into capacity cost and operating cost. The cost of providing transport capacity with pipelines is roughly proportional to distance. In principle, there are several types of economics of scale. Some are related to the pipeline itself, others are gains obtained from laying pipelines along the same track. Economics of scale fade out at a capacity of 20 bcm/year, though this effect is somewhat weaker with offshore pipelines than with onshore pipes.[15] For simplicity we ignore scale effects and assume proportional cost in the following calculation. As we obtain rather large additional investments, this will be of little consequence. There are several reasons to install additional pipes parallel to existing ones (track economics of scale). To account for these we use specific cost estimations for the different routes from Hubert & Ikonnikova (2004) and inflate cost of entirely new pipelines by 15%. For additional adjustments see the appendix.

Operating costs consist of management and maintenance cost and the cost of gas for compression. The first depend little on actual usage and the second are related to capacity cost because the compressor gas is delivered through the same pipelines. Operating costs are small compared to annualized investment costs and they have a large fixed cost component. To simplify the analysis, we capitalize them and adjust investment cost. Energy costs are accounted for by adjusting the capacity for the fraction of gas used in compressor stations. This approach allows us to ignore operating costs of existing pipelines while accounting for some of their differences at the investment stage.

Table 2 summarizes information on the options to increase transport capacity. It reveals a clear ordering of investment possibilities according to annualized unit cost of capacity. The cheapest option, $c_{s1} = 71\$/\text{tcm}$, is to renovate and upgrade the system in the *South* using already existing pipelines that run at below maximal capacity due to aging compressor stations. However, this option is limited to approximately 15 bcm/a. Additional capacity along this track requires new pipelines, for which costs are much higher, $c_{s2} = 131\$/\text{tcm}$. The cheapest option for new pipelines is *Yamal II* with $c_y = 117\$/\text{tcm}$. It can share infrastructure with *Yamal I* and is shorter than the southern track.[16] With an estimated $c_n = 202\$/\text{tcm}$ the off-shore pipeline through the Baltic Sea is by far the most expensive option.

For $(1 + r)^\delta$ we use a value of 1.15, which might be obtained with a discount rate of 5%

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

[16] This statement has to be somewhat qualified if gas is coming from Turkmenistan rather than Western Siberia.

Table 2: Transport Links for Russian Gas

	capacity limit [bcm/a]	length[a] [km]	capacity cost[b] [$/tcm]	players[c]
Southern track, existing	70[d]	2000	sunk	$\{R, S\}$
A system of parallel pipelines, gas storages, compressors, mostly depreciated and in poor state of repair.				
Southern track, upgrade	15	2000	$c_{s1} = 71$	$\{R, S\}$
Repair and replacement of compressor power using existing pipelines only. Capacity is limited by existing pipelines.				
Southern track, extension	∞	2000	$c_{s2} = 131$	$\{R, S\}$
Adding pipelines to the system.				
Yamal I	28	1600	sunk	$\{R, P, B\}$
Frankfurt/O — Torzhok. The pipeline was finished in 1998 and scheduled to run at full capacity in 2007. By then all investment is sunk.				
Yamal II	∞	1600	$c_y = 117$	$\{R, P, B\}$
Frankfurt/O — Torzhok. Parallel to Yamal I. Major river crossings have already been laid.				
North European Gas Pipeline	∞	1600	$c_n = 202$	$\{R\}$
Greifswald (Germany) — Vyborg (Russia) 1200 km offshore, 400 km onshore to Torzhok. Originally planned for 18 bcm/a under the name North Trans Gas. Now planned for 60 bcm/a.				

[a] From point of delivery in Western Europe to the main Russian export node of the grid.

[b] For details on the estimation see appendix.

[c] Smallest coalition to establish the connection. R: Russia, P: Poland, B: Byelorussia, U: Ukraine.

[d] Only capacity used for export to Western Europe.

and a delay of 3 years. For real investment in international pipeline we assume a rather high capital cost of 15%.

