An Application of Cooperative Game Theory: Strategic Investments in the Natural Gas Network

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Introduction

The dissertation contains three independent essays on the international natural gas trade. Chapter 1 is a joint–work with Franz Hubert, and chapter 2 is published as Cobanli (2014). The gas sector model, its calibration, and the cooperative approach, which are used in the dissertation, result from the research project with Franz Hubert and Ekaterina Orlova in the Chair for Management Science at Humboldt University of Berlin.

The International Energy Agency (IEA) forecasts in its New Policies Scenario that the global primary energy demand will increase by 35% over the period from 2010 to 2035.[1] Fossil fuels will make up 60% of the increase in energy demand and prevail as the dominant source of energy. Among fossil fuels demand for natural gas will be the fastest growing, thanks to its low carbon content. Over the period natural gas demand will increase from 3.3 to 5 tcm (trillion cubic meters), a notable growth of 50%. On the demand side, the growth will be fuelled by rising income and population of emerging economies in the Asia Pacific region, such as China and India, while demand in developed markets, such as Europe, will increase only slightly. On the supply side, new suppliers, e.g., Brazil and East Africa, will come into the picture, and half of the increase in gas supply will stem from unconventional fields (IEA (2012b)).

According to the IEA, the increase in natural gas demand will bring with major changes in the inter–regional trade of natural gas. The natural gas trade within regions will almost double from 0.7 to 1.2 tcm over the period. While pipelines' share in the trade will decrease gradually from 70 to 50%, liquefied natural gas (LNG) shipments within overseas markets will account for most of the growth. The

[1] All forecasts in this chapter are given for the New Policies Scenario, which is the central scenario in IEA studies. The scenario considers policies which have been already carried out or are waiting for implementation. For a detailed presentation of the New Policies Scenario see IEA (2012b).

increase in the LNG trade is expected to abate price differences within regions and to create a single global natural gas market (IEA (2012b)).

Natural gas is the second most consumed fuel in the European Union's (EU) energy mix and accounts for a quarter of its primary energy consumption (EU (2012)). The EU consumed 536 bcm (billion cubic meters) of natural gas in 2010. The IEA expects that European demand will remain stable in the mid term due to the sluggish economic growth, the increase in renewable energy production, and low carbon prices favoring coal in electricity generation (IEA (2012b)). However, a reform of the EU Emission Trading Scheme and an introduction of capacity markets in electricity generation may promote consumption of natural gas and hence boost the continent's natural gas demand in the near future.

Although the EU is the world's second largest consumer of natural gas, it owns less than 1% of the world's proven gas reserves. The European indigenous production (mainly from the Netherlands and the UK) covers only one third of the continent's consumption and is in permanent decline. In 2010, the EU produced 201 bcm of natural gas, and the IEA forecasts that its production will decrease to 158 bcm in 2015 and to 133 bcm in 2020 (IEA (2012b)). Unconventional supplies might compensate the decline in the continent's conventional production, but so far, the EU has failed to replicate the United States' breakthrough in unconventional shale gas since resistance from environmental groups, difficult geology, and property rights favoring states instead of landowners discourage investment in the continent.

Short in indigenous supply, the EU depends on non-EU suppliers to serve two thirds of its natural gas consumption, and the share of non-EU suppliers in the continent's supply portfolio is expected to rise further. Around 80% of the European natural gas imports are transported through pipelines from a small number of suppliers in the continent's near geography, i.e., Russia, Norway, Algeria, and Libya, while LNG from overseas suppliers, such as Qatar and Nigeria, constitutes only one fifth of the continent's imports.

Accounting for 30% of the European natural gas imports, Russia is the dominant supplier in the continent. Since 1970s Russia (the Soviet Union at that time) has proven itself as a reliable supplier to Western Europe, even in the politically turbulent times right after the dissolution of the Soviet Union. However, the dissolution of the Soviet Union altered the constellation of the Eurasian natural gas trade radically. The former Western Soviet republics such as Ukraine and Belarus gained their independence and emerged as the transit countries in the Europe-bound natural gas trade. In the further West, Russia lost its political influence in the former members of the Warsaw Pact, such as Czech Republic, Slovakia, and Poland, and hence control over their transit pipelines.

European energy companies and Russia handled to secure Europe–bound gas deliveries as well as to safeguard their bargaining power vis–a–vis the new transit countries. European energy companies acquired the ownership of the transmission pipelines in Czech Republic, Slovakia, and Poland, which joined the EU in 2004, while Russia took the control of the transmission pipelines in Belarus. In Ukraine the EU has promoted the Energy Charter Treaty to open the country's transmission pipeline network to third parties while Russia has pursued its ownership through political and economical pressure. However, Ukraine has resisted both sides to waive the ownership and/or control of its transmission pipelines and became an indispensable player in the Eurasian gas trade.

Inheriting the Soviet pipeline network, Ukraine transits half of Europe-bound Russian deliveries.[2] Thanks to its market power in the natural gas transit, Ukraine has paid for natural gas imports from Russia considerably lower prices than European consumers. In other words, Russia has had to share rents from its Europe-bound exports with Ukraine. However, the dependency in the natural gas trade is reciprocal. Ukraine relies on Russia for almost all of its imports and hence 60% of its consumption.[3] Russia has threatened Ukraine with sharp increases in the import price as well as with disruptions of supplies if the latter fails to pay its accumulated debt from imports. In exchange of the Ukrainian accumulated debt and a discounted import price, Russia has sought the ownership of the country's transmission pipelines. These tensions peaked in 2006 as well as 2009 and resulted in the short-lived disruptions of Russian deliveries to Ukraine and Europe, which stained the Russian reputation as a reliable supplier and have raised concerns about the European sup-

[2]After the dissolution of the Soviet Union at the beginning of the 1990s, all Russian deliveries to Western Europe had to cross through Ukraine. In 1997, the inauguration of the Yamal pipeline -a 4200 km long pipeline ranging from Yamal Peninsula in Western Siberia through Belarus and Poland to Germany- added an outside option to the East-West gas trade and mitigated the Russian dependency on Ukraine to 80%. In 2011, Nord Stream -an offshore pipeline from Russia through the Baltic Sea to Germany- decreased the Ukrainian share in the natural gas transit to 50%.

[3]The dependency of Ukraine on Russia is not limited only to the natural gas trade. Russia accounts for around 30% of the Ukrainian foreign trade, which amounted to 35 billion € in 2012 (EC (2014)).

ply security in Brussels and other capitals of the continent.[4]

Three controversial pipeline projects have promised to alter the interdependencies in the Eurasian natural gas trade thoroughly. Russia proposed two offshore pipelines, i.e., Nord Stream and South Stream. Inaugurated in the late 2011, Nord Stream connects Russia through the Baltic Sea to Germany. The pipeline was supported by the European Commission as a strategic infrastructure project despite objections of Poland and the Baltic states. South Stream will link Russia through the Black Sea to Bulgaria, from where gas will flow to Central Europe, Italy, and Turkey. In the late 2012, Russia and its partners launched the construction of the pipeline. However, the construction of the offshore section -the most crucial section of the project- has not started yet. Russia and the European Commission still disagree about third party access to the pipeline's onshore section in the Balkans.[5] Both of the offshore pipelines bypass Ukraine and Belarus and hence strengthen the European supply security, but they do not diversify the continent's suppliers. The pipelines, especially South Stream, are often perceived as Russian attempts to block the access of alternative suppliers to the European markets (EurActiv (2010)).

Worried about the Russian dominance in the continent, the European Commission endorsed Nabucco. The pipeline would open a southern corridor through Turkey and carry supplies from the Caspian Sea region, Central Asia, and the Middle East to the Balkans and Central Europe. Although Nabucco was listed as a project of European interest in the Trans-European Energy Networks (TEN-E), the pipeline failed to secure commitments from potential suppliers and support from European investors. After several postponements and a considerable downsizing of its range and capacity Nabucco was abandoned in 2013. Currently, in the southern corridor the Trans Adriatic and Trans Anatolian pipelines are on the agenda. Together they will carry Azerbaijani supplies through Turkey to the Balkans and from there through an offshore pipeline under the Adriatic Sea to Italy. However, the projects' capac-

[4] In the recent Crimea crisis, the Russia-Ukraine disputes follow the same pattern. The parties struggle to reach an agreement over the price of Ukrainian natural gas imports from Russia. On the 16th of June in 2014 Russia cut deliveries to Ukraine once again since the latter failed to pay its accumulated debt from natural gas imports.

[5] Differing in their dependency on natural gas imports, the European governments disaccord about South Stream. Russia signed construction agreements with Serbia and Bulgaria which are in conflict with the European competition law. In June 2014, Bulgaria bowed to the pressure from the European Commission and suspended the construction of the pipeline (Wall Street Journal (2014)). Serbia is expected to follow.

ity (10 bcm/a (billion cubic meters per annum)) is too small to diversify European imports significantly.

The three pipeline projects, i.e., Nord Stream, South Stream, and Nabucco, jointly would increase the transmission capacities between Europe and its suppliers by 150 bcm/a, equivalent to half of the then existing capacities. However, the stable European demand and production possibilities of the suppliers suggest that these additional transmission capacities will remain idle in the foreseeable future. Although the pipeline projects are not needed to transport additional supplies, they may alter the power structure, i.e., final payoffs of the players, in the international natural gas trade substantially. Thereby, investments in the pipeline projects are *strategic*.

Chapter 1, the joint–work with Franz Hubert, aims to rationalize players' interest in the three pipeline projects. The international natural gas network is represented by a stylized disaggregated quantitative model.[6] To investigate the pipelines' *strategic* role in the network, the model is calibrated in such a way that given consumers' willingness to pay for natural gas and costs of production and transmission, the existing network has sufficient capacities to carry natural gas from production fields to consumer markets efficiently. Hence, the investments in the pipeline projects are socially inefficient. The grand coalition composed of all players or a social planner aiming to maximize the joint benefit of all players would not undertake any of these pipeline projects. However, a group of players might want to amend the network to alter the power structure to their benefit. The geographical scope covers Europe and the suppliers in the continent's near geography such as Russia, Norway, North Africa, the Caspian Sea region, Central Asia, and the Middle East, but regards LNG as non-strategic. The results explain real investment patterns in the Eurasian natural gas network. Large benefits accruing to Russia and Germany justify their investment in Nord Stream while the transit countries, Ukraine and Belarus, suffer significant losses. Nord Stream already in place, benefits from South Stream are too small to cover the project's large investment cost. Nabucco promises to mitigate Russia's power in the Eurasian gas trade considerably, but the project benefits mostly Turkey, i.e., the transit country in the southern corridor, instead of the project's European investors.

Chapter 2, Cobanli (2014), studies pipeline options of the Central Asian countries,

[6] Chapter 1 shares the model and its calibration with Hubert and Orlova (2014).

i.e., Turkmenistan, Kazakhstan, and Uzbekistan, to diversify their transit routes and export markets. Following the dissolution of the Soviet Union, the landlocked Central Asian countries became major sovereign suppliers in the Eurasian natural gas trade. They depended solely on the Soviet pipeline system running through Russia to export their supplies to western markets. To mitigate their dependency on Russia, several Europe-bound pipeline projects have been proposed since the 1990s, but none of the pipelines could be realized due to political conflicts in the region. The inauguration of the Turkmenistan-China pipeline in 2009 introduced China as an alternative market to Europe and altered the Eurasian natural gas game remarkably. To investigate the interaction among the major powers such as Europe, Russia, and China in Central Asia, the chapter extends the geographical scope of the disaggregated quantitative model eastwards to Central Asia and China. The results explain the Central Asian countries' endorsement for the Turkmenistan-China pipeline instead of a westbound option and show negligible demand competition between China and Europe for Central Asian supplies. Among the Europe-bound pipeline options the Trans Caspian pipeline -an offshore pipeline under the Caspian Sea from Turkmenistan to Azerbaijan and then to Turkey- is the most beneficial option for the Central Asian suppliers. The results also elucidate the recent pipeline competition in the southern corridor, which will link rich fields in Azerbaijan through Turkey to the European markets.

