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

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Abstract

We develop a dynamic model of strategic investment in a transnational pipeline system. In the absence of international contract enforcement, countries may distort investment in order to increase their bargaining power, resulting in overinvestment in expensive and underinvestment in cheap 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 for natural gas, 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.

JEL Classification: L95, L14, C71

Keywords: Multilateral Bargaining, Hold-up, Irreversible Investment, Collusion

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1 Introduction

In late 2005, Russia and Germany singed a treaty to build a huge new pipeline, later named *Nord Stream*, through the Baltic Sea. Plans for an offshore pipeline to Western Europe have been around since the mid nineties under names like *Baltic Ring*, and *North Trans Gas*. However, for a long time Russia's western partners 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 by far the most expensive one.[1] The cheapest alternative would be to modernize the old system in the south, which suffers from underinvestment for more than two decades. For larger additions to capacity, a second pipeline, parallel to *Yamal*, and even new pipelines in the south would be cheaper and technologically less demanding than *Nord Stream* (see Figure 1 for an illustration of the network). However, cost and technological risk are only part of the picture. As the hostile reactions from neighboring countries suggest, *Nord Stream* will permanently alter the balance of power in the region.[2]

Production and transportation of natural gas are characterized by large 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, transport capacities generate large quasi-rents. Hence, it is essential that the players can credibly commit to grant access to pipelines on agreed terms. Historically, the Eurasian transmission system was developed under long-term agreements. However, with the collapse of the Soviet empire, such cooperation became fragile. Transit countries are sovereign nations and energy companies are often strongly connected to their respective governments. If the separation of business and politics is not firmly established and there is no truly independent legal system, national institutions offer little protection against opportunistic recontracting. As some important transit countries do not belong to the European Union (EU), there is also no international arbitration system, which could enforce contracts. Even if it is plainly clear who is breaching the contract, for non-EU countries such as Belarus and Ukraine, there would be little

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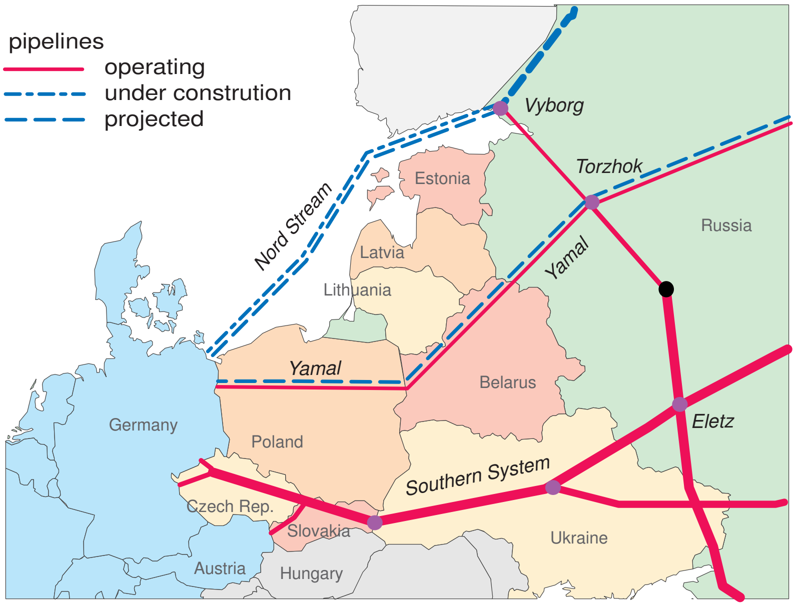
[1] Throughout this paper we will refer to "Western Europe" as the market consisting of the old EU-countries excluding Greece. For ease of reference, we use the names of the countries instead of companies when there is no risk of confusion. Hence, we speak of Russia rather than Gazprom, Ukraine instead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

[2] It looks as if history is repeating itself with *Nord Stream*. In the late nineties a new pipeline through Belarus and Poland, *Yamal I*, had been built, although it would have been much cheaper to invest in the south.

Figure 1: Transit Options



legal remedies. If some countries cannot commit to grant access to pipelines on agreed terms, recontracting after completion of the investment is anticipated, and investment may be distorted to gain leverage in the bargaining process — the hold-up problem arises.

In this 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 share the rent from previous investment. At the same time, they can invest in new capacities. Additional transport capacities are permanent and have a long lasting impact on bargaining power, but they become available only with some delay. Such a framework of repeated interaction reveals yet another problem, which is absent in the static hold-up setting: the inability to commit *not* to invest in the future. With repeated interaction, we can distinguish between non-cooperative and collusive equilibria, the latter being supported by tit-for-tat or trigger strategies.[3]

In the non–cooperative equilibrium, 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

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[3] The notion of collusion is borrowed from the industrial organization literature. Other labels for cooperation sustained by the value of future cooperation have been “self enforcing contracts”, “relationship contracts” or “implicit contracts”.

account the impact on future profit sharing. This equilibrium largely corresponds to the static hold-up situation and may involve under- as well as overinvestment. We speak of overinvestment (underinvestment) on a link, if the capacity on that link is larger (smaller) than the capacity which would be installed if the players could commit, write comprehensive contracts, and invest to maximize the joint profit of the supply chain. Hence, overinvestment on some links can coexist with underinvestment on others. Collusion has a potential to alleviate distortions of investment. Under collusion, the players agree on a sharing of profit and an investment policy, which differ from current bargaining power and economize on total investment cost. However, in the absence of external contract enforcement, these agreements have to be incentive compatible. The long term gains from cooperation must not be offset by the short term gains from defection.

In the theoretical part, we identify two mechanisms by which strategic investment in capacities affects collusion. The first, direct effect operates through the gains from deviating from cooperation. Compared to the efficient network, players may underinvest in cheap pipelines and overinvest in alternative, though expensive, routes in order to reduce the gains from deviation. This effect follows from the same strategic reasoning as in the non–cooperative scenario, but is less pronounced. The direct effect helps to avoid overinvestment. Since investment can be delayed, investing less in expensive capacities today creates a rational threat to do so in the future, should cooperation break down. The second, indirect effect is new. It works through the lasting impact of investment on the out-of equilibrium capacities and payoffs, in the punishment phase, which would follow a breakdown of cooperation. Increasing investment in cheap links, not only makes deviation from cooperation more attractive for the involved transit countries, it also discourages investments in alternative routes should cooperation break down. Hence, the threat to punish deviation is permanently impaired. As a result, alleviating underinvestment turns out to be more difficult than avoiding overinvestment.