In addition to the cost of transportation, we estimate the cost of production at the field. Production costs increase as production from old, low cost fields declines and new, more expensive fields have to be developed. Since this happens faster as production levels increase, annualized production cost increase with quantity. Production depends to a substantial extent on sunk investment (exploration, wells, pipelines) in old fields. Hence, there is room for argument as to what exactly should be counted as cost. For simplicity, we assume a linear average cost schedule $c(x) = 11 + 0.4x$ for a quantity x at the Russian export node. The intercept $c(0) = 11$ \$/tcm reflects production costs from old fields such as Urengoy or Zapolyarnoye. For the current export level we obtain $c(90) = 47$ \$/tcm, which corresponds well to estimated development costs for the Yamal gas field or the current price for imports from Turkmenistan.[17]

Unfortunately, data on gas prices and consumption in Western Europe are too poor to allow an econometric estimation of the demand function. The bulk of the deliveries is under a small number of long–term contracts, the details of which are not made public. Available data on gas prices largely reflect oil–price movements. They are of little relevance for the buyers tied up in these agreements. Moreover, many of the important structural determinants of demand for Russian gas, such as environmental concerns, preferences for diversity of supplies, turbine technology etc., are changing fast. For simplicity, we assume a linear demand schedule and make 'plausible assumptions' for the parameters. We consider two variants, a low and a high one. In both we obtain prices slightly above to the current ones at current import levels, which reflects the expectations of growth in demand over the coming years. The main difference is in the investment that would be justified in narrowly commercial terms — that is without taking strategic considerations into account (the first best). Starting from the existing capacities, 70 bcm/a at *South* and 28 bcm/a along *Yamal*, upgrading the capacity in the south by 15 bcm/a would be justified, but expanding *Yamal* would not be warranted in the low demand variant. In the high demand case, we would also realize *Yamal II* with a capacity of 28 bcm/a as originally planned. This approach yields $P_L(q) = 156 - 0.36q$, and $P_H(q) = 170 - 0.35q$ for the calculation of operating profits.

Table 3: Equilibrium Capacities [bcm/a] for Low Demand Variant

	South	*Yamal*	*NEGP*	total	used
First best	70+15	28	0	113	113
No country can commit					
non-cooperative	70	28	0+71	169	129
cooperative	70+15	28	0	113	113
Russia, Poland can commit					
non-cooperative	70	28	0+66	164	129
cooperative	70+15	28	0	113	113
Russia, Poland, Byelorussia can commit					
non-cooperative	70	28+70	0	168	129
cooperative	70+14	28+8	0	120	120
Russia, Poland, Ukraine can commit					
non-cooperative	70+15+8	28	0	121	121
cooperative	70+15	28	0	113	113

Table 4: Equilibrium Capacities [bcm/a] for High Demand Variant

	South	*Yamal*	*NEGP*	total	used
First best	70+15	28+15	0	128	128
No country can commit					
non-cooperative	70	28	0+85	183	145
cooperative	70+15+12	28	0	125	125
Russia, Poland can commit					
non-cooperative	70	28	0+80	178	145
cooperative	70+15+12	28	0	125	125
Russia, Poland, Byelorussia can commit					
non-cooperative	70	28+85	0	183	145
cooperative	70+15	28+21	0	134	134
Russia, Poland, Ukraine can commit					
non-cooperative	70+15+23	28	0	136	136
cooperative	70+15+15	28	0	128	128

5 Quantitative Results

As a last step, we calculate the equilibrium capacities for the non–cooperative and the cooperative equilibria. The results for the different variants are displayed in tables 4 and 3. In both tables we assume the existing capacities to be *South*: 70 bcm/a, *Yamal*: 28 bcm/a, and *NEGP*: 0 bcm/a, to which we add the equilibrium investment.