As matter of fact, the diversification of transit routes, suppliers, and markets through pipelines entails strategic limitations. Pipelines are capital intensive infrastructure projects, and once built, they cannot be moved or used for other purposes. Hence, the both ends of a pipeline, i.e., the supplier and the consumer, are mutually dependent on each other. Ranging over long distances, a pipeline may have to cross through transit countries. The large number of parties involved in a pipeline complicates the cooperation for its realization as well as the long-term rent sharing after its completion. After a pipeline's completion a transit country may demand the renegotiation of the rent sharing since the pipeline increases its bargaining power vis–a–vis other parties involved in the pipeline. There is no international authority to regulate such disagreements within national parties. Therefore, a transit country which lacks the credibility not to renegotiate ex-post might lead to a hold-up problem and hence to an inefficient investment in the transmission network.[7]

[7]As an example, in the 1990s Russia invested in the Yamal pipeline through Belarus and Poland instead of in the modernization of the Ukrainian transmission pipeline network although the latter was considerably cheaper than the former. The Russia-Ukraine disputes compelled Russia to look for an

LNG promises to be an attractive alternative to pipelines. The LNG chain is composed of three distinctive steps: liquefaction, shipping, and regasification. Liquefaction terminals liquefy natural gas and load it to special ships which can carry gas to overseas markets as far as 7000 km. Then, regasification terminals process LNG and serve natural gas to the pipeline network. In contrast to pipelines, the LNG chain is free of transit countries. The long range of LNG ships opens 80% of the world's proven reserves to European consumers and hence diversifies the supplier base of the continent remarkably. Since regasification terminals can be served by any supplier, consumers may respond to price differences as well as supply disruptions easily.

To benefit from LNG's favorable characteristics, European countries expand their regasification capacities. LNG imports from overseas suppliers will strengthen competition in the European markets and hence leverage the continent's bargaining power vis–a–vis established suppliers, especially Russia. However, the global LNG market is supply constrained. Almost fully utilized, liquefaction capacities amount to only 40% of regasification capacities. A strong growth in LNG demand, e.g., in the Asia Pacific region, may constrain liquefaction terminals and lead to an increase in demand competition within LNG importers. In case of a tightness in the global LNG market, LNG cargoes will sail to the market with the highest price, i.e., to the Asia Pacific region instead of Europe, since the price in the former is 35-50% higher than the price in the latter. LNG exports from the United States might relieve the tightness in the global LNG market and change global trade patterns remarkably. In the last decade, the shale gas boom has flooded the country's markets with unconventional supplies and depressed prices in its spot markets to one third of in Europe and one sixth of in Japan. Despite the ongoing controversy about the export of cheap supplies to overseas markets, several liquefaction terminals are under construction on the country's coasts. The U.S. Energy Information Administration (EIA) forecasts that the United States will turn into a net LNG exporter in 2016 and a net gas exporter in 2018 (EIA (2013)).

Chapter 3 studies major supply and demand developments in the global LNG market as well as their impact on the power structure in the Eurasian natural gas trade. The chapter models the global LNG market explicitly and considers LNG as a strategic instrument. Thereby, the model pictures gas-to-gas competition in the European markets in detail, i.e., the interplay within overseas suppliers of LNG and

alternative route to avoid an ex-post renegotiation of the rent sharing with Ukraine.

established suppliers of pipeline gas. The geographical scope represents around 80% of the global LNG trade. Asia Pacific is the largest LNG consumer. Qatar, Australia (including Malaysia and Indonesia), and Nigeria represent the supply side, and the United States is a prospective LNG exporter. Given the enlargement of the European regasification capacities, the supply and demand developments in the global LNG market are illustrated in two scenarios: *the United States' LNG exports*, and *the growth in Asia Pacific's LNG imports*. While *the United States' LNG exports* floods the global LNG market with supplies and increases supply competition in the European markets, *the growth in Asia Pacific's LNG imports* devours LNG supplies and counters the former development. The two developments together benefit the European consumers significantly but curtail barely the power of the established suppliers in the European near geography, such as Russia.

For the analysis of the power structure in the international natural gas network two–stage games proposed by Jackson and Wolinsky (1996) and Jackson (2010) are well suited. Brandenburger and Nalebuff (1997) designate two–stage games also as "biform" games since different approaches are applied to solve the two stages. In the non–cooperative first stage, players settle the equilibrium network by adding or removing links. The dissertation does not attempt to determine the equilibrium network in the first stage. Given real investment patterns, it defines the network exogenously and considers only the second stage. The second stage is designed as a cooperative game. The value function captures the interdependences in the network, and the well known solution concepts, e.g., the Shapley value, core, and nucleolus, allocate the surplus generated by the cooperation among the players. A player's final payoff is interpreted as its (bargaining) power.

Cooperative game theory is well suited to analyze the power structure in the second stage. Firstly, the natural gas network is a vertical chain with a small number of sophisticated players, and players at different stages have market power, such as Russia in production and Ukraine in transit. A player with market power sets a markup over its marginal cost which yields to double marginalization and hence inefficiencies in the vertical chain. To ensure efficient exploitation of the network, sophisticated players use long term contracts in their trade of natural gas. These comprehensive contracts impose prices and quantities as well as tariffs to transit countries.[8] In line with long term contracts, cooperative game theory assumes that players make efficient use of the network. Secondly, in the natural gas trade

[8] See Energy Charter Secretariat (2007) for details on the contractual formats.

bargaining within parties is clandestine and does not follow a firm procedure. Cooperative game theory abstains from any assumptions about bargaining procedures and derives the power structure endogenously from the players' role in the natural gas network.

The natural gas trade provides a distinct opportunity to study *strategic* investment in networks since the architecture of the natural gas network determines the power structure. The natural gas network is one of the few networks providing enough information to calibrate a network model, calculate the value function, and solve the game. While it is difficult to obtain direct empirical evidence on the power structure, indirect evidence is provided by investments into new pipelines and LNG terminals.

There exists a large and sophisticated literature on virtues of different solution concepts for cooperative games and their mutual relations. However, beyond voting games and cost allocation, cooperative game theory has been rarely applied to industrial relations. As a result, little is known about the intuitive appeal and explanatory power of solution concepts. Chapter 1 addresses this gap in the literature and compares outcomes of two solution concepts, the Shapley value and the nucleolus, with real investment patterns. New links, i.e., pipelines, will only be established when the gains for participating players are larger than the investment cost. The chapter relates the investment into the new pipelines with their impact on the power structure and thereby makes conclusions about the explanatory power of the solution concepts. While the Shapley value can explain the recent investments in the new pipelines as a rational attempt to alter the power structure in the network, the nucleolus, in contrast, fails to replicate the empirical evidence.

After each chapter a dedicated appendix (A-B) presents the parameters used for the calculation of the value function and their calibration in detail since the models employed in chapters 1-3 differ in their geographical scope, set of regions, benchmark year, etc. Appendix C provides the technical documentation of the gas sector model, which is used to calculate the value function and solve the game. An interested reader may download the data files and codes published on the website "http://www.ms-hns.de/research_gas" and replicate the results presented in the dissertation.

Chapter 1

Pipeline Power: A Case Study of Strategic Network Investments

Abstract

We use the Shapley value and the nucleolus to analyze the impact of three controversial pipeline projects on the power structure in the Eurasian network for natural gas. Two pipelines, ‘Nord Stream’ and ‘South Stream’, allow Russian gas to bypass transit countries, Ukraine and Belarus. The third project, ‘Nabucco’, aims at diversifying Europe’s gas imports by accessing producers in Middle East and Central Asia. For the Shapley Value we obtain a clear ranking of the projects which corresponds to the observed investment patterns. Nord Stream’s strategic value is huge, easily justifying the high investment cost for Germany and Russia. The additional leverage obtained through South Stream is much smaller and Nabucco is unviable. For the nucleolus in contrast, none of the pipelines has any strategic relevance at all, which contradicts the empirical evidence on investment.

Keywords: Cooperative games, Networks, Strategic Investment, Natural Gas, Shapley Value, Nucleolus
JEL class.: C71, L5, L95, O22

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1.1 Introduction

Pipeline gas from the Russian Federation accounts for a quarter of the consumption in the European Union (EU) and for more than 40% of its imports. Until 2011 essentially all of these imports depended on transit through either Belarus or Ukraine, both being major importers of Russian gas themselves. On both routes conflicts over transit fees and gas prices led to several interruptions of supply, the most serious one in January 2009 when transport through Ukraine was shut down for three weeks with dire consequences for heating and power supply in the Balkans.[9] European power companies and policy makers are struggling to find a coherent response to these challenges. On the one hand, new pipeline links with Russia diversify transit routes for Russian gas. On the other hand, such pipelines have the potential to further increase the dependency on Russian gas and reduce the viability of investments securing supplies from alternative sources.

The Eurasian pipeline network can be seen as a specific example of a network, which enables the parties to trade. Its architecture determines not only the actual trade flows but also the power of the parties, i.e., how they will share the gains from trade. Hence, the actors are trying to shape the network to their own advantage. By opening new options for trade a new link can decrease the value of established links if substitutable, or increase their value if complementary.

That the formation or severance of trade links can be used to enhance the power of a nation has been recognized long ago (Hirschman (1969)). But no generally accepted approach has been established for the assessment of power relations in networks. Analyzing communication networks Myerson (1980) proposed to use cooperative game theory, and more specifically the Shapley value as a power index. Jackson and Wolinsky (1996) and Jackson (2010) extended the idea to general networks and delineated two stages. In the first, non-cooperative stage, players can change the network architecture by adding or removing links. In the second stage, a cooperative game defined by the existing network determines the final payoffs. Brandenburger and Nalebuff (1997) coined the term ‘bi-form games’ to emphasize that different approaches are used to determine outcomes at the two stages, but they argue that the cooperative stage should be solved with the core, instead of the Shapley value. The core, if not empty, is typically not unique, so they resort to an

[9] For a comprehensive account of major conflicts over transit through Belarus and Ukraine see Bruce (2005) and Pirani et al. (2009), respectively.

exogenous assumption on the ‘players’ confidence’ in their own bargaining power to solve the indeterminacy. In addition, there is a literature on non-cooperative, decentralized bargaining in networks, which invokes specific bargaining protocols to single out particular solutions (e.g., Manea (2011), Elliott (2011)). In this paper we avoid exogenous assumptions on bargaining power or bargaining protocols and use the nucleolus instead of the core. The nucleolus is unique and in the core, provided the latter is not empty.