In the second part of the paper we calibrate the model to analyze investment in the Eurasian transmission network for natural gas. We calculate capacities for the non–cooperative and the collusive equilibria, for various assumptions on demand and the players' abilities to make long term commitments. The non–cooperative scenarios all imply underinvestment in cheap links and massive overinvestments in expensive links. We also find that the potential for avoiding investment distortions through collusion is large. In some cases the collusive equilibrium can implement efficient investment. However, comparison with real–world data suggests that the countries have failed to fully exploit this potential. Our analysis also reveals the importance of national or international institutions, which allow a country to credibly commit to grant access to pipelines. If Belarus or Ukraine would have achieved this status, *Nord Stream* would have never been built.

The theoretical literature has proposed a number of solutions for the hold-up problem, namely vertical integration and the assignment of asset ownership (see, e.g., Klein, Crawford, and Alchian, 1978, Grossmann and Hart, 1986, Hart and Moore, 1990, Rajan and Zingales, 1998) and option contracts (Nöldeke and Schmidt, 1998). However, these solutions require outside institutions to enforce property rights or contracts and have limited applicability for the Eurasian transport infrastructure for natural gas, in which the players are sovereign states. In this aspect, our setting relates to the lack of investor protection and tax competition among sovereign states (see Janeba, 2000). Without recourse to outside enforcement, the players are left with what has been sometimes called self–enforcing contracts, that is cooperation sustained by the value of future cooperation. The insight, that hold-up can be alleviated in repeated interaction has been explored in the theory of the firm (see, e.g., Baker, Gibbons, and Murphy, 2002, Halonen, 2002), in the efficiency wage literature (see, e.g., MacLeod and Malcomson, 1993), and in corporate finance (see, e.g., Chiappori, Macho, Rey, and Salanié, 1994). This literature typically considers a repeated bilateral relationship, in which non-contractible actions affect only the surplus of the current period.

In this paper we consider a network of heterogeneous agents, in which investment is irreversible, hence, has a permanent impact on the value of cooperation. Irreversible investment is also analyzed in Pitchford and Snyder (2002). They address pure underinvestment in a dynamic bilateral relationship. The project is divided into a sequence of installments, each increment being compensated by the buyer. As investment gradually accumulates towards the efficient level, the threat of loosing further investment becomes less a deterrent, hence, investment installments and the corresponding payments have to decrease over time to avoid defection. Neher (1999) provides a dynamic extension of the notion that investors collateralize loans to prevent the firm from reneging on its debt obligations (see Bolton and Scharfstein, 1990). He shows that staged investment can relax the problem of hold-up by gradually building a collateral base. The installments increase over time as non-contractible human capital is complemented by contractible physical capital and the bargaining position of the investor improves.

However, the applicability of such dynamic investment strategies to pipelines appears limited. In international gas transport systems substantial scale economies dictate lumpy investment.

The paper can also be related to the large literature on collusion in oligopoly. In this literature firms overinvest to steal business, which corresponds to overinvestment for increasing bargaining power in our set up. However, we deviate from the standard model of repeated interaction, because with irreversible investment current actions have lasting effects on future payoffs. This issue is also addressed in Nocke (2007) who analyzes a repeated duopoly with irreversible investment in product quality. Under collusion firms reduce quality compared to the non-cooperative case. Collusion is supported by the credible threat to increase quality in case of deviation. With respect to overinvestment our results are similar in spirit, but the issue of underinvestment does not arise in Nocke's duopoly.[4] For another contribution in this vain see Feuerstein and Gersbach (2003) who look at irreversible investment in Cournot duopoly. They show that the ability to sustain collusion in Cournot-competition is curtailed if investment is irreversible. In Cournot equilibrium all players overinvest compared to the profit maximizing capacities. Collusion is supported by the threat of delayed investment. However, if capacities are irreversible, the deviating firm enjoys a first mover advantage, like in the Stackelberg model. The advantage is permanent and renders punishment less effective.

There is a small literature on international gas networks (for a review see Smeers, 2008, and Hubert and Ikonnikova, 2007). Most papers take the architecture and capacity of the system as given and none of them accounts for the repeated nature of the interaction. Closest to the present paper is Hubert and Ikonnikova (2004) who use a two stage bargaining game to investigate strategic distortions of investment under incomplete contracts and limited commitment. At the first stage, those players who can make long term commitments over access rights form strategic coalitions and coordinate their investment in transport capacities. At the second stage, capacities are given, investment cost are sunk, and all players bargain over the sharing of the rents from previous investment. Essentially, we extend their analysis to a dynamic setting.

In Section 2 we develop the analytical framework and establish the basic asymmetry: it is easier to avoid overinvestment through dynamic cooperation than

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[4] Nocke (2007) uses welfare maximization as a benchmark, hence, speaks of underinvestment with collusion, while we would speak of overinvestment in the non-cooperative equilibrium.

underinvestment. In Section 3 we apply this framework to the Eurasian gas network. First we show how geography and access rights interact to determine the payoff from bargaining over rents (Section 3.1). Then we calibrate the model (Section 3.2). We present and discuss the results of the numerical calculation in Section 3.3. Finally, Section 4 concludes.

2 Analytical Framework

The set of players is denoted $N = \{R, P, B, U\}$, with upper case initials referring to Russia, Poland, Belarus, and Ukraine, respectively. These players control three links for the transport of gas: *Nord Stream*, *Yamal*, and *South*, the latter referring to the system of pipelines running through Ukraine (Figure 1). The capacities of the transport system are given by $K = (n, y, s)$, where lower case initials denote the capacity at a particular track.[5] As there is little danger of confusion, we will denote the set of links also with K. In any period, K can be used to generate operating profit $\pi(K)$. Since investment costs are sunk, 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 capacity at any two links $l,\ h \in K$.