The figures reveal that strategic considerations are of outmost importance in the Eurasian transport network. All non–cooperative equilibria feature overinvestment to create countervailing power. If both Byelorussia and Ukraine cannot commit, countervailing power is created by investing in *NEGP*. If only Ukraine cannot commit, *Yamal* provides the leverage, and if only Byelorussia is prone to recontract, expanding *South* provides countervailing power. However, given the large existing capacity at *South*, it is not surprising that the effect is strongest when directed against Ukraine. All but one equilibria also feature underinvestment in the cheapest link.[18]

For a more detailed interpretation we focus again on the variant in which only Poland and Russia can commit. For low demand, the most efficient solution would be to upgrade *South* by 15 bcm/a. For high demand, *Yamal II* should be built with a capacity of 28 bcm/a. However, in the non–cooperative equilibrium the players fail to upgrade *South* or to invest in *Yamal II*. Instead, *NEGP* is built with a staggering capacity of 66 and 80 bcm/a for low and high demand, respectively. With 169 bcm/a and 178 bcm/a the aggregate capacities are about 50 bcm/a larger than the efficient ones. And for both variants of demand we obtain substantial excess capacity.

Given this huge overinvestment there is a large potential for dynamic cooperation to improve the efficiency. In the case of low demand, dynamic cooperation can even achieve the first best outcome. The credible threat to install a large capacity in *NEGP* is a strong enough deterrent for Ukraine and Byelorussia not to exploit their bargaining position to the full. The threat is so powerful, that it is even possible to increase the capacity in the Ukraine thereby solving the underinvestment problem. Restoring first best, however, is not possible in the high demand scenario. Once demand is strong enough to warrant investment in *Yamal II*, dynamic cooperation, however, fails to implement the optimal solution. Rather than switching to *Yamal* after exhausting the cheap upgrading option at *South*, the players continue to invest in *South* by installing new pipelines.

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

[18]If Ukraine can commit, *South* is expanded to gain leverage over Byelorussia. If demand is low, so that *Yamal* is not warranted, then there is no underinvestment in equilibrium. However once demand is increased to justify additional investment, underinvestment emerges because *Yamal* will not be extended.

To understand the motive for this distortion, we have to take a closer look at the effect of investment in *South* and in *Yamal* on the dynamic incentive constraint. We consider first the short run gains from deviation. An increase of capacity along *Yamal* increases the short run gains from deviation for Byelorussia and decreases the gains from deviation for Ukraine. Investment in *South* has the opposite effect. Numerical evaluation of expression (8) shows that the combined impact on the transfers necessary to avoid deviation favors investment in *Yamal*. However, adding capacity to *Yamal* impairs the threat of 'punishment', whereas investment in *South* does not. Given that capacity at *South* is already large (85 bcm/a), any coalition which has access to both *South* and *NEGP* would have excess capacity in the non–cooperative equilibrium. For all these coalitions, an increase of capacity in *South* is irrelevant. Hence, the marginal condition determining non–cooperative investment in *NEGP* is not affected by the increase of capacity in *South*. With 28 bcm/a initial capacity of *Yamal* is much smaller. For realistic numerical values a coalition having only access to *Yamal* and *NEGP* will make full use of both pipelines. The more we invest in *Yamal*, the smaller will be the non–cooperative capacity at *NEGP*. As a result Ukraine and Byelorussia can expect higher profits during the 'punishment' after deviating from cooperation. For realistic values of the parameters, the detrimental effect on the ability to retaliate more than offsets the effect on the incentives to deviate and the differences in cost of the two links.

How do real–world investment patterns compare to the implications of our analysis? From the fact that investment in *NEGP* with an initial capacity of 30 bcm/a is well under way, one may already conclude that the countries failed to realize the full potential of dynamic cooperation. For all our variants of commitment and demand, investment in *NEGP* could have been avoided through dynamic collusion. Not surprisingly, they also failed to prevent underinvestment in *South*. However, the magnitude of real–world overinvestment is well below what the model predicts for the non–cooperative equilibrium. Even for low demand and the case in which Russia and Poland are able to make long term arrangements, we obtain a non–cooperative investment of 66 bcm/a on *NEGP*. Current investment will provide less than half of this figure in the near future. For high demand, the calculation yields a staggering 80 bcm/a which is much higher than even ambitious plans for a second offshore pipeline.