There are good reasons to analyze gas trade in a given network, the second stage, as a cooperative game. Most pipeline gas is traded under negotiated, comprehensive price-quantity-contracts with so called ‘take–or–pay’ provisions. By stipulating prices and quantities, contracts can ensure the efficient usage of the existing capacities and avoid double marginalization. Contracts with transit countries also cover tariffs and quantities.[10] So we assume that the pipeline system will be used efficiently and the surplus is shared through negotiations among the partners.[11]

When the network is changed trough a new pipeline at the first stage, we obtain a different game entailing gains for some and losses for other players. We say that a project is a viable strategic option if the gains of the winners are larger than the cost of the pipeline. Strategic viability does not necessarily imply that the pipeline will be built. First, those players who would benefit, have to succeed in setting up a consortium, sharing costs and benefits, etc., which might be difficult if the gains spread over many regions or if some players cannot make credible long term commitments. Second, those players who are set to lose power might dissuade those who will gain from carrying out the project. Such a move might also require a substantial amount of cooperation.

Again, there is no generally accepted approach to determine the equilibrium network investments at the first stage. Obviously, some impediments to cooperation have to be assumed, otherwise the two stages could be collapsed into a single cooperative game, yielding efficient investment and trade. With imperfect coordination at the investment stage inefficiencies may arise: under-investment, due to potential hold up, and over-investment to improve the bargaining position.[12] In this paper we

[10]For details on contractual formats see Energy Charter Secretariat (2007).

[11]There is also a literature using large scale non-cooperative models of gas trade with players acting in a Cournot or Betrand fashion. See Smeers (2008) for a review and Hubert and Ikonnikova (2011b) for a critic of the assumptions.

[12]The literature on incomplete contracts and the resulting issues of under–investment as well as

do not try to predict the equilibrium network structure. Instead we simply quantify the impact of a possible pipeline link on the power structure as measured by the Shapley value or the nucleolus and compare it to its cost.

This framework is used to investigate three controversial pipeline projects, which have the potential to thoroughly transform the Eurasian supply system for natural gas (for an illustration see figure 1.1). In the North, the offshore twin-pipeline *Nord Stream* establishes a direct link between Russia and Germany through the Baltic Sea. Initiated in 2005, it faced strong opposition from Poland and some Baltic states. Nevertheless it received support form the EU as a strategic infrastructure project and was completed in 2012. Further to the South, Italy and Russia discuss another offshore pipeline through the Black Sea, called *South Stream*. If realized, it would provide a direct connection between Russia and Bulgaria, from where gas should flow to Central Europe, Italy, and Turkey. By bypassing the transit countries, Belarus and Ukraine, both projects diversify transit routes for Russian gas. However, critics argue that they will also increase the European dependency on Russian exports and safeguard the Russian dominance in the European markets by preempting investments into alternative gas supplies.[13] The EU's support for South Stream has been lukewarm and the Commission clearly favors a third project, *Nabucco*, aiming at diversifying gas imports. It would open a southern corridor through Turkey connecting Europe to new suppliers in the Middle East and the Caspian region. Nabucco also offers a new transit option to producers in Central Asia, which currently ship gas through Russia. The EU made Nabucco a major strategic project under its Trans-European Energy Networks (TEN-E), but the project failed to raise sufficient support from national governments and the private sector.

Our focus is on the *strategic* role of the pipelines. Even if not needed to transport *additional* gas, the pipelines may have a substantial impact on the balance of power in the network. In fact, the size of these projects appears out of range with both production possibilities and market demand. With 55 bcm/a and 63 bcm/a, respectively, Nord Stream and South Stream would increase transport capacities for Russian gas by 63% from approximately 186 bcm/a to almost 304 bcm/a. If

over–investment is extensive. For networks see among others Bloch and Jackson (2007), and Elliott (2011), for gas pipelines Hubert and Ikonnikova (2011a), and Hubert and Suleymanova (2008).

[13] South Stream and Nabucco are often portrayed as competing projects because South Stream might drain Nabucco of potential gas supplies in Central Asia and the Caspian region.

compared to the peak of actual gas deliveries in 2008, the increase is almost 80% (BP (2010)). Given growing domestic consumption and slow progress in developing new fields in Western Siberia, Russia will not be able to produce enough gas to make use of the additional offshore transmission capacities any time soon.[14] Taken together all three pipelines would increase the European import capacities by 150 bcm/a (47%). While declining production in the EU makes an increase of imports a likely scenario, pipeline gas faces stiff competition from liquefied natural gas (LNG), which experienced a sharp drop in prices due to decreasing cost and competing supplies of non-conventional shale gas. Hence, we consider it as very unlikely that demand could take up so much additional pipeline gas in the foreseeable future.[15]

When assessing the power structure with the *Shapley Value* we find that Nord Stream's strategic value is huge, easily justifying the high investment cost for Germany and Russia. It severely curtails the power of the transit countries, Belarus and Ukraine, outside producer Norway, and the EU's main producer, Netherlands. In principle, South Stream fulfills a similar strategic role. However, with Nord Stream already in place, the additional leverage obtained through South Stream is too small to make the project viable for its main beneficiaries; i.e., Russia, Germany, and some central European countries. Nabucco has a large potential to curtail Russia's power, but the benefits accrue mainly to Turkey, which will diversify its gas imports and become a major potential transit hub. The gains for the consortium, composed of companies from the EU, in contrast, are negligible. With financial support from Turkey some sections appear viable but our results cast doubts on the prospects of raising the necessary funds within the EU. Somewhat surprisingly, South Stream has little effect on Nabucco's attractiveness. The European Commission's concern (or Russian hopes) that South Steam might preempt the investment in the southern corridor through Turkey appears unfounded.

Our results for the *Shapley value* nicely explain real investment patterns. Nord Stream was swiftly build by those players for whom we predict large gains. South Stream, in contrast, has been faltering and is struggling to move on from the plan-

[14]For the long term perspectives for the Russian gas production see Stern (2005).

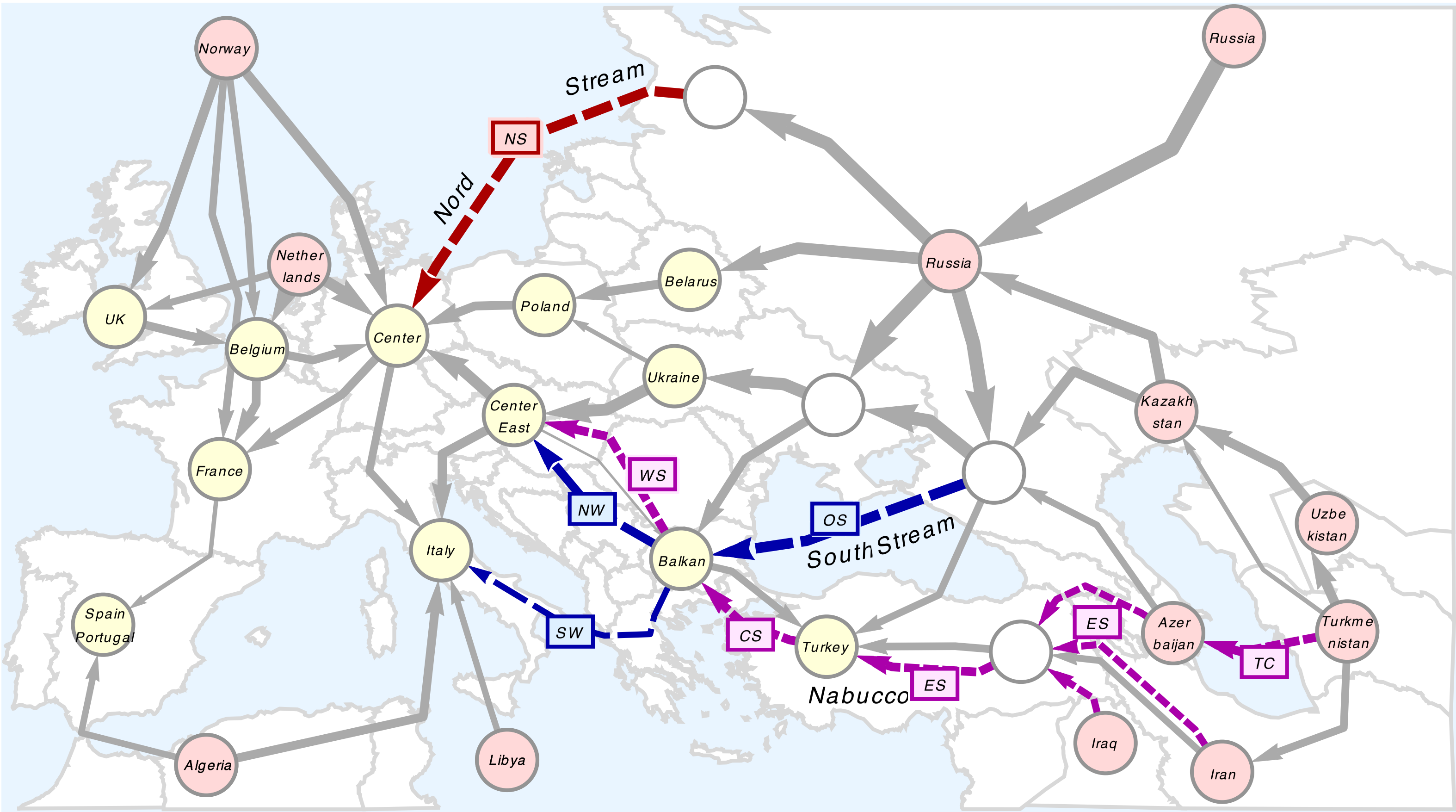
[15]It is misleading to relate the projects to import needs projected for 2030 or later. While a pipeline might last more than 40 years, the decision to invest at a given time should be based on a much shorter forecasting range. Once the 'go ahead' is given, it will take 3-7 years before the pipeline is ready to deliver gas. Hence, if demand forecasted for a decade ahead is too low or too uncertain to justify the project, the investment should be *delayed* though not necessarily scrapped. For the option like nature of sunk investment under uncertainty see Dixit (1994).

ning stage. After several postponements, it is still unclear whether the offshore section will be built. Finally, in spite of substantial support from the EU, no lasting European consortium could be established to launch Nabucco. Recently Turkey, the only player for which the Shapley value predicts large gains, took the initiative with respect to particular sections of the projects.

When using the *nucleolus* as a power index instead, we receive results which are difficult to match with the empirical evidence. None of the projects has any strategic value at all. Nord Stream's and South Stream's impacts on the power structure are so tiny that no one would be interested in the pipelines, even if investment cost were negligible. Nabucco has some minor effects but these are smaller than project cost by order of magnitude. Essentially, all these pipeline are completely irrelevant for the power structure if it is measured with the nucleolus.

Given that all projects attracted a great deal of interest, both from governments and the private sector, that resources have been spend on project consortia, feasibility studies, etc., and that Nord Stream has been build, we conclude that the Shapley value gives a better prediction how major players in the industry assess the strategic impact of pipelines than the nucleolus.

Figure 1.1: The Network and the Projects



Solid gray arrows represent the pipeline network as existing in 2010. Pipeline projects which we consider in detail are dashed: Nord Stream in red (NS), South Stream in blue (with sections: OS, NW, SW), and Nabucco in Magenta (with sections: TC, ES, CS, WS). The arrows point in the direction of the typical flow and line thickness indicates capacity. Light red nodes represent major exporters, and yellow nodes are importers.

1.2 The Framework

1.2.1 The Network Game

Network.