Suppose a decision is made in $t = 0$ to increase the capacity of the links by $k = (k_n, k_y, k_s)$. Planning, preparations, and construction cause a delay of δ periods before available capacity increases to $K + k$ in $t = \delta + 1$. To simplify the exposition in this section, we assume the unit costs of capacity 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 $c = (c_n, c_y, c_s)$. We abstract from depreciation and assume that capacity is permanent and irreversible. With discount rate r we obtain the annualized cost of investment for $t > \delta$ as $r \cdot c \cdot k$. 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.

The players have to cooperate to make use of the transportation network. We represent the mutual dependency as a game in characteristic function form. The value v of a coalition $S \subseteq N$ depends on its access to transport capacities. If every country has access only to sections of pipelines within its own territory, the

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[5] In this section we use the countries and pipelines of the Eurasian gas-supply chain for illustrative purposes only. The particular structure of this network will be addressed in the next section.

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 *Nord Stream* and *South.* For Russia and Belarus we obtain $v(\{R,B\}) = \pi(n,0,0)$. However, if we assume that Poland made a commitment to grant Russia access to its sections of *Yamal*, then the value would change to $\tilde{v}(\{R,B\}) = \pi(n,y,0)$. With assured access to the Polish section of *Yamal*, Russia and Belarus can use both the *Yamal* pipeline and *Nord Stream.* Thus, the value function reflects access rights and capacities. To stress the dependency on the latter we occasionally write $v(S;K)$. For a full characterization of the value function under different access regimes and capacities see Appendix.

In the absence of a long term agreement, profits are shared through some form of bargaining process. We follow Hart and Moore (1990), Rajan and Zingales (1998), and Hubert and Ikonnikova (2007) in solving the rent-division game with the Shapley value ϕ^i, $i \in N$. To simplify notation we extend the definition to subsets of players writing $\phi^S = \sum_S \phi^i$, $S \subseteq N$. As with the value function, we take the liberty to write $\phi^i(K)$ if we want to stress the dependency on capacities and denote partial derivatives as $\phi^i_l(K) = \partial\phi^i(K)/\partial l$.[6]

If investment were contractible and all players could commit to grant access based on a long term sharing rule, the first best solution could be achieved without a need for collusion based on dynamic strategies. The decisions how to share and how to invest could be separated and the grand coalition of all players would choose investment $k \geq 0$ to maximize $v(N; K+k) - c \cdot k \cdot r$. Using $v(N;\cdot) = \phi^N$, and defining F^*_l as

$$F^*_l := \phi^N_l(K+k) - c_l \cdot r, \tag{1}$$

we can characterize the investment and resulting capacity, denoted $k^*(K)$ and $K^*(K)$ respectively, by the Kuhn-Tucker conditions: $F^*_l \leq 0$, $l^* \geq 0$, and $F^*_l l^* = 0$, for all $l \in K$.

2.1 Benchmarks from the Static Setting

Before we turn to collusion in the dynamic setting, we analyze the equilibrium of the stage game, which is also the non-cooperative equilibrium of the dynamic game.

If some players cannot commit to grant long term access to pipelines on agreed

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[6] Our notation emphasizes the role of capacities. The functions v and ϕ^i also reflect the access regime which will be addressed in more detail in the next section.

terms, then the effect of capacities on bargaining power in the future will be anticipated. The lack of institutions for contract enforcement also questions the ability of the players to coordinate at the investment stage. A convenient way to model different assumptions within a common framework is to allow the players to agree on a system of cost sharing and tentative contributions before each player decides individually on how much capacity to contribute to the various links. The scope for coordination is then captured by restrictions on feasible cost sharing rules.

Let $\alpha_i = (\alpha_{in}, \alpha_{iy}, \alpha_{is})$ denote the shares of the cost of capacity levied on country i. Each player i selects a vector of investments k_i^b to maximize his expected payoffs from future bargaining net of initial investment cost given the strategies of the other players.[7] Since the contributions of different players to the capacity of a particular link are perfect substitutes, we can write $k = \sum_{i \in N} k_i$. Formally, the best response is given as

$$k_i^b = \arg\max_{k_i \geq 0} \ \phi^i(K + \sum_{N \setminus i} k_j + k_i) - \alpha_i \times c \cdot k_i \cdot r. \tag{2}$$

where × denotes multiplication by components. Using $\phi^i = \phi^N - \phi^{N \setminus i}$ we obtain the equivalent to (1) for an individual player i as:

$$\hat{F}_l^i := \phi_l^N(K + k) - \phi_l^{N \setminus i}(K + k) - \alpha_{il} \cdot c_l \cdot r. \tag{3}$$

The equilibrium investments and resulting capacities, denoted $\hat{k}(K)$ and $\widehat{K}(K)$ respectively, depend on the initial capacity K. They can be obtained from the Kuhn-Tucker conditions: $\hat{F}_l^i \leq 0$, $\hat{l}_i \geq 0$ and $\hat{F}_l^i \hat{l}_i = 0$ where $l \in K, \ i \in N$. The second term in (3) reflects the strategic role of investment and is responsible for the differences between non-cooperative capacities $\hat{K}$ and efficient capacities K^*.

We obtain the typical setting of the hold-up literature, referred to as *non-contractible investment*, by restricting $\alpha_{il} = 1$. Every player is confronted with the full cost of his contribution to capacity, while not receiving the social returns at the margin. Since contributions of different players are substitutes, the player, for whom ϕ_l^i is largest, will crowd out all other players in equilibrium.[8] For the sake of the argument, suppose that investment is efficient in all links except for

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[7] With constant marginal cost, all investment is done in the first period. To see this, consider a link $l \in K$ and a player i such that $\phi_l^i > 0$, 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 $\phi_{lh}^i \leq 0$, $\forall\, h \in K$. 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.

[8] If there is more than one player with maximal marginal returns to investment, the division

one link l, in which the player i contemplates investing and that first best investment k_l^* is positive ($F_l^* = 0$). If investment increases the bargaining power of the other players, $\phi_l^{N\setminus i} > 0$, then for player i the returns to 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 $\phi_l^{N\setminus i} < 0$ and c_l sufficiently small, we even obtain excess capacity, i.e., capacity for which $\phi_l^N(\hat{K}(K)) = 0$, so that part of it remains idle. More generally, we may obtain a combination of underinvestment in cheap links and overinvestment in expensive ones, in which the latter reinforces the former. We summarize:

Proposition 1. *In the non–cooperative stage game with non–contractible investment,* $\alpha_{ij} = 1$*, the equilibrium may feature underinvestment, or overinvestment, or a combination of both.*

Proof. See Appendix.