In this sense, it appears as if the countries managed to maintain at least some dynamic cooperation. The current benefits, monetary and in kind, for Ukraine and Byelorussia must be effectively restrained by the threat of a direct link. Otherwise, Russia should have invested much larger amounts and much earlier into this option. Given that interaction is repeated and investment can be delayed, simple two stage models of investment and recontracting tend to overestimate the need for strategic distortion.

Finally, we turn to the role of commitment. In the early nineties Byelorussia's independence from Russia was limited. Apparently, the players underestimated the risk from recontracting. Otherwise investment in *Yamal I* cannot be explained in our framework. Currently, the country looks increasingly isolated from the West, which may force it back into Russia's arms. It is difficult to say whether this would make opportunistic recontracting vis-a-vis Russia less likely. In any case, the development of *Yamal II* has a chance only if Byelorussia is conceived to be a country able to make long term commitments. This holds true independently of the type of equilibria in the market.

Although not very likely in the near future, Ukraine may join the European Energy Charter. By providing a framework for international contract enforcement, the charter may enable Ukraine to enter long term agreements, which in turn is a precondition for investment in *South*. However, preliminary calculations show that it may already be too late do so. Once the current *NEGP* is completed with a capacity of 30 bcm/a, it makes little sense to invest in *South* unless demand grows well beyond our high demand variant.

Appendix 1: Proofs

Proof proposition 2: Consider the case of pure overinvestment. The existing capacities K affect the optimization problem (2) only because investment is constrained to be non-negative. But this constraint is not binding in the case of pure overinvestment. Since marginal investment costs are constant, the first order conditions determining $\hat{K}$ are the same for all $K \leq \hat{K}$, hence $\hat{K}(\tilde{K}) = \hat{K}(K)$, $\forall \tilde{K} \leq \hat{K}$. It follows that $(\partial/\partial l)\hat{l} = (\partial/\partial l)\hat{h} = 0$, hence D simplifies to $D = (\partial/\partial l)\phi_{N\setminus i}(\tilde{K}(K))$. Compared to non–cooperative investment, the gains from strategically distorting investment are reduced by the factor $(1-(1+r)^{-\delta})$. For $\delta = 0$, the term vanishes and we obtain the first best. For $\delta \to \infty$ it approaches 1 and we obtain the same condition as in the non–cooperative case.

Now turn to the case of underinvestment, for which $\tilde{l} \geq \hat{l}(K)$. Since capacities are permanent we have $\hat{l}(\tilde{K}) = \tilde{l}$ and $(\partial/\partial l)\hat{l}(\tilde{K}) = 1$. Capacities at different links are strategic substitutes, but investment is constrained to be non-negative. Hence $(\partial/\partial l)\hat{h}(\tilde{K}) = 0$, which implies $D = 0$ and leaves us with the same condition for investment as in the non-cooperative case. □

Proof proposition 3: We consider the case of two links, l with underinvestment $l^* > \hat{l}$, and h with overinvestment $h^* < \hat{h}$. For the first claim we have to show that D might be larger than zero. For $\hat{h} > \tilde{h}$ the difference between the first terms of D is positive, since $(\partial/\partial l)\phi_{N\setminus i}(\tilde{K}(K)) > (\partial/\partial l)\phi_{N\setminus i}(\hat{K}(\tilde{K}))$ and $(\partial/\partial l)\hat{l}(\tilde{K}) = 1$. The claim will be true, provided the third term in (8), which is non-positive, is small enough. A sufficient condition is that there is excess capacity in all coalitions, which have access to both links, which implies $(\partial/\partial l)\hat{h}(\tilde{K}) = 0$.