The analysis is based on a calibrated model of the Eurasian gas network consisting of a set of nodes R, which may be production sites R_P , customers R_C, or pipeline hubs R_T, and a set of directed links L. Each link $l = \{i, j\},\ i \neq j \in R$ connects two nodes. Let f_{ij} denote gas flows, with negative values indicating a flow from j to i. For those links, which connect a producer to the network or the network to a customer, flows have to be positive ($f_{ij} \geq 0,\ \forall\, i \in R_P$ or $j \in R_C$). Links between hubs can be used in both directions. For each link $\{i, j\}$ we have a capacity limit k_{ij} and link specific transportation cost $T_{ij}(f_{ij})$, which includes production cost in case of $i \in R_P$. For existing capacities, transportation costs consist only of operation costs because investment costs are sunk. Each customer is connected through a single dedicated link to the network. So consumption at node $j \in R_C$ is equal to f_{ij}. The inverse demand is $p_j(f_{ij})$.

Game.

For a given network, gas trade is represented by a game in value function form (N, v), where N is the set of players. Let 2^N denote the set of all subsets of N. The value (or characteristic) function $v : 2^N \to R_+$ gives the maximal payoff, which a subset of players $S \subseteq N$, also called coalition, can achieve. The legal and regulatory framework determines the access rights of the various players. So for any coalition $S \subseteq N$ we have to determine to which links $L(S) \subseteq L$ the coalition S has access. Access to the link $\{i, j\},\ i \in R_P$ is equivalent of having access to production at i. Access to $\{i, j\},\ j \in R_C$ yields access to customer j. The value function is obtained by maximizing the joint surplus of the players in S using the gas-flows in the links which are accessible for S:

$$v(S) := \max_{\{f_{ij} | \{i,j\} \in L(S)\}} \left\{ \sum_{\{i,j\} \in L(S),\, j \in R_C} \int_0^{f_{ij}} p_j(z)dz - \sum_{\{i,j\} \in L(S)} T_{ij}(f_{ij}) \right\} \tag{1.1}$$

subject to

$$
\begin{aligned}
\textstyle\sum_i f_{it} &= \textstyle\sum_j f_{tj}, & \forall\, t \in R_T(S) & \quad \text{(node-balancing)}\\
|f_{ij}| &\leq k_{ij}, & \forall\, \{i,j\} \in L(S) & \quad \text{(capacity constraints)}\\
f_{ij} &\geq 0, & \forall\, i \in R_P \text{ or } j \in R_C & \quad \text{(non-negativity)}
\end{aligned}
$$

The value function captures the essential economic features, such as the geography of the network, different cost of alternative pipelines, demand for gas in the different regions, production cost, etc. It also reflects the institutional framework, such as ownership titles and access rights through its dependence on $L(S)$. By adding a pipeline to the system we obtain a new network, which in turn defines a new value function.

Solutions.

Cooperative game theory has developed a number of solutions for games in value function form. In the following we emphasize the Shapley value (Shapley (1953)), which assigns a unique payoff to each player $i \in N$. It is based on the contribution $v(S \cup i) - v(S)$ which a player i can make to the various subgroups of other players S. The Shapley Value nicely captures the intuition, that a player's payoff from cooperation, interpreted as his power in the game, should increase with his importance for other players, as measured by the value of his contributions.[16] Formally, it is calculated as player i's weighted contribution:

$$\phi_i = \sum_{S: i \notin S} P(S)\,[v(S \cup i) - v(S)] \tag{1.2}$$

where $P(S) = |S|!\,(|N| - |S| - 1)!/|N|!$ is the weight given to S. For convenience ϕ denotes the vector of Shapley Values and $\phi_S = \sum_{i \in S} \phi_i$ the sum of Shapley Values of a coalition S.

[16]The Shapley value has several axiomatic foundations. Surprisingly, it is the only rule of dividing the gains from cooperation featuring *monotonicity*: a player's share never decreases when his contributions weakly increase (Young (1985b), Young (1985a)). It is also the unique rule with so called *balanced contributions*: For any two players i and j it is true that i loses as much if j withdrew from the game, as j loses if i withdrew. Hence, if a player objects the Shapley allocation by pointing out the damage he can impose on another player through a boycott of cooperation, his opponent can always counter the argument (Myerson (1980)). In this sense it is often considered as a 'fair' division. Finally, the Shapley value can be considered as the expected utility of a player from participating in the game (Roth (1977)). The Shapley value can be supported as the subgame-perfect equilibrium of several non–cooperative models of structured bargaining processes, i.e. Gul (1989), Evans (1996), Stole and Zwiebel (1996a), Stole and Zwiebel (1996b), and Inderst and Wey (2003).

The other major solution concept for the cooperative games is the core. Let x be a payoff vector and $x_S := \sum_{i \in S} x_i$ be the total payment to the members of S. We consider only payoff vectors x which are efficient $\sum_{i \in N} x_i = v(N)$ and individually rational $x_i \geq v(i)$, so called imputations. The excess e is the difference between what a coalition can achieve alone and what it receives $e(S, x) := v(S) - x_S$. The larger the excess is, the 'worse' is the coalition doing under x. If the excess is positive, the coalition should reject (block/veto) a proposed x because it can do better on its own. The core is the set of imputations for which no coalition has positive excess: $c(\epsilon) := \{x : e(S, x) \leq 0,\ \forall S \subset N\}$.

If not empty, the core is typically not unique and its characterization through $2^{|N|} - 2$ inequalities is cumbersome if the number of players is large. Instead, we use the nucleolus, which always exists, is unique and in the core if this is not empty. Originally, the nucleolus has been proposed as the imputation which minimizes 'inequity' among coalitions (Schmeidler (1969)). Let $\theta(x)$ be the vector of excesses arranged in decreasing order for a payoff vector x and let $\preceq$ stand for lexicographical smaller. The nucleolus, denoted μ, is defined as the imputation which minimizes the excess in lexicographic ordering: $\mu := \{x \in I : \theta(x) \preceq \theta(y)$ for all $y \in I\}$, where I denotes the set of imputations. It can be computed by solving a nested sequence of linear optimization problems (Maschler et al. (1979)). First excess is made minimal for the coalitions, which are doing worst. Then excess is reduced for the coalitions, which come second, and so on. In this sense, the nucleolus can be interpreted as the lexicographic center of the game.[17]

1.2.2 Specification & Calibration

Regional scope and players.

To obtain a detailed representation of the various customers, owners of pipelines, gas producers, etc. we would like to consider a large set of players. Unfortunately, computational complexity increases fast in the number of players as we have to solve $2^{|N|} - 1$ optimization problems to calculate the value function. It is for computational reasons that we restrict the geographical scope by aggregating customers into large markets and leaving out producers which appear to be of minor strategic

[17] In the terminology of operation research the computation of the nucleolus is a 'hard' problem for which we use an algorithm proposed by Potters et al. (1996), who also provided us with the code for the calculation.

relevance.

As to producers, we focus on Russia, the supplier for Nord Stream and South Stream, its main competitor Norway, and those countries in the Middle East and Central Asia which have a potential to serve Nabucco: Iraq, Iran, Azerbaijan, and Turkmenistan. The player "Turkmenistan" embraces all production and transport in Central Asia (Uzbekistan, Kazakhstan, Turkmenistan).[18] Main transit countries are Belarus and Ukraine. Turkey is a major consumer and a potential transit country for Middle Eastern and Caspian gas. We aggregate customers and producers within the EU into eight regional players. France, Italy, Poland, Netherlands, and Belgium correspond their respective countries. In each of these countries a national champion dominates imports and local supply (GDF, ENI, PNGiG, Gasunie and Fluxys, respectively). We collect Austria, Czech Republic, Slovakia and Hungary in one region called "Center-East". South Stream and Nabucco will end in Center-East, from where gas will be distributed to other regions in Europe. The countries in the region exhibit similar consumption and import dependency patterns. With very little alternative supplies the region depends with almost 90 % of its consumption on imports from Russia. The pipeline networks are largely privatized. The Austrian OMV can be seen as the dominant private supplier in the region. Germany, Switzerland, Denmark, and Luxembourg are bundled to "Center". In terms of consumption the region is clearly dominated by Germany, which is also home of large gas suppliers, E.ON-Ruhrgas and Wintershall. The region covers more than three quarters of gas consumption by imports, but its imports are well diversified between Russia (40.2%), Norway (38.1%), and Netherlands (29.3%).[19] Finally, we collect Romania, Bulgaria, and Greece in a region called "Balkan". The region has only weak links to the other European regions and its imports depend largely on Russian gas.

We aggregate all pipelines and interconnection points between any two players into one link. The arrows in figure 1.1 indicate the direction of net flows between the regions according to IEA (2010a). The new projects, i.e., Nord Stream, South Stream, and Nabucco, are shown as dashed arrows. Their arrows display the direction of flow as expected by their initiators, namely from the East to the West.

As to access rights, we assume that outside the EU every country has unrestricted control over its pipelines and gas fields. For the regions within the EU, in contrast,

[18] Preliminary calculations have shown that Algeria, Libya, and Spain would hardly be affected by the pipelines we consider in this paper.

[19] Calculated from BP (2010), and IEA (2011a).

we assume that common market rules ensure open third party access to the international high pressure transport pipelines. Hence, regions within the EU cannot derive bargaining power from blocking gas transit.

Temporal scope / network flexibility.

We assume a stationary environment with constant demand, technology, production cost, etc. The value of a coalition, nevertheless, depends on the temporal scope of the model. In the short run, the pipeline network is essentially static. The longer one projects into the future, however, the more options to invest in pipelines, compressors, etc. can be exploited, hence the more flexible the transport system becomes. Here, we adopt a rather short horizon assuming that all pipelines can be made bi-directional, but capacities cannot be increased.[20]

Cost and demand.

The details of the numerical calibration are given in appendix A. Here we outline only the main idea. We calibrate the model using data for 2009 from IEA (2010a) and IEA (2011a) on consumption and production in the regions and flows between the regions from November 2009 to October 2010 taken from IEA (2010a). We assume piecewise constant transportation and production cost and linear demand functions with the same intercept for all regions. The slope parameters are then estimated as to replicate the consumption in 2009, given our assumption on production and transportation cost.[21] The most important implication of our calibration of demand in relation to cost is that the pipeline system as existing in 2009 is efficient. Given the willingness to pay and the cost of producing gas, it is able to deliver the efficient amount of gas into the different consumption nodes. Thus, none of the expensive pipeline projects considered in this paper can be justified in narrow economic terms. The grand coalition of all players, or a benevolent central planner maximizing welfare, would not invest in any of the projects. Only a subgroup of the players might find investment beneficial because it increases their bargaining

[20] See Hubert and Ikonnikova (2011a) for a more detailed analysis of the static/shortsighted versus the flexible/farsighted approch.

[21] As a result of our assumptions on functional forms, we obtain a quadratic programming problem with linear constraints. Details of the programming code are available in appendix C.

power at the cost of the others.

This approach also ensures that the main difference between the regions is consumption and how it relates to own production on which we have solid information and not our assumption on demand intercepts on which information is poor. The main difference between producers is production capacity and pipeline connections to the markets, for which data are reasonably good, and not differences in wellhead production cost, which are difficult to estimate.

A critical part of the calibration is the relation of the common demand intercept and production cost, which largely determines the overall surplus from gas trade. The relative shares of different players, measured in percent of the total surplus, tend to be rather robust with respect to a change of the demand intercept in relation to the production cost. However, an increase of demand, keeping the production and transportation cost constant, will increase the total surplus and as a result more pipeline projects will become strategically viable for given investment cost. In our baseline scenario we assume a difference of 1500 €/tcm between the demand intercept and supply cost, yielding a total surplus of approximately 167 bn €/a.[22] As previous research has revealed strong incentives to invest for strategic reasons (Hubert and Ikonnikova (2011a)), we use a rather high discount rate of 15% to account for depreciation and real option nature of the investment when annualizing investment cost or discounting cash flows. In our baseline scenario the resulting present value of total surplus is approximately 1112 billion €.