As a second benchmark we consider simple cost sharing, which does not require transfers between players and has balanced budget, $\alpha_{il} \in [0, 1]$, $\sum_i \alpha_{il} = 1$, $i \in N$, $l \in K$. For pipelines, simple cost sharing can be implemented by assigning to each party the task of building a section of the pipeline, which corresponds to its share of cost. There would be no need to make any side payments. Consider first the case of *pure* underinvestment, in which all players benefit from the investment but fail to receive the full margin $0 \leq \phi_l^i < \phi_l^N$, $\forall i \in N$, $l \in K$.

Proposition 2. *In the non–cooperative stage game, simple cost sharing with* α_{il} *given by* $\alpha_{il} = \phi_l^i(K^*)/\phi_l^N(K^*)$, $\forall\, i \in N, l \in K$ *can avoid pure underinvestment.*

Proof. See Appendix.

Overinvestment, however, is more difficult to avoid in the static setting. Simple cost sharing is generally not sufficient to align private and social incentives. Overinvestment on a link l implies that for some player i private returns are excessive, $\phi_l^i > \phi_l^N$, so that a "penalty" $\alpha_{il} > 1$ is required to correct the incentives. Such penalties will usually require additional lump sum transfers to compensate players, for which $\phi^i(K^*) - \alpha_i \times c \cdot k_i^* \cdot r < \phi^i(\hat{K}) - \alpha_i \times c \cdot \hat{k}_i \cdot r$. Players, who forego overinvestment, have to be compensated up-front for the associated loss in

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of 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.

bargaining power. If we further relax the restriction on cost sharing to $\alpha_{il} \in R$, $\sum_i \alpha_{il} = 1$, and allow for unlimited lump-sum transfers, we essentially obtain the case of *contractible investment.*

Proposition 3. *In the non–cooperative stage game, with contractible investment the players can implement first best investment by setting* $\alpha_{il} = \phi_l^i(K^*)/\phi_l^N(K^*)$, $\forall\ i \in N, l \in K$ *and making lump-sum payments* $t_i \in R$ *with* $\sum_i t_i = 0$ *so that* $\phi^i(K^*) + t_i - \alpha_i \times c \cdot k_i^* \cdot r \geq \phi^i(\hat{K}) - \alpha_i \times c \cdot \hat{k}_i \cdot r, \quad \forall\, i \in N.$

Proof. See Appendix.

Not surprisingly, a comprehensive system of (Pigouvian) taxes and subsidies combined with a system of lump sum transfers is able to implement the efficient outcome and make every party better off — even though long term access rights are not contractible. However, such a "once and for all" solution, may not be feasible in a dynamic setting of repeated interaction, when investment can be delayed. After receiving the compensation for the loss in bargaining power from forgone overinvestment, the player may renege and invest at a later stage. If the inability to commit comprises both, granting long term access and future investments, the contractibility of present investment is not enough to achieve efficiency.

2.2 Dynamic Cooperation

Now we turn to the central question of this paper. Can the inefficiencies associated with strategic investment be alleviated through collusion? Of the many equilibria, which can be supported by dynamic strategies, we focus on the extremal equilibrium, which yields highest total payoff. As to the non-cooperative outcome, we assume the worst case of non-contractible investment ($\alpha_{il} = 1$) characterized in Proposition 1.

To characterize the equilibrium, 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:

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

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 collusive investment, it is anticipated that he will renegotiate payments once the capacities become available. Backward induction leads the other players 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. $\phi(K)$. Once capacities increase to $\hat{K}(K) = K + \hat{k}$ in $t = \delta + 1$, payments adjusts to $\phi(\hat{K}(K))$.

Definition 1. Collusion. *A collusive equilibrium is characterized by* $(\tilde{T}_i, \tilde{k}_i)$, $i \in N$ *so that:*

$$\frac{\tilde{T}_i}{r} \geq \phi^i(\tilde{K}) \sum_{t=1}^{\delta} \frac{1}{(1+r)^t} + \frac{\phi^i(\hat{K}(\tilde{K}))}{r} \frac{1}{(1+r)^{\delta}} - c\hat{k}_i(\tilde{K}) \frac{1}{(1+r)^{\delta}}, \tag{4}$$

$$\tilde{T}_i - c \cdot \tilde{k}_i \cdot r \geq \phi^i(\hat{K}(K)) - c \cdot \hat{k}_i \cdot r \tag{5}$$

$$\sum_{i \in N} \tilde{T}_i = \phi^N(\tilde{K}) - c \cdot \tilde{k} \cdot r \tag{6}$$

In order to sustain cooperation, the present value of future income from cooperation (given by the left hand side of Expression (4)) 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 resulting from bargaining at collusive 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. The players must not be worse off than by repeatedly playing the non–cooperative stage game from the very beginning on (Condition (5)), and finally the payments must be feasible.

In order to gain from collusion, 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. 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.[9] From the dynamic incentive constraint (4) we derive the minimum transfer to player $j \in N \backslash i$ as

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[9] As will become clear in the next section, this will be true for a reasonable calibration of the model if we assume that Russia plays the role of the coordinator.

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

Player i proposes a compensation scheme $\tilde{T}$ and capacities $\tilde{K}(K) = K + \tilde{k}$ to maximize $\phi^N(\tilde{K}(K)) - \sum_{N\setminus i} \tilde{T}_j - r \cdot c \cdot \tilde{k}$.[10] Substituting for T_j we obtain the following equivalent to Expression (1):

$$\tilde{F}_l := \phi_l^N(\tilde{K}(K)) - \phi_l^{N\setminus i}(\tilde{K}(K)) + \frac{1}{(1+r)^\delta} D \; - \; r \cdot c_l \tag{7}$$

with

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

D captures the difference which collusion 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 collusive 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, respectively).

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 underinvestment requires that there exists at least one link so that $l^* > \hat{l}$ and there is no $h \in K$ for which $h^* < \hat{h}$. The next proposition establishes a fundamental asymmetry in the possibility to improve efficiency through dynamic cooperation.