For the second claim we have to point out that in general $D < (\partial/\partial l)\phi_{N\setminus i}(\tilde{K}(K))$. Given that $(\partial/\partial l)\hat{l}(\tilde{K}) = 1$ this is true except if (i) $(\partial/\partial l)\hat{h}(\tilde{K}) = 0$ and/or $(\partial/\partial h)\phi_{N\setminus i}(\hat{K}(\tilde{K})) = 0$ and (ii) $(\partial/\partial l)\phi_{N\setminus i}(\hat{K}(\tilde{K})) = 0$. □

Appendix 2: The Value Function

The natural access regime:

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

Russia having access to sections of *Yamal*:

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

Russia having access to *South*:

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

Appendix 3: Calculation of Capacity Cost

We use the same estimations for link–specific investment cost as in Hubert & Ikonnikova (2004). However, we make a number of simplifying assumptions in order to solve analytically for the optimal investment. In particular, we abstract from depreciation and ignore operating costs like management and maintenance and gas for compressor stations. In order to obtain reasonable approximations, we adjust the investment cost I by multiplying constants. In the following we sketch how this is done.

Annualized investment cost i can be calculated from upfront cost I as $i = r \cdot I/(1-(1+r)^{-T})$. A reasonable figure for the lifetime of the investment is $T = 25$. For real investment we used the interest rate $r = 0.15$. In order to obtain the same annualized cost in our infinite horizon framework ($T = \infty$), we have to inflate investment cost by a factor of $c_1 = 1/(1-(1+r)^{-25}) = 1.03$.

Hubert & Ikonnikova (2004) assume specific management and maintenance costs m for every link. Here we use the same figures, but assume them to be independent of pipeline usage. This allows us to capitalize these cost and adjust capacity cost by a factor $c_2 = (i+m)/i$.

For every pipeline, Hubert & Ikonnikova (2004) calculate the specific cost of gas for pressurizing. We approximate this by correcting the capacity cost. If $x\%$ of gas is lost on the way, investment cost are inflated by $c_3 = (100+x)/100$.

Investment in additional capacity takes time to complete. For illustration assume that old capacities are K and there is a single increase k. Let $t = 0$ be the last period before the capacity $K + k$ becomes available. From $t = 1$ onwards the operating profits will be $\pi(K + k)$, which in $t = 0$ have a present value of $\pi(K + k)/r$. Suppose construction takes n periods, i.e., from $t = -n + 1$ until $t = 0$ and expenditures are evenly distributed. Let I denote the nominal expenditures per unit of capacity. Then the present value of the expenditures in $t = 0$ will be $c = (I/(n+1)) \sum_0^n (1+r)^t$. Spreading investment over time increases the investment cost. The longer construction takes, the less attractive the investment opportunity becomes. For investment in new pipelines, we assume that expenditures are spread over three years, which yields a factor of $c_4 = 1.15$

6 References

Castaneda, Marco (2005), The Hold-up Problem in a Repeated Relationship, Discussion Paper

Chollet, Andreas & Meinhart, Berit & von Hirschhausen, Christian & Opitz, Petra (2001), Options for transporting Russian gas to Western Europe : a game-theoretic simulation, Discussion Papers of DIW Berlin.

Gersbach, Hans & Feuerstein, Switgard (2003), Is Capital a Collusion Device, Economic Theory, 21(1), 133-154.

Grais, Wafik & Zheng, Kangbin (1996), Strategic interdependence in European east-west gas trade: a hierarchical Stackelberg game approach, The Energy Journal Vol. 17(3).

Hubert, Franz & Ikonnikova, Svetlana (2003), Investment Options and Bargaining Power in the Eurasian Supply Chain for Natural Gas. Humboldt University, Discussion paper

Hubert, Franz & Ikonnikova, Svetlana (2004), Hold–Up, Multilateral Bargaining, and Strategic Investment: The Eurasian Supply Chain for Natural Gas, paper presented at the annual meeting of the European Economic Association

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

Inderst, Roman & Wey, Christian (2001), Bargaining mergers, and technology choice in bilaterally oligopolistic industries, Discussion paper, London School of Economics, CEPR

Janeba, Eckhard (2000), Tax competition when governments lack commitment: Excess capacity as a countervailing threat, American Economic Reveiw, Vol. 90(5), 1508-1915

Jeon, Seonghoon (2002), Shapley bargaining and merger incentives in network industries with essential facilities, Sogang University, Discussion Paper.