1.3 Evaluating Network Power with the Shapley Value

Since a player's Shapley value is the weighted sum of his contributions to the values of possible coalitions of other players, any change in the bargaining power can be traced back to changes of these contributions. The value of a coalition depends on its access to pipelines, markets, and gas fields. Hence, a player can increase the coalition value by providing additional markets, additional supply, or by improving connections through transit. In any case, the value of his contribution will depend on how well his resources complement what is already at the coalition's disposal.

[22] As usual in cooperative game theory surplus is measured by the difference between economic rent derived from jointly using the resources of the system minus the sum of the economic rents of the individual players acting in autarky (zero-normalized game). Economic rent is given by the sum of the customer rents minus the cost of producing and transporting gas (equation C.1).

Adding a market to other markets with no access to production helps little compared to making the same market available to several producers, which are short of customers. Generally speaking, a pipeline benefits a player by improving his access to inputs complementary to his own. It hurts him by improving others players' access to resources, which are substitutable to his own. The effects are complicated by the fact that most countries play multiple roles. While Norway is a pure producer in our model, Russia and the Netherlands are producers as well as a customers. Belarus and Ukraine are main transit regions, but they are also customers, and Ukraine has own production. Moreover, the role of a player depends on the coalition against which he is evaluated. For example, Turkey is a net-importer when all players are in the coalition. However, it becomes a transit country for Russian gas in a smaller coalition, for which neither transit through Belarus nor Ukraine is available. Multiple and changing roles make it sometimes difficult to predict what the overall impact of a new pipeline on a player will be.

Given our calibration of demand, the new pipeline projects do not create value. They can only change the power structure. First, we measure the impact of a pipeline on the power structure by the change of the players' percentage shares in the total surplus. Extensive checks have shown that these figures are quite robust with respect to different calibrations of demand, hence surplus, and production cost. Second, we convert the differences to absolute values and compare them to our information on investment cost.

1.3.1 Nord Stream

Nord Stream bypasses the transit countries in the Northern corridor and connects Russia via a twin offshore pipeline through the Baltic Sea to Germany. The project was initiated by Russian Gazprom and the German companies EON-Ruhrgas and Wintershall in 2005 and completed in late 2012 providing a pipeline capacity of 55 bcm/a. We estimate the total cost including complementary pipelines in Russia and Germany at approximately 15 billion €.[23]

[23] Published figures on investment cost have been revised several times. Nord Stream's consortium put the cost at 7.4 billion € (Nord Stream (2013)). However, this figure does not include complementary infrastructure onshore. We assume 5.3 billion € for the Gryazovets-Vyborg line on the Russian side and 1 billion € for OPAL and NEL, the two links on the western shore (EEGA (2010)). These numbers would add to a total cost of 14.7 billion €.

Table 1.1: Nord Stream's Impact on Bargaining Power

Players[a]	Shapleyvalue [%] without Nord Stream	Shapleyvalue [%] with Nord Stream	difference
Russia	12.8	15.9	3.0
Ukraine	9.4	6.9	−2.5
Belarus	6.7	5.9	−0.8
Norway	13.	10.5	−2.5
Netherlands	6.	5.	−0.9
UK	1.9	1.9	0.
Center	16.7	18.2	1.5
Center-East	8.9	9.7	0.8
Italy	3.1	3.4	0.4
Poland	1.7	1.8	0.2
France	6.6	7.3	0.7
Belgium	3.1	3.4	0.3
Balkan	0.8	0.8	0.
Turkey	7.6	7.6	0.

[a]Turkmenistan, Iraq, Iran, and Azerbaijan are omitted because they are not affected by the project. For full results see the technical appendix.

Table 1.1 exhibits Nord Stream's effect on the players' relative power. For each player we report the Shapley value in percent of the total surplus without and with the pipeline as well as the difference between the two measuring the project's impact. The shares of suppliers reflect their production capacities as well as their dependency on the transit countries to access to consumer markets. Although Russia exports more gas than Norway to the European markets, Norway's surplus without Nord Stream (13.0%) is slightly larger than Russia's (12.8%). Norway has direct access to the European pipeline network while Russia depends on the transit countries, Ukraine and Belarus, to ship gas to the European markets. The shares of Ukraine and Belarus, 9.4% and 6.7%, respectively, reflect their differences in own consumption and production as well as the different transport capacities. The largest European producer, Netherlands obtains 6.0%. The other European regions are net importers, hence their benefits tend to increase with the size of their markets and their dependence on pipeline gas. The figures reflect the gains from trading gas, not the gains from consuming gas. A country whose own production or LNG imports are large enough to cover its demand will gain little from participating in the gas trade even if its gas market is large. The EU as a whole obtains 48.8%, with Center, Center-East, and France having the largest shares. Turkey benefits from its consumption of pipeline gas as well as its potential transit position between

Balkan and suppliers such as Russia, Iran, and Azerbaijan.

The last column in Table 1.1 presents Nord Stream's impact on the players' surplus in terms of the differences. Russia gains 3.0 percentage points, an increase of approximately one fourth of its share in the benchmark case. Increased transport competition mitigates the power of Ukraine and Belarus, which loose 2.5 and 0.8, respectively. The transit countries together lose one fifth of their relative power in the benchmark case. Due to intensified supply competition in the European markets, Norway and Netherlands suffer losses of 2.5 and 0.9 points, respectively. The European players together benefit from increased transport and supply competition, gaining 3.0 points. With 1.5 points Center has the largest increase in the EU.

Nord Stream's total strategic value for the initiators of the consortium, in our model Center and Russia, is huge. With our baseline assumptions on demand and interest rate, a gain of 4.5 percentage points translates into a gain of 50 billion €, which clearly exceeds the project's cost of 15 billion € and yields a cost benefit ratio of more than 1:3.[24] It is worth stressing that the project is beneficial because it increases the bargaining power of the consortium vis-a-vis other players. Given our calibration of demand, the pipeline is not needed to transport additional gas.[25]

1.3.2 South Stream

South Stream can be seen as the Black Sea twin of Nord Stream. Russia pushes the project to bypass Ukraine when supplying gas to Central and Southwestern Europe. According to the initial planning, the project consisted of three sections: offshore, northwestern and southwestern.

OS: The offshore section crosses the Black Sea and connects Russia directly to Bulgaria with a capacity of 63 bcm/a. The consortium for the offshore section

[24] For similar results see Hubert and Ikonnikova (2011a), Hubert and Ikonnikova (2011b), and Hubert and Suleymanova (2008)).

[25] After Russia and Germany kicked off the project, the consortium was joined by Gasunie of Netherlands and GDF Suez of France, each with a share of 9%. In view of our results, the participation of Gasunie is surprising since Netherlands supplies 15% of the EU's consumption and is set to loose from intensified supply competition. Our interpretation is the following. Not being able to prevent Nord Stream, Gasunie joined in anticipation of its changing role in the system. Due to declining reserves, Netherlands will become a net importer around 2025. The country also intends to become a gas hub in Northwestern Europe transiting Russian gas from Germany to UK (Netherlands Ministry of Economic Affairs, Agriculture and Innovation (2010)).

includes Gazprom of Russia, Eni of Italy, and EDF of France. Onshore the pipeline splits in two sections.

NW: The northwestern section runs from Bulgaria to Baumgarten in Austria via Serbia and Hungary with a capacity of 30 bcm/a.

SW: The southwestern section connects Bulgaria to Italy via Greece and a short offshore pipeline through the Adriatic Sea. It has a capacity of 10 bcm/a.

The different national sections of the northwestern and southwestern tracks were to be undertaken by a joint-venture between Gazprom and the national gas companies of the respective countries. In November 2012, Gazprom scaled down the project and abandoned the southwestern section.[26] Apparently, Gazprom started to order pipes for South Stream's offshore section in January 2014 although major issues such as the financing, the northwestern section's final route, etc. have not been cleared yet. First delivery through the offshore pipeline are now planned for late 2015 while full service is scheduled for the end of 2018.

There is substantial uncertainty about the expected cost of the project. Here we take 30 billion €, double the cost of Nord Stream, as a reasonable estimate.[27]

Russia enjoys a very strong bargaining position in Southeastern Europe. Competing producers such as Norway or Netherlands cannot reach this region since the transport capacities between Balkan and Central Europe are very small (1.7 bcm/a). The northwestern section improves the connection between Center and Balkan; thus, it has a potential to increase competition for Russian gas in Balkan

[26] However, a similar pipeline may still be build. The Trans Adriatic pipeline (TAP) was selected as a left-over from ambitious plans for the new Southern Corridor. It is scheduled to carry Caspian supplies through a slightly different route, but with the same capacity from the Turkish-Greek border to Southern Italy. UK's BP, Azerbaijan's SOCAR, Norway's Statoil, and Belgium's Fluxys are the major members of the project's consortium while France's Total, Germany's E.ON, and Switzerland's Axpo have smaller shares (TAP (2013)).

[27] So far, South Stream's consortium did not release transparent estimates of the project's cost. In 2009, Gazprom CEO Alexei Miller mentioned a cost of 8.6 billion € (Rianovosti (2009)), apparently referring to the offshore section only. Since then, figures have increased steadily. In 2010, the aggregate cost of the three sections was supposed to amount to 15.5 billion € (South Stream (2010)). Later, the offshore southwestern section was cancelled, but the project's expected cost remained the same. Referring to the need of upgrading the Russian domestic onshore pipelines, Gazprom raised cost estimates first to 29 billion €, and then to 33.6 billion € (Reuters (2013b), Reuters (2013c)). However, some sources expect that the project's total cost might exceed 56 billion € (Natural Gas Europe (2013)).

Table 1.2: South Stream's Impact on Bargaining Power

	without Nord Stream		*with Nord Stream*			
	Shapley value [%]	Impact[a] OS, NW, SW	Shapley value [%]	Impact of pipeline sections[b] OS	OS, NW	OS, NW, SW
Russia	15.8	2.9	16.7	0.3	0.8	0.8
Ukraine	7.	−2.4	6.	−0.3	−0.8	−0.9
Belarus	6.1	−0.7	5.7	0.	−0.2	−0.2
Norway	10.9	−2.1	9.8	0.	−0.5	−0.6
Netherlands	5.2	−0.8	4.8	0.	−0.2	−0.2
UK	1.9	0.	2.	0.	0.	0.
Center	17.9	1.2	18.7	0.	0.4	0.5
Center-East	9.6	0.7	9.9	0.	0.2	0.2
Italy	3.4	0.3	3.5	0.	0.1	0.1
Poland	1.8	0.1	1.9	0.	0.	0.
France	7.2	0.5	7.5	0.	0.1	0.2
Belgium	3.4	0.2	3.5	0.	0.1	0.1
Balkan	1.	0.2	1.	0.2	0.2	0.2
Turkey	7.6	0.	7.6	0.1	0.1	0.1
Iran	0.9	−0.1	0.9	−0.1	−0.1	−0.1
Azerbaijan	0.5	−0.1	0.5	−0.1	−0.1	−0.1
Turkmenistan	0.1	0.	0.1	0.	0.	0.