Proposition 4. Pure Cases. *In the case of pure overinvestment, collusion 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.*

Proof. See Appendix.

In the case of pure overinvestment, cooperation allows for lower capacities. There is no lasting impact. If collusion were to break down at a later stage, the same

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[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.

capacities would be installed as if cooperation would have failed from the very beginning. Without delay, the threat of overinvesting is enough to insure full cooperation. This result is known as "folk theorem", 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, collusion aims to increase the capacity. Such an increase, however, has a permanent effect. In the case of pure underinvestment, dynamic cooperation cannot bring any improvement over the stage game. This result does not contradict the folk-theorem, because investment, being permanent, alters the game over time.

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

Proposition 5. 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.*

Proof. See Appendix.

If both distortions prevail in the non–cooperative case, it is possible to alleviate both through collusion. By deferring overinvestment in expensive links a credible threat is created, which, in principal, may allow to increase the capacity in cheap links, hence, reduce underinvestment.

3 Strategic Investment in the Eurasian Pipeline System

In this section we use the analytical framework to analyze the scope for dynamic cooperation in the Eurasian gas supply system. We focus on the players: Russia, Belarus, Ukraine, and Poland; and on investments in: *Nord Stream*, *Yamal*, and *South*.[11] We start with the analysis of the non–cooperative outcome as it depends on the player's ability to make commitments with respect to future access. First we focus on results, which follow from the geography of the network. Then, we calibrate the model to obtain quantitative results for equilibrium investments in

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[11] Hubert and Ikonnikova (2007) show that other pipeline option, such as bypassing Ukraine or Belarus, have little strategic value, and the countries involved in these options, like Slovakia, Lithuania and Latvia receive very small shares under Shapley bargaining. To simplify the analysis we omit them in this paper.

the non–cooperative and the collusive case.

3.1 Geography and Access Rights

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. In the property rights literature, asset ownership is usually the key to determine the access regime. Since much of the literature has two sides, such as upstream and downstream firms or firm and workers, there is a clear distinction of two cases referred to as integrated versus non-integrated, or employment versus outsourcing etc. In the case of natural gas transport, the players are heterogeneous – both in their ability to grant access to physical assets (ownership) and their role in the cooperation.

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 Poland, being a member of the European Union, can commit to grant long term access to its pipelines. In this standard case, we allow the coalition $\{R, P\}$ to form, optimally exchange access rights and jointly determine investment, while Ukraine and Belarus act independently. In the third variant, reflecting the situation in the middle nineties, we assume that Belarus' 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 and Ikonnikova (2004) analyze in some detail how the different coalitions would optimally modify the access regime. Using results from Segal (2003), they show that the coalition $\{R, B, P\}$ would grant Russia access rights to the sections of $Yamal$ in Poland and Belarus. Moreover, the coalitions $\{R, P, U\}$ and $\{R, U\}$ would grant Russia access rights to South and all other coalitions would not change the natural access regime.

By granting Russia access rights to the sections of $Yamal$ in Poland and Belarus the coalition of $\{R, B, P\}$ weakens Ukraine's bargaining power — the only player outside the coalition. Somewhat surprisingly, the smaller coalition of $\{R, P\}$ would not change the natural access regime, as this would weaken their bargaining power, because Belarus is complementary to Poland in the presence of Russia.

Regarding the calculation of the Shapley values, the results of Hubert and Ikonnikova (2004) leave us with three distinct cases. If Belarus and Ukraine cannot commit, we can calculate the Shapley 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 Belarus 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 Appendix of this chapter.

As an example, consider the benchmark case in which every country acts on its own. Straightforward application of the Shapley formula 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 *Nord Stream*. The second, weighted with 1/12, is obtained by jointly using *Nord Stream* and *Yamal*. The third and forth terms, both with weight 1/4, reflect the joint usage of *Nord Stream* 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.

The analysis is greatly simplified if we ignore small differences in operating cost between the links. For pipelines, operating cost are by order of magnitude smaller than capacity cost. They also have a large fixed component, which can be capitalized and accounted for when estimating capacity cost (see below). With operating cost being the same, all existing pipelines are perfect substitutes and with a slight abuse of notation we may write $\pi(n + y + s)$. We will say a player (or coalition) i has a stronger preference for investing in a link l than another player j if $\phi^i_l > \phi^j_l$. Having a stronger strategic preference and facing the same cost, player

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

Source: Hubert and Ikonnikova (2004)

i would ‘crowd out’ player j in the non-cooperative equilibrium characterized in Proposition 1.

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 6. *In the non–cooperative equilibrium (characterized by Proposition 1) the coalition of Russia and Poland may invest in Nord Stream or Yamal, Ukraine may invest in South and Belarus will not invest.*

Proof. See Appendix.

Proposition 6 is as far as we can get, by exploiting the geography of the network and our assumptions on the player’s ability to commit. Further results require quantitative assumptions on operating profits and capacity cost. For example, the coalition $\{R,P\}$ will invest in n rather than in y, provided that $\frac{1}{3}\pi'(n) > r(c_n - c_y)$. The need to relate marginal operating profit, evaluated at the capacity at n, to the difference in capital cost, leads us to the calibration of the model.

3.2 Calibration

Transportation Cost

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 economies of scale. Some are related to the pipeline itself, others are gains obtained from laying pipelines along the same track. Economies of scale fade out at a capacity of 20 bcm/year, though this effect is somewhat weaker with offshore pipelines than with onshore pipes (see International Energy Agency, 1995, and Organization for Economic Co-operation and Development, 1994). For simplicity we ignore scale effects and assume proportional cost in the following calculation. As we obtain rather large additional investments in most cases, this will be of little consequence — though, for some new pipelines our results have to be qualified. There are several reasons to install additional pipes parallel to existing ones (track economies of scale). To account for these we use specific cost estimations for the different routes from Hubert and Ikonnikova (2004) and inflate cost of entirely new pipelines by 15%.

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 most of their differences at the investment stage. For details see Appendix.

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 \$/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, a constraint, which has to be added to the non-negativity constraints already mentioned in Section 2. Additional capacity

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.				
Nord Stream	∞	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: Belarus, U: Ukraine.