Segal, Ilya (2003), Collusion, Exclusion, and Inclusion in Random-Order Bargaining, Review of Economic Studies, vol 70, 439-460

Observatoire Mediterraneen de L'Energie (2002), Assessment of internal and external gas supply options for the EU, Executive Summary.

Oil, gas and coal supply outlook (1994), edition of the World Energy Outlook.

Stern, Jonathan P (1995), The Russian gas bubble, The Royal Institute of International Affairs.

7 Results

Non cooperative investment, for given capacities

Before we plunge into the numerical calibration and evaluation of the model it is worthwhile to take the qualitative analysis one step further. This will help to identify the critical assumptions which are easily lost in the quantitative analysis. To simplify the central argument we assume that operating cost are the same on all links, so that all pipelines are perfect substitutes and only the total capacity matters for operating profits. We will say a player (or coalition) i strategically prefers a link l over h if $\partial\phi_i/\partial l > \partial\phi_i/\partial h$.

We focus on the standard case in which only Poland and Russia can make long term commitments. First we characterize the non–cooperative equilibrium, then the cooperative one.

Upon writing down the Shapley values using table 1 it is straightforward to establish that B and U are harmed by all capacities except in y and s, respectively, whereas the coalition $\{R, P\}$ gains from all links. However, $\{R, P\}$ strategically prefers y over s and n over y. Comparing the difference in marginal returns and the difference in capital cost it will invest in n rather than in y if:

$$\frac{1}{3}\pi'(n, 0, 0) > r(c_n - c_y).$$

Since the operating profit is evaluated ignoring the capacities on all other links, this inequality is fulfilled for realistic values of the parameters.

U crowds out $\{R, P\}$ on s
$\{R, P\}$ crowd out B on y

Definition 3 *Strategic Preference: A player or coalition has a strategic preference for link l over h if he prefers to invest in l if capacity cost are if*

Proposition 5 *In the non–cooperative equilibrium $\{R, P\}$ may invest in n or y, B may invest in y and U may invest in s.*

Proposition 6 *In the non–cooperative equilibrium $\{R, P\}$ has a strategic interest to favour investment in n over y and s.*

Proposition 7 *In the cooperative equilibrium $\{R, P\}$ has a strategic interest to favour investment in y over s.*

$$\frac{\partial(\phi_R + \phi_P)}{\partial y} > \frac{\partial\phi_B}{\partial y} \tag{9}$$

since investment cost are the same, the coalition of Russia and Poland has a stronger interest to invest in Yamal. Hence their investment would 'crowd out' Belorussia's. However, if they decide not to invest in y (as will follow from assumption 1, then Belorussia may do so in equilibrium.

Since:

$$\frac{\partial(\phi_R + \phi_P)}{\partial s} < \frac{\partial\phi_U}{\partial s}, \tag{10}$$

only Ukraine will invest in the south.

To simplify the exposition we ignore them at the operating stage. Then it does not matter through which link gas is delivered and all pipelines are perfect substitutes at the operating stage.

8 Strategic Effect of Investment, Relative Cost of Options

The marginal impact of investment on rents has to be evaluated for all $S \subseteq N$.

Excess capacity, if capacities will be left idle for coalitions which are sufficiently large.

Define $\pi_j := \max\{\partial\pi/\partial j, 0\};\ j \in K$

It is somewhat more difficult to compare investment in n with y because $c_n > c_y$. But looking at the numbers we can assume that investment in North Trans Gas is favored if Byelorussia cannot commit:

Assumption 1 *In the relevant range of capacities:*

$$\begin{aligned} \frac{\partial(\phi_R + \phi_P)}{\partial n} - rc_n &> \frac{\partial(\phi_R + \phi_P)}{\partial y} - rc_y \qquad (11) \\ \frac{1}{3}\pi_n(n) + \frac{1}{6}\pi_n(n,y) + \frac{1}{2}\pi_n(n,y,s) - rc_n &> \frac{1}{6}\pi_y(n,y) + \frac{1}{2}\pi_y(n,y,s) - rc_y \end{aligned}$$

or

$$\frac{1}{3}\pi'(n,0,0) > r(c_n - c_y)$$