[a]difference to column 1 table 1.1

[b]difference to column 2 table 1.1

and Turkey. However, we assume that the consortium will seek exemption from the European third party access (TPA) rules, so that Gazprom can prevent its competitors from using the pipeline.[28]

Since Nord Stream became operational, before the construction of South Stream even started, the impact of South Stream has to be assessed for a network which already includes Nord Stream (the right panel of Table 1.2). Nevertheless, it is instructive to study the counterfactual case first (the left panel of Table 1.2). The comparison of the left panel's last column in Table 1.2 and the last column in Table 1.1 shows that South Stream and Nord Stream alter the power structure in a similar way. It does not matter much whether Russian gas is injected at the German border

[28]To incentivize new investment in infrastructure projects, the European Commission can grant for so called 'regulatory holidays' (for details see EU (2009a)). We also analyzed what would happen if South Stream's northwestern section were not exempted from the rules on free TPA. In this case, Russia's strategic gains from bypassing Ukraine would be largely offset by losses due to increased competition from Dutch and Norwegian gas.

or in the Balkans if third party access to the existing European network is assured while Russia's dominance in Southeastern Europe remains protected. However, the gains in the bargaining power by Russia and its major customers in Europe are somewhat smaller than in the case of Nord Stream while the cost of South Stream would be larger, which explains why Nord Stream was given precedence.

What are the effects of South Stream once Nord Stream is already in place (the right panel of Table 1.2)? We start with the impact of the offshore section alone (the column headed 'OS'). The leverage gained is very small, since the gas could only be transported to Balkan, a small market, and Turkey, which is already accessible through Blue Stream. Without substantial onshore investments the offshore section is of little strategic use. If both complementary sections are added the picture, we obtain a scaled down version of the counterfactual case. Russia gains 0.8 points. While Ukraine and Belarus suffer from transit competition, Netherlands and Norway lose from intensified supply competition in Western and Central Europe. Surprisingly, Center, which does not participate in the consortium obtains the largest gains in the EU. It is also worth noting that the southwestern section has very little impact on the power structure. With Nord Stream and the northwestern section in place, there is already a large amount of spare capacity to transport Russian gas to Central Europe and Italy.[29] Adding a 10 bcm/a link through the Adriatic Sea makes hardly a difference. In view of this finding Gazprom's decision to abandon the southwestern section of South Stream appears rational.

Finally, we again ask whether the project is worth the cost. As an *alternative* to Nord Stream, South Stream would be viable for the broad consortium (Russia, Italy, France, Center-East and Balkan). The gains of 4.6 percentage points translates to 51.1 billion €, which is well above our cost estimate of 30 billion €. At the same time the cost benefit ratio is clearly worse than for Nord Stream. With Nord Stream in place, however, South Stream's impact on bargaining power is much diminished which casts doubts on its strategic viability. In the baseline scenario the consortium gains 1.5 percentage points, amounting to 16.7 billion €, which is only about half of the expected cost.

In summary, considered as an alternative, both South Stream and Nord Stream have similar effects on the power structure, since both projects bypass the transit

[29] The northwestern and offshore sections of South Stream and Nord Stream together increase pipeline capacities between Russia and Europe (except Balkan) from 140 bcm/a to 225 bcm/a while in 2008 the demand for Russian gas in the area was 108.3 bcm (BP (2009)).

countries and allow Russia to compete more effectively with Norway and Netherlands, without loosing its strong position in the Southeast. However, in the presence of Nord Stream's large capacities, South Stream provides much less additional leverage. The gains for the consortium appear too small to compensate for the project's high cost.

1.3.3 Nabucco

Plans for a new 'Southern Corridor' have been discussed for almost two decades. In the 1990s the U.S. government pushed for a 'Trans-Caspian pipeline' from Central Asia through the Caspian Sea, Azerbaijan, and Georgia into Turkey and further on to Southern Europe. The strategic aim was twofold: to reduce the dependency of Turkey and Europe on Russian gas and to decrease Russia's leverage in the newly independent former Soviet republics. However, U.S. energy companies dragged their feet over uncertain economic prospects. These worsened when Russia started to contract large volumes of gas from Turkmenistan in 2002 at much higher prices than before. With the U.S.' support withering the Europeans took over the initiative. A consortium lead by OMV of Austria and Botas of Turkey (later joined RWE of Germany) coined the new name 'Nabucco' in 2002.[30] The focus of the new project has shifted, in the East from Central Asia towards suppliers in the Middle East and in the West towards extending the pipeline into the heart of Europe. The EU made Nabucco a major strategic project under its Trans-European Energy Networks (TEN-E). The European Bank for Reconstruction and Development, the European Investment Bank, and IFC (a member of the World Bank Group) tentatively earmarked 4 billion € for funding.[31] However, Nabucco had been postponed several times due to lack of supply commitments as well as its high investment cost. Nabucco's consortium downsized its project's range and capacity in May 2012. Called Nabucco-West, the new project would cover only the European section of the initial project and have one third of its capacity. In June 2013, the project was abandoned after Trans Adriatic was selected to carry Caspian supplies from Turkey to the Continental European markets.[32]

Here we consider the initial proposal for Nabucco, right after the last Russia-Ukraine

[30] The consortium also included companies from transit countries: Bulgargaz of Bulgaria, Transgaz of Romania, and MOL of Hungary. In 2013, GDF Suez of France replaced RWE of Germany.

[31] For the position of the EU see EU (2006), EC (2007), and EurActiv (2011).

[32] For details on the competition between Nabucco-West and Trans Adriatic see Cobanli (2014).

gas dispute in January 2009. For the assessment of the pipeline's impact it is useful to divide it into four sections: Trans-Caspian, the eastern section, the central section, and the western section.

TC: Trans-Caspian, for the purpose of this paper, is narrowly defined as the offshore pipeline between Turkmenistan and Azerbaijan with a capacity of 30 bcm/a. For a while RWE of Germany and OMV of Austria, both also members of Nabucco's overall consortium, had the initiative, but at the time of writing European companies have lost their interest in the project. We estimate the cost at approximately 5 billion €.[33]

ES: The Eastern section consists of several pipelines connecting Turkey with potential suppliers, i.e., Azerbaijan, Iran, and Iraq. We include Iran even though at present this appears to be very unlikely for political reasons. The country has the second largest gas reserves in the world, and Turkey already imports gas from Iran. Even though none of the parties involved in the project will openly admit, Iran is an important potential supplier for Nabucco. For the calculation we assume that the existing pipelines from Iran and Azerbaijan are enlarged by 15 and 45 bcm/a, respectively while a new feeder pipeline of 10 bcm/a connects Iraq to Eastern Turkey. The section from Turkey's East to the West is extended by 30 bcm/a. We estimate the total cost of these investments at approximately 16 billion €.[34]

CS: The central section connects western Turkey with Balkan. It is important to note that existing pipelines with a capacity of approximately 16 bcm/a are currently used to pump Russian gas into the opposite direction, from Balkan into Turkey. Nabucco plans to reverse the direction of the flow through the central section and expand its capacity by 30 bcm/a to an estimated total of 46 bcm/a. Based on distance and comparable projects we estimate the cost of the central section at 2 billion €.

[33] There are also older estimates putting the figure slightly lower at 3.7 billion € (Jamestown Foundation (2006)).

[34] Again there is little solid information on the different sections. The Trans Anatolian pipeline, which connects Turkey's eastern and western borders with half of Nabucco's capacity, is expected to cost 5.9-7.4 billion € (Reuters (2013a)). Accounting for some economies of scale, we estimate the cost of the pipeline running through Turkey at 10 billion €. The expansion of the South Caucasus pipeline, which connects Azerbaijan to Turkey, by 16 bcm/a is expected to cost 2.2 billion € (Jamestown Foundation (2014)). We assume that a capacity expansion of 45 bcm/a will cost 4 billion €. Based on distance, we estimate the cost of the interconnectors to Iran and Iraq at another 2 billion €.

WS: The western section connects Balkan to Center with a planned capacity of 30 bcm/a. The current connection with 1.7 bcm/a is used to pump gas into the opposite direction. The section is analogous to South Stream's NW section. The Nabucco consortium rallied political support in the EU arguing that it would help to integrate the region to other European markets by eliminating the bottleneck. The pipeline is designed for bidirectional use and shall be open for gas transport for all interested parties. So, we assume that every player has access to Nabucco's western section, whereas we assumed exclusive access for South Stream's NW section. Based on distance we estimated the cost at 3.5 billion €.

Taken together we obtain a total cost for the project of 26.5 billion €, or 21.5 billion € if TC excluded.[35] These figures are in the upper range of estimates, but on the other hand we do not account for the cost of developing the fields to produce the gas in Azerbaijan, Iraq, and Iran.

It is worth emphasizing that Nabucco's commercial prospects are built on reversing flows in the present network. Currently, gas flows in small quantities from Center to Balkan and in substantial quantities from Balkan to Turkey. Considering the pipeline in isolation, it is easy to underestimate how much additional gas in Turkey is needed to justify its capacity. Let's consider the central section of Nabucco. First, some 10 bcm/a are needed to substitute for the current flow from Balkan to Turkey. Second, existing capacities can be made bidirectional at modest cost to pump some 16 bcm/a from Turkey to Balkan without new pipelines. Third, 30 bcm/a are needed to fill the additional pipeline capacities. In total it would require approximately 55 bcm/a additional gas in Turkey to make fully use of the new pipeline. As with Nord Stream and South Stream, many observers raised serious doubts as to whether such quantities can be provided anytime soon. We, rather optimistically, assume that Iraq, Azerbaijan, and Central Asia could supply an additional 56 bcm/a and Iran another 15 bcm/a compared to the output in 2009.

In Table 1.3 we report selected results for the strategic impact of Nabucco. We focus on a scenario where Nord Stream is already completed and then Nabucco is added to the system (left panel). The first column shows the Shapley values for the completion of all sections in percent of the total surplus. It should be compared to

[35]As usual, initial cost estimates have been much lower, as low as 7.9 billion € and then kept on rising to 14 billion € (New York Times (2011)) and 24-26 billion € (BP in Natural Gas Europe (2011)).

Table 1.3: Nabucco's Impact on Bargaining Power

	without South Stream				*with South Stream*	
	Shapley value [%]	Impact of pipeline sections[a] TC, ES	WS	TC, ES, CS, WS	Shapley value [%]	Impact[b] TC, ES, CS, WS
Russia	12.8	−2.3	−0.1	−3.1	13.4	−3.3
Ukraine	6.2	0.	−0.5	−0.7	5.7	−0.4
Belarus	5.9	0.	0.	0.	5.7	0.
Norway	9.7	−0.4	0.3	−0.8	9.1	−0.7
Netherlands	4.7	−0.2	0.1	−0.3	4.5	−0.3
UK	1.9	0.	0.	−0.1	1.9	−0.1
Center	18.5	0.1	−0.1	0.3	19.	0.3
Center-East	9.9	0.	0.	0.2	10.1	0.2
Italy	3.5	0.	0.	0.	3.6	0.
Poland	1.9	0.	0.	0.	1.9	0.
France	7.4	0.	0.	0.1	7.6	0.1
Belgium	3.5	0.	0.	0.1	3.5	0.1
Balkan	1.1	0.1	0.2	0.2	1.1	0.1
Turkey	10.4	1.7	0.6	2.8	10.2	2.6
Iraq	0.4	0.4	0.	0.4	0.4	0.4
Iran	1.	−0.1	−0.2	0.	0.9	0.1
Azerbaijan	1.2	0.4	−0.1	0.7	1.1	0.7
Turkmenistan	0.3	0.	0.	0.1	0.3	0.1

[a]difference to column 2 table 1.1

[b]difference to column 3 table 1.2

column 2 in Table 1.1. The difference between the two, i.e., the impact of the whole project, is shown in column 4 under the header 'TC, ES, CS, WS'.