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

along this track requires new pipelines, for which costs are much higher, c_{s2} =131 \$/tcm. The cheapest option for new pipelines is *Yamal II* with c_y =117 \$/tcm. It can share infrastructure with *Yamal I* and is shorter than the southern track. With an estimated c_n =202 \$/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% and a delay of 3 years. For real investment in international pipelines we assume a rather high capital cost of 15%.

Demand and Cost of Supply

For simplicity we assume demand and production cost to be linear and independent of the transport route. The latter requires that pipeline capacity in North-South direction in Germany are large enough to avoid large discrepancies in prices between the different regions. On the supply side, it requires low variable transportation cost between Torzhok and the Ukrainian border. The assumption allows us to speak of demand in “Western Europe” and of “Russian gas” without further regional disaggregation. We choose parameter values for the functions to obtain sensible investment scenarios, given our assumptions on investment cost.

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. We assume an average cost function $c(x) = 11 + 0.4x$ 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. [12]

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. 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. We consider two variants, a low demand and a high demand scenarios. The main difference is in the investment that would be justified. Starting from the existing capacities, 70 bcm/a at *South* and 28 bcm/a along *Yamal*, in the low demand variant upgrading the capacity in the south by 15 bcm/a would be justified, but expanding *Yamal* would not be warranted. In the high demand case, one would also realize *Yamal II* with a capacity of 15 bcm/a. The total investment would therefore be 30 bcm/a. This approach yields $P_L(q) = 156 - 0.36q$, and $P_H(q) = 170 - 0.35q$ for the inverse demand function.

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

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

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

* With values smaller than 10bcm/a for new pipelines, these results are somewhat questionable if scale economies are taken into account.

3.3 Quantitative Results

As a last step, we numerically calculate the equilibrium capacities for the non–cooperative, the cooperative equilibria and for comparison with the first best solution using the Kuhn-Tucker conditions associated with (2), (7), and (1), respectively. The results for the different variants are displayed in Tables 3 and 4. In both tables we assume the existing capacities to be *South*: 70 bcm/a, *Yamal*: 28 bcm/a, and *Nord Stream*: 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 Belarus and Ukraine cannot commit, countervailing power is created by investing in *Nord Stream.* If only Ukraine cannot commit, *Yamal* provides the leverage, and if only Belarus 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 non–cooperative equilibria

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

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

also feature underinvestment in the cheapest link.[13]

For a more detailed interpretation we focus again on the variant in which only Poland can commit to grant access. For low demand, the most efficient solution would be to upgrade *South* by 15 bcm/a. For high demand, *Yamal II* should also be built with a capacity of 15 bcm/a. However, in the non–cooperative equilibrium the players fail to upgrade *South* or to invest in *Yamal II.* Instead, *Nord Stream* is built with a staggering capacity of 66 and 80 bcm/a for low and high demand, respectively. With 164 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.[14]

Given this huge overinvestment there is a large potential for dynamic coopera-

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[13] If Ukraine can commit, *South* is expanded to gain leverage over Belarus. 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.

[14] These results have been derived for the most restrictive assumption on the players' ability to use cost sharing rules. However, the results would not change if we allow for simple cost sharing. Even if we would start from a situation in which investment in cheap links were already first best, i.e. underinvestment is avoided, the incentives for overinvestment would be strong enough to produce excess capacities in equilibrium.

tion 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 *Nord Stream* is a strong enough deterrent for Ukraine and Belarus not to exploit their bargaining positions to the full. The threat is so powerful, that it is even possible to increase the capacity in 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 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.

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 defection. An increase of capacity along *Yamal* increases the short run gains from deviation for Belarus 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 *Nord Stream* 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 *Nord Stream* 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 *Nord Stream* will make full use of both pipelines. The more we invest in *Yamal*, the smaller will be the non–cooperative capacity at *Nord Stream.* As a result Ukraine and Belarus 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 renege.

How do real–world investment patterns compare to the implications of our analysis? From the fact that investment in *Nord Stream* 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 *Nord Stream* 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 *Nord Stream*. 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 Belarus 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.

Finally, we turn to the role of commitment. In the early nineties Belarus'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. There is also the possibility for renewed intensification of relations between Belarus and Russia. 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 Belarus 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 implement the European Energy Charter or join the EU. By providing a framework for international contract enforcement, these institutions would 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 *Nord Stream* 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.

4 Conclusion

We developed a dynamic model of strategic investment and calibrated it for the international transport systems for Russian natural gas. Production and transportation of natural gas are characterized by large investment in specialized facilities with long lifetime and low operating cost. Once installed, transport capacities generate large quasi-rents. In the absence of an international arbitration system sovereign nations may not be able to credibly commit to grand access to pipelines on agreed terms. In this case, recontracting after completion of investment is anticipated, and investment may be distorted to gain leverage in the bargaining process. The hold-up problem may lead to underinvestment in cheap links and overinvestment in expensive links. However, interaction is repeated and investment can be delayed, hence, simple two stage models of investment and recontracting tend to overestimate the need for strategic distortion.

In this paper we analyzed whether these distortions can be decreased through collusive agreements between the players. In every period of our infinitely repeated game players share the rents from the previous investment. At the same time they can invest in new capacities. In the theoretical part we identify a fundamental asymmetry. It is easier to avoid overinvestment than underinvestment through dynamic collusion. We explain this result by identifying two mechanisms by which strategic investment in capacities affects collusion. The first, direct, effect operates through the gains from deviating from cooperation. The direct effect helps to avoid overinvestment. Since investment can be delayed, investing less in expensive capacities today creates a rational threat to do so in the future, should cooperation break down. The second, indirect, effect works through the lasting impact of investment on the out-of equilibrium capacities and payoffs, in the punishment phase. Increasing investment in cheap links, not only makes deviation from cooperation more attractive for the involved transit countries, it also discourages investments in alternative routes should cooperation break down. Hence, the threat to punish deviation is permanently impaired. As a result, alleviating underinvestment turns out to be more difficult than avoiding overinvestment.