By bringing in new suppliers in the East and connecting them with the center of the European network Nabucco weakens the bargaining power of all established suppliers. With a loss of 3.1 points Russia is particularly hard hit. The lion's share of the benefits, however, accrues to Turkey (2.8 points) and Azerbaijan (0.7 points) while the impact on the regions within the EU is surprisingly small. Balkan and Center benefit 0.2 and 0.3 points, respectively. Nabucco and the Trans Caspian pipeline also do little to improve the position of the Central Asian producers, here represented by Turkmenistan. We attribute this to the fact, that the new supply route has several transit countries of which Azerbaijan is also a competing producer.

In our baseline scenario, these percentage points amount to a gain of 7.8 billion € for the European members of the Nabucco consortium, 31.1 billion € for Turkey, and another 7.8 billion € for Azerbaijan. Comparing these figures to the cost of approximately 21.5 billion € (including TC 26.5 billion €), it is not surprising that European consortium failed to fly while Turkey and Azerbaijan took the initiative with some sections of Nabucco.

It is also instructive to consider the effect of the different sections separately. Suppose only the sections in the East are built (TC and ES), which connect Turkey to the producers in the Middle East and Central Asia (second column). As increased supply competition harms other producers, in particular Russia, it benefits Turkey and to a much lesser extend Balkan. The effects on other EU regions are negligible, which is not surprising in view of the bottleneck between Balkan and the rest of Europe. Taken altogether, the pipelines in the East appear to have little effect on the power of the various potential suppliers in the region, such as Iran, Iraq, and Turkmensitan because they can be played off against each other.

Next, we consider only the western section (WS) connecting Balkan and Central Europe (column three). This pipeline with a capacity of 30 bcm/a will hardly be used. Nevertheless, the option to move gas from the Northwest to the Southeast intensifies competition for customers in the Southeast which benefits Turkey and Balkan as well as producers in the Northwest at the cost of Russia and the producers in the Middle East and Caspian region. Some regions in the EU, such as Center and Center-East, are slightly harmed from increased demand competition since Norway and Netherlands will gain better access to other markets. Again the effect on the EU as a group is negligible. With a total gain of 13.3 billion € and cost of 3.5 billion € the section would be a viable option for producers in the Northwest together with Turkey and Balkan, but it is difficult to envisage how such diverse players can implement a project, which has little potential to generate direct revenues. The 'returns of the investment' come only indirectly with Turkey paying less for gas from Russia and Iran, and Central Europe paying more for gas from Norway and Netherlands.

Finally, we return to the perception that South Stream and Nabucco are competing projects and the concern that the former might preempt investment into the latter. In the right panel of Table 1.3 we show the strategic impact of Nabucco in a situation where South Stream and Nord Stream will be fully operational. Comparing the fourth column of the left and the second column of the right panel, we find very little difference. Even if fully implemented, South Stream has almost no impact on the strategic viability of Nabucco.

1.3.4 Evaluating Network Power with the Core & Nucleolus

In the previous sections we considered a number of cooperative games, one for each configuration of the gas network. All these games had a non-empty core, but the Shapley value was never in the core of the respective game. The same is also true for the games we analyzed for our robustness checks. This observation raises the question, whether we obtain very different results for the strategic value of pipelines if we solve the network game with the core or related concepts.

Adding a pipeline to the system will increase the value of some coalitions. Other coalitions will remain unaffected, but for no coalition the value will be decreased. As a result, the core will be compressed. But will the pipelines change the core systematically to the favor of the same players as they do for the Shapley value? As the core is a set, the answer will depend on which element in the core we select. Here, we consider the nucleolus which is in the core and can be considered as the lexicographical center of the game.

We computed the equivalent of tables 1.1-1.3 for the nucleolus to find results, which differ drastically from the previous ones. If power is measured with the nucleolus, none of the three projects has any strategic value at all — essentially because they have no significant impact on bargaining power. We abstain from printing the equivalent of tables 1.1-1.3 here, as all, but the few instances we discuss in the text below, are equal to zero when rounded to the first decimal. The tables are available in appendix A.

We start again with Nord Stream. There is only one country, which is slightly affected by this huge project: Russia. Surprisingly its power is *reduced* by 0.1 percentage points even though the project will (weakly) increase the value of coalitions which include this country.[36] For all other players the impact of Nord Stream is minute and lost when rounding to the first decimal. For South Stream we find no effect whatsoever, even if the project is considered as an alternative to Nord Stream. Nabucco has some minor effects. For the non-European players the effects go in the same direction as under the Shapley value, but are smaller by order of magnitude. Russia and Ukraine lose 0.2 and 0.1 percentage points, respectively while Turkey gains 0.3 percentage points. Balkan, Azerbaijan, and Iran benefit 0.1 per-

[36] It is well known that the nucleolus is not monotone, i.e., a player's payoff can decrease even if its contributions to coalitions weakly increase. Our result for Nord Stream prove that this is not a theoretical oddity.

centage points each from the project. However, the European players, such as Center, Center-East, and France, suffer by 0.1 percentage points each although coalitions containing them will gain from diversity of supplies. The remaining countries are not affected. Overall, the impacts of the pipelines on the power structure are smaller by orders of magnitude than the cost of these projects. As a result, no project had any strategic value if the players would assess the network power with the nucleolus.

We also computed the minimum and the maximum a player can obtain in the core. For most players these two values define a narrow range around the nucleolus. In this sense, the nucleolus gives a reasonably precise estimate of the possible effects of a pipeline to a players payoff in the core. We take Russia and Nord Stream as an example. The pipeline *decreases* both, Russia's minimal and maximal payoff in the core by a small amount — as it does for nucleolus. If we go to the extreme and pick the smallest possible value in the core without Nord Stream and the largest possible value with Nord Stream, the small loss would turn into a small gain. However this gain would still be only a tenth of what Russia gains under the Shapley value — not enough to make Nord Stream viable. Since similar claims can be made for all other important players, our results for the pipelines' impacts under nucleolus yield a good picture for any other possible solution in the core.

1.4 Concluding Remarks

We analyzed the strategic impact of three large pipeline projects, i.e., Nord Stream, South Stream, and Nabucco. Starting with a disaggregated quantitative model of the Eurasian network for natural gas, consisting of its major producers, customers, and trunk-pipelines, we calculate the value function to characterize the interdependencies among the main actors in the current system. We solve the game with the Shapley Value, and the nucleolus as alternative indexes for the power of the different players. Adding a new pipeline changes the network, hence the value function and as a result the power index. We identified those players who are set to gain in bargaining power from a specific pipeline link and those who will be harmed. Moreover, we obtain quantitative estimates of the size of these effects, which can be compared to the cost of the link.

For the Shapley value we obtain intuitive results, which help to make sense of major developments in the industry since 2005. If considered as an alternative, both

South Stream and Nord Stream have very similar effects on the power structure in the Eurasian network for natural gas. The pipelines bypass the transit countries Belarus and Ukraine and allow Russia to compete more effectively with Norway and Netherlands. Nord Stream's strategic impact can hardly be overstated. For the initiators of Nord Stream, i.e., Russia and Germany, the gains in bargaining power clearly justify the cost of the investment. Russia had a very rocky relationship with the transit countries, i.e., Belarus and Ukraine, throughout the 1990s and several attempts for a long-term solution covering transit fees, prices for gas imports, and control of trunk-pipes have failed. In view of our results, it is not surprising that more cost efficient pipeline projects such as Yamal II through Belarus or the modernization of the Ukrainian system, have been abandoned in favor of the expensive direct offshore link.

The main beneficiaries of South Stream are Russia, Germany, and some Central European countries. However, once Nord Stream's large capacities become operational, South Stream's additional leverage is much reduced, and the gain in power hardly compensates for the high cost. Not surprisingly, the project has been repeatedly delayed and if realized at all, we expect that it will be a scaled down version of the original plan.

Nabucco opens a southern corridor through Turkey connecting Europe to new suppliers in the Middle East and the Caspian region. It also offers a new option to the producers in Central Asia, which currently ship gas through Russia. Initiated in 2009 the EU made Nabucco a major strategic project under its Trans-European Energy Networks (TEN-E) and substantial public funds have been earmarked for the project. In view of our results, this policy is difficult to rationalize. The project has large potential to decrease Russia's power, but the benefits would accrue mainly to Turkey, which could diversify its gas imports and become a major potential transit hub. The gains for the players in the EU, in contrast, are negligible. Again, the empirical evidence supports this assessment. The original consortium has disintegrated because it failed to command enough support from private investors such as Austrian OMV and German RWE. Meanwhile, Turkey, the player who has to gain most according to our analysis, took the initiative. It agreed with Azerbaijan on the Trans Anatolian pipeline from Shah Deniz gas field to Turkey's West, which corresponds to the eastern sections of Nabucco but has half of its capacity, 16 bcm/a (Businessweek (2011)).

If we assess network power with the nucleolus, however, we obtain results which appear strikingly counterintuitive and are difficult to reconcile with observed investments in Nord Stream. Under the nucleolus, none of these pipelines has any strategic value at all. The reward in terms of increased bargaining power is by order of magnitude smaller than the investment cost.

Appendix A

Pipeline Power: A Case Study of Strategic Network Investments

A.1 Calibration

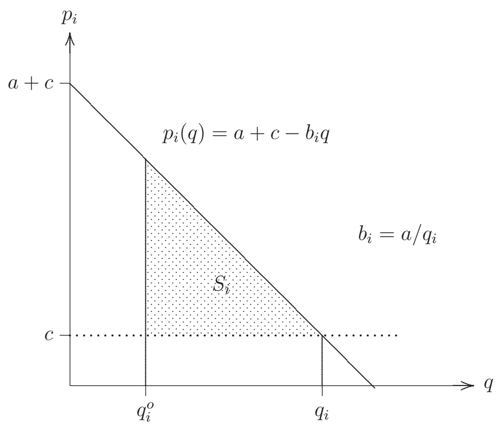
This appendix describes the functions and parameters used for the calculation of the value function (equation (1.1) in the main text). Let f^*_{ij}, $\{i, j\} \in L(N)$ denote the solution to the program in (1.1) when solved for the grand coalition, which has access to all resources. To calibrate the model, marginal willingness to pay for gas, p_i and costs of transportation and production, T_{ij} have to be determined such that f^*_{ij} are reasonably close to observed consumption and flows. As it is assumed that the players cooperate effectively, they will make efficient use of the existing network. Hence, for each player $p_i(q)$ will be equal to the local marginal cost of supplying gas, i.e., the nodal cost $c_i(q)$, which takes into account the physical constraints of the system. This feature is used to calibrate first inverse demand and then supply cost using data on consumption and flows.

A.1.1 Demand

Transport costs within Europe are small compared to the cost of producing gas and transporting it to the European borders. As a first approximation, the small differences among local costs are neglected, and a common constant supply cost c is assumed. When the program is solved for the grand coalition, none of the links within Europe are capacity constrained. So, nodal costs differ only by the variable transportation cost between connected nodes which are small.

Each consumption node's willingness to pay for gas is represented with a linear inverse demand function. To reduce the number of the parameters, for all consumption nodes the same intercept $a + c$ is assumed. Efficiency requires $p_i(q) = a + c - b_i q = c$ for each consumption node i. The slope parameters b_i are then calibrated as to replicate the consumption in 2009: $b_i = a/q_i$, where q_i is the consumption of gas in the consumption node i. As illustrated in Figure A.1, the surplus, which a player obtains from participating in the trade of pipeline gas, depends on three parameters: the difference between the demand intercept and the common supply cost a, its consumption in the base year q_i, and its indigenous production q_i^o. The common supply cost c acts as a shift parameter, which does not affect the surplus.