We then calibrate the model to analyze the Eurasian transport network for Russian gas, which has been investigated previously within the framework of a non-dynamic two-stage model. As is known from this analysis, there are strong incentives to distort investment for strategic reasons in this network. Our numerical results show that the potential to improve efficiency through collusion is large. In particular overinvestment in expensive pipelines can be reduced or avoided for all our scenarios. In some cases even first best investment can be supported in an equilibrium with collusion.

However, the recent decision to go ahead with a large offshore pipeline through the Baltic Sea, *Nord Stream*, indicates that in real life, the players failed to realize the full potential of dynamic collusion. Comparing past investments with our noncooperative and collusive equilibria we find that only a modest degree of collusion has been achieved.

Appendix

In this Appendix we provide the omitted proofs (Appendix 1), the information on the value function (Appendix 2), and on calculation of capacity cost (Appendix 3).

Appendix 1. Proofs

Proof of Propositions 1-3. The propositions result immediately from substituting α in the first order conditions and evaluation of the sign of the strategic term.

Proof of Proposition 4. 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 $D = \phi_l^{N\backslash i}(\tilde{K}(K))$. 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 $\delta \rightarrow \infty$ 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. This completes the proof of the proposition.

Proof of Proposition 5. 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 $\phi_l^{N\backslash i}(\tilde{K}(K)) > \phi_l^{N\backslash i}(\hat{K}(\tilde{K}))$ 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 $(\partial/\partial l)\hat{h}(\tilde{K}) = 0$.

The second claim follows from the fact that generically $D < \phi_l^{N\setminus i}(\tilde{K}(K))$. 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) $(\partial/\partial l)\phi^{N\setminus i}(\hat{K}(\tilde{K})) = 0$. This completes the proof of the proposition.

Proof of Proposition 6. We start from the investment incentives of the coalition $\{R, P\}$. For the investment in *Nord Stream*, *Yamal* and *South* we get correspondingly

$$\phi_n^{RP}(n, y, s) = \frac{1}{3}\pi'(n) + \frac{1}{6}\pi'(n + y) + \frac{1}{2}\pi'(n + y + s)$$

$$\phi_y^{RP}(n, y, s) = \frac{1}{6}\pi'(n + y) + \frac{1}{2}\pi'(n + y + s)$$

and

$$\phi_s^{RP}(n, y, s) = \frac{1}{2}\pi'(n + y + s),$$

and can conclude that $\phi_n^{RP}(n, y, s) > 0$, $\phi_y^{RP}(n, y, s) > 0$ and $\phi_s^{RP}(n, y, s) > 0$. Hence, the coalition $\{R, P\}$ may invest in all the three links provided that the other players do not have stronger investment incentives for the corresponding links. Turning to the investment incentives of B we get correspondingly

$$\phi_n^{B}(n, y, s) = -\frac{1}{12}\pi'(n) + \frac{1}{12}\pi'(n + y) - \frac{1}{4}\pi'(n + s) + \frac{1}{4}\pi'(n + y + s)$$

$$\phi_y^{B}(n, y, s) = \frac{1}{12}\pi'(n + y) + \frac{1}{4}\pi'(n + y + s)$$

and

$$\phi_s^{B}(n, y, s) = -\frac{1}{4}\pi'(n + s) + \frac{1}{4}\pi'(n + y + s)$$

and can conclude that $\phi_n^{B}(n, y, s) < 0$ and $\phi_s^{B}(n, y, s) < 0$ since $\pi'(K)$ is a decreasing function, while $\phi_y^{B}(n, y, s) > 0$. Hence, B may only invest in *Yamal*. Turning finally to the investment incentives of U we get

$$\phi_n^{U}(n, y, s) = -\frac{1}{4}\pi'(n) - \frac{1}{4}\pi'(n + y) + \frac{1}{4}\pi'(n + s) + \frac{1}{4}\pi'(n + y + s)$$

$$\phi_y^{U}(n, y, s) = -\frac{1}{4}\pi'(n + y) + \frac{1}{4}\pi'(n + y + s)$$

and

$$\phi_s^{U}(n, y, s) = \frac{1}{4}\pi'(n + s) + \frac{1}{4}\pi'(n + y + s)$$

and can conclude that $\phi_n^{U}(n, y, s) < 0$ and $\phi_y^{U}(n, y, s) > 0$, while $\phi_s^{U}(n, y, s) > 0$. Hence, U may only invest in *South*. Moreover, we get that $\phi_s^{U}(n, y, s) >$

$\phi_s^{RP}(n,y,s)$, what implies that U would crowd out the coalition $\{R,P\}$ on *South*. Hence, only U may invest in *South* and coalition $\{R,P\}$ may invest in either *Nord Stream* or *Yamal* . Since it is also true that $\phi_y^{RP}(n,y,s) > \phi_y^{B}(n,y,s)$, B will not invest. This completes the proof of the proposition.

Appendix 2. The Value Function

We provide the value functions for different players (coalitions of players) under the possible access regimes. Under the natural access regime the value function is given by:

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

Under the access regime in which R has access to sections of *Yamal* in Belarus and Poland the value function is given by:

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

Under the access regime in which R has access to *South* the value function is given by:

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

Appendix 3. Calculation of Capacity Cost

The calibration of the model essentially follows Hubert and Ikonnikova (2004) to obtain comparable results. However, these authors use an iterative algorithm to solve for optimal investment, which allows them to account for operating cost, depreciation etc. when calculating the rent. In the present paper, we capitalize these cost and enlarge investment cost accordingly. To obtain adjusted capacity cost c_i we multiply the cost of capacity I_i with a number of factors k_i^j, so that $c_i = I_i k_i^1 k^2 k_i^3 k_i^4$. The index i refers to the different options $i = \{s_1, s_2, y, n\}$ (s_1: southern track upgrade, s_2: southern track extension, y: Yamal, n: Nord Stream). The coefficients k_i^1 and k^2 adjust for the duration of the investment stage and lifetime of investment. The coefficients k_i^3 and k_i^4 adjust for management and maintenance cost and loss of gas for compressor stations, respectively.

We use the estimates for investment cost per unit of capacity I_i from Hubert and Ikonnikova (2004), which were obtained from different public sources and communication with Wintershall. These are $I_{s_1} = 50$ \$/tcm, $I_{s_2} = 89$ \$/tcm, $I_y = 86$ \$/tcm, $I_n = 140$ \$/tcm.

Investment in new capacities 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 E denote the nominal expenditures per unit of capacity. Then the present value of the expenditures in $t = 0$ will be $\frac{E}{n} \sum_0^{n-1}(1 + r)^t$. Hence, investment cost per capacity must be adjusted by $k^1 = \frac{\sum_0^{n-1}(1+r)^t}{n}$. 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, for the interest rate we take again the value 15%, which yields a factor $k_i^1 = \frac{\sum_0^2(1,15)^t}{3} = 1.15$ for $i \in \{s_2, y, n\}$. For the upgrading of existing pipelines we assume $k_{s_1}^1 = 1$.

Hubert and Ikonnikova (2004) use $T = 25$ for the lifetime of the project, whereas in our model we assume that investment increases capacity forever, hence we need to make the corresponding adjustment. Let π be the profit generated after the capacities are installed. Under the assumption that capacities last forever the discounted value of the profits is given by $\frac{\pi}{r}$. If lifetime of investment is T, it is given by $\pi \sum_1^T (\frac{1}{1+r})^t = \frac{1-(1+r)^{-T}}{r}\pi$. Hence, investment must be adjusted by the factor $k^2 = \frac{1}{1-(1+r)^{-T}} = 1.03$.

Hubert and Ikonnikova (2004) assume specific management and maintenance costs m_i for every link. Here we adjust capacity cost by a factor $k_i^3 = (l_i + m_i)/l_i$, where l_i is annualized capacity cost per distance and m_i is annual cost of management and maintenance per distance and capacity. $m_{s_1} = m_{s_2} = m_y = 0.1\$/(\text{a tcm 100km})$ and $m_n = 0.2\ \$/(\text{a tcm 100km})$. From $l_{s_1} = 50 \cdot 1 \cdot 1.03 \cdot 0.15/20$, $l_{s_2} = 89 \cdot 1.15 \cdot 1.03 \cdot 0.15/20$, $l_y = 86 \cdot 1.15 \cdot 1.03 \cdot 0.15/16$, and $l_n = 140 \cdot 1.15 \cdot 1.03 \cdot 0.15/16$ we obtain $k_{s_1}^3 = 1.26$, $k_{s_2}^3 = 1.13$, $k_y^3 = 1.1$, and $k_n^3 = 1.13$.

For every pipeline, Hubert and Ikonnikova (2004) calculate the specific cost of gas for pressurizing. We approximate this by correcting the capacity cost. If $x\%$ of gas (per 100 km) is lost on the way, investment cost are inflated by $k_i^4 = \frac{100+x_i \cdot d_i}{100}$, where d_i is the distance of link i (in 100 km). We use the following figures $k_{s_1}^4 = k_{s_2}^4 = (100 + 0.5 \cdot 20)/100 = 1.1$, $k_y^4 = (100 + 0.25 \cdot 16)/100 = 1.04$, $k_n^4 = (100 + 0.5 \cdot 16)/100 = 1.08$.

Taking into account all the adjustments we arrive at the following investment cost for different options: $c_{s_1} = 71\ \$/tcm$, $c_{s_2} = 131\ \$/tcm$, $c_y = 117\ \$/tcm$, $c_n = 202\ \$/tcm$, given in Table 2.

References

Baker, G., Gibbons R., and Murphy, K.J. (2002), Relational Contracts and the Theory of the Firm, Quarterly Journal of Economics 117, 39–84.

Bolton, P. and Scharfstein, D.S. (1990), A Theory of Predation Based on Agency Problems in Financial Contracting, American Economic Review 80, 93–106.

Chiappori, P.-A., Macho, I., Rey, P., and Salanié, B. (1994), Repeated Moral Hazard: The Role of Memory, Commitment, and the Access to Credit Markets, European Economic Review 38, 1527-1-553.

Feuerstein, S. and Gersbach, H. (2003), Is Capital a Collusion Device?, Economic Theory 21, 133–154.

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

Halonen, M. (2002), Reputation and the Allocation of Ownership, Economic Journal 112, 539–558.

Hart, O. and Moore, J. (1990), Property Rights and the Nature of the Firm, Journal of Political Economy 98, 1119–1158.

Hubert, F. and Ikonnikova, S. (2004), Hold–Up, Multilateral Bargaining, and Strategic Investment: The Eurasian Supply Chain for Natural Gas, Mimeo.

Hubert, F. and Ikonnikova, S. (2007), Investment Options and Bargaining Power in the Eurasian Supply Chain for Natural Gas, Mimeo.

International Energy Agency (1995), Oil, Gas and Coal Supply Outlook, Organization for Economic Co-operation and Development.

Janeba, E. (2000), Tax Competition When Governments Lack Commitment: Excess Capacity as a Countervailing Threat, American Economic Review 90, 1508–1519.

Klein, B., Crawford R.G., and Alchian, A.A. (1978), Vertical Integration, Appropriable Rents and the Competitive Contracting Process, Journal of Law and Economics 21, 297–326.

MacLeod, W.B. and Malcomson, J.M. (1993), Investments, Holdup and the Form of Market Contracts, American Economic Review 83, 811–837.

Neher, D.V. (1999), Staged Financing: An Agency Perspective, Review of Economic Studies 66, 255–274.

Nocke, V. (2007), Collusion and Dynamic (Under-) Investment in Quality, Rand Journal of Economics 38, 227-249.

Nöldeke, G. and Schmidt, K.M. (1995), Option Contracts and Renegotiation: A Solution to the Hold-up Problem, Rand Journal of Economics 26, 163–179.

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.

Organization for Economic Co-operation and Development (1994), Natural Gas Transportation–Organization and Regulation, Paris: Organization for Economic Co-operation and Development.

Pitchford, R. and Snyder, C.M. (2004), A Solution to the Hold-up Problem Involving Gradual Investment, Journal of Economic Theory 114, 88–103.

Rajan, R.G. and Zingales, L. (1998), Power in a Theory of the Firm, Quarterly Journal of Economics 113, 387–432.

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

Smeers, Y. (2008), Gas Models and Three Difficult Objectives, Mimeo.

Stern, J.P. (1995), The Russian Gas Bubble, The Royal Institute of International Affairs.