Figure A.1: Surplus (S_i)



A change of a, with b_i being adjusted, affects all players proportionally. Such a change has little impact on the *relative* Shapley value (measured in percent of the total), hence, will have little effect on the relative index for the bargaining power. However, a determines the absolute size of the surplus and thus, the *absolute* Shapley value, which is of relevance if the changes in the bargaining power are compared to the cost of a pipeline project. It is difficult to support any assumption for a by hard data. Obviously, it will depend a lot on how much time customers are given to substitute to other sources of energy. Making a bold assumption, in the baseline variant a is set equal to 1500 mn €/bcm yielding a total surplus from consuming gas of 949.9 bn €/a. To check the robustness of the results, a 'low-

Table A.1: Network: Consumption

Consumption nodes	Consumption[a] [bcm/a] q_i	Slope Baseline $a = 1500$ b_i	Slope Low surplus $a = 500$ b_i	Needed for access
AzerbaijanC	10,	150	50	Azerbaijan
BelarusC	17.9	83.9	28.	Belarus
IranC	136.5	11.	3.7	Iran
KazakhstanC	22.9	65.6	21.9	Turkmenistan[b]
RussiaC	426.4	3.5	1.2	Russia
TurkeyC	36.4	41.2	13.7	Turkey
TurkmenistanC	18.6	80.6	26.9	Turkmenistan
UkraineC	53.3	28.1	9.4	Ukraine
UzbekistanC	51.8	29.	9.7	Turkmenistan
BalkanC	20.2	74.3	24.8	Balkan
BelgiumC	16.9	88.9	29.6	Belgium
CenterC	104.6	14.3	4.8	Center
Center-EastC	41.4	36.2	12.1	Center-East
FranceC	44.1	34.	11.3	France
ItalyC	75.6	19.8	6.6	Italy
NetherlandsC	48.3	31.1	10.4	Netherlands
PolandC	16.	93.8	31.3	Poland
UKC	90.5	16.6	5.5	UK

[a] Data for consumption in 2009 is compiled from IEA (2010a) and IEA (2011a).

[b] To reduce the number of the players, Turkmenistan stands for Kazakhstan, Uzbekistan, and itself.

surplus' scenario with $a = 500$ mn €/bcm is considered as well. In this case, the total surplus decreases to 334.3 bn €/a. Table A.1 presents the resulting values of the slope parameter b_i depending on a. All quantities are quoted in bcm/a. All prices or costs are quoted in mn €/bcm, giving the same figure as the more common €/tcm.

The parameter c acts as a shift parameter for the demand system and supposed to reflect cost of production and typical transportation. Accordingly, it is decomposed as $c = c^P + \bar{c}^T$, where c^P stands for the common production cost parameter and $\bar{c}^T$ for an adjustment made for the typical transportation cost. These values determine the patterns of production and transport, which are presented next.

A.1.2 Production

Table A.2 presents the players' production capacities, production volumes, as well as production costs. Production volumes in 2009 are collected from IEA (2010a) and IEA (2011a). For the players except Russia and Turkmenistan the production capacities are assumed equal to their production volumes in 2009.

Differences in the production cost of existing fields are small compared to differences in the cost of developing new fields. Since meaningful information on wellhead production cost is difficult to obtain, a common supply cost parameter c^P is introduced. In accordance with Table 13.6 in IEA (2009), Δ_i accounts for regional differences in wellhead production cost and adjusts c^P for each player. For the players, who are net importers, cost of using their indigenous production is ignored. Since it is more difficult to produce at maximal capacity k_{ij}, the production cost is assumed

Table A.2: Network: Production

Links from	Links to	Capacity k_{ij} [bcm/a]	Flow [bcm/a]	Cost[a] $c_p + \Delta_i$ [€/tcm]	needed for access
Net Exporters					
AzerbaijanP	Azerbaijan	14.9[b]	14.9	$c_p - 5$	Azerbaijan
IranP	Iran	137.4[c]	137.4	$c_p - 16$	Iran
IraqP	Iraq	1.1[d]	1.1	$c_p - 8$	Iraq
KazakhstanP	Kazakhstan	27.2	27.2	$c_p + 1$	Turkmenistan[e]
NorwayP	Norway	99.4	99.4	$c_p - 7$	Norway
RussiaP	Russia	650.8	550.5	c_p	Russia
TurkmenistanP	Turkmenistan	70.9	38.3	$c_p + 3.4$	Turkmenistan
UzbekistanP	Uzbekistan	65.6	65.6	$c_p + 1$	Turkmenistan
NetherlandsP	Netherlands	78.7	78.7	$c_p - 4.4$	Netherlands
Net Importers					
BalkanP	Balkan	10.8	10.8	0.	Balkan
BelarusP	Belarus	0.2	0.2	0.	Belarus
BelgiumP	Belgium	0.	0.	0.	Belgium
CenterP	Center	23.7	23.7	0.	Center
Center-EastP	Center-East	4.8	4.8	0.	Center-East
FranceP	France	0.9	0.9	0.	France
ItalyP	Italy	8.1	8.1	0.	Italy
PolandP	Poland	5.8	5.8	0.	Poland
TurkeyP	Turkey	0.7	0.7	0.	Turkey
UKP	UK	62.1	62.1	0.	UK
UkraineP	Ukraine	21.9	21.9	0.	Ukraine

[a] The global parameter c_p is set equal to 20 mn €/bcm. The production cost of the players, who are net importers, is set equal to zero. The unit cost is given for flows up to 75% of the capacity. For the remaining 25% of capacity the numbers are increased by 20%.

[b] The Shah Deniz II field will increase Azerbaijan's current production capacity by 16 bcm/a and serve Nabucco.

[c] Investment in Iran's South Pars field will supply an additional 15 bcm/a to Nabucco.

[d] Northern Iraqi fields will produce an other 10 bcm/a to fill Nabucco's large capacities.

[e] To reduce the number of the players, Turkmenistan stands for Kazakhstan, Uzbekistan, and itself.

to be piecewise constant : $T_{ij}(f) = (c^P + \Delta_i)(\min[f, 0.75 * k_{ij}] + 1.2\max[f - 0.75 * k_{ij}, 0])$. These adjustments help to get more realistic flows for the network, but have only a negligible impact on the estimate of the bargaining power. Since the demand system is adjusted to any choice of c^P, its absolute value is rather irrelevant and arbitrarily set as $c^P = 20$ mn €/bcm.

A.1.3 Transport

The total cost of transporting gas consists of, in principle, operating cost and capacity cost. Since capacity costs of existing pipelines are sunk, they are not taken into account. This simplification is based on the assumption that bargaining among rational players should not be influenced by sunk cost. The operating cost is composed by management & maintenance cost and energy cost, which are proportional to the length of the pipeline as well as to the quantity of gas transported. The oper-

Table A.3: Network: Transmission pipelines A

Links from	Links to	Capacity [bcm/a]	Flow [bcm/a]	Operation[a] Cost: c_{ij}^T [mn €/bcm]	Needed for access
Transit outside the EU					
Azerbaijan	RussiaS	13.	0.	3.8	Azerbaijan, Russia
Azerbaijan	TurkeyE	7.	4.5	2.4	Azerbaijan, Turkey
Iran	TurkeyE	13.7	7.2	1.2	Iran, Turkey
Iraq	TurkeyE	0.	0.	1.7	Iran, Turkey
Kazakhstan	Russia	49.	0.	5.1	Russia, Turkmenistan[b]
Kazakhstan	RussiaS	49.	32.3	3.6	Russia, Turkmenistan
Russia	Belarus	100.	49.2	2.1	Russia, Belarus
Russia	RussiaN	165.	0.	2.3	Russia
Russia	RussiaS	240.	8.9	2.1	Russia
Russia	UkraineE	415.	109.1	2.	Russia, Ukraine
RussiaN	Center	0.	0.	6.9	Russia
RussiaS	Turkey	16.	8.9	4.8	Russia, Turkey
RussiaS	UkraineE	200.	24.6	1.2	Russia, Ukraine
TurkeyE	Turkey	20.	11.8	2.4	Turkey
Turkmenistan	Iran	20.	5.8	2.3	Turkmenistan, Iran
Turkmenistan	Kazakhstan	5.	0.	2.7	Turkmenistan
Turkmenistan	Uzbekistan	44.	10.7	1.7	Turkmenistan
UkraineE	Ukraine	122.	95.1	2.5	Ukraine
Uzbekistan	Kazakhstan	44.	22.5	1.8	Turkmenistan

[a] The unit cost is given for flows up to 75% of the capacity. For the remaining 25% of capacity the numbers are increased by 20%.

[b] To reduce the number of the players, Turkmenistan stands for Kazakhstan, Uzbekistan, and itself.

ating cost is represented as a piecewise constant function: $T_{ij}(f) = c^T_{ij} * (\min[f, 0.75 * k_{ij}] + 1.2 * \max[f - 0.75 * k_{ij}, 0])$, where k_{ij} denotes the maximal capacity. Per unit transportation costs are constant, but only up to three quarters of the pipeline capacity and increased by 20% for the remaining quarter.

Capacities of the pipelines linking the players' transit nodes are collected from ENTSOG (2010) and public sources. Capacities of the pipelines which are connected to areas outside of the regional scope are limited to flows through them in 2009. The pipeline capacities and the flows through them are presented in the first two columns of Tables A.3 and A.4. Flows in 2009 are compiled from IEA (2010a) and IEA (2011a).

Table A.4: Network: Transmission pipelines B

Links from	Links to	Capacity [bcm/a]	Flow [bcm/a]	Operation[a] Cost: c^T_{ij} [mn €/bcm]	Needed for access
Transit into (out of) EU					
Balkan	Turkey	16.3	8.9	1.8	Turkey
Belarus	Poland	33.	31.3	1.4	Belarus
Norway	Belgium	15.	12.2	5.2	Norway
Norway	France	18.2	15.	5.9	Norway
Norway	Center	46.	29.2	5.2	Norway
Norway	UK	46.4	24.	4.9	Norway
UkraineE	Balkan	31.3	16.5	3.4	Ukraine
Ukraine	Center-East	105.8	77.	1.9	Ukraine
Ukraine	Poland	3.2	3.2	1.2	Ukraine
Transit within EU					
Belgium	France	30.	14.9	0.8	Free third party access to transit pipelines within the EU
Belgium	Center	26.	1.	0.6	
Center-East	Balkan	1.7	1.	3.3	
Center-East	Center	77.8	18.4	2.4	
Center-East	Italy	37.	21.3	2.7	
Center	France	28.	4.3	1.4	
Center	Italy	20.2	9.1	3.5	
Netherlands	Belgium	53.	10.7	0.5	
Netherlands	Center	80.	11.7	0.6	
Netherlands	UK	15.3	7.	1.	
Poland	Center	31.4	24.4	3.2	
UK	Belgium	25.5	7.5	1.5	
Out of Regional Scope					
Algeria	Italy	25.4	25.4	6.2	Italy
France	Iberia	1.1	1.1	3.2	France
Libya	Italy	9.	9.	4.7	Italy

[a] The unit cost is given for flows up to 75% of the capacity. For the remaining 25% of capacity the numbers are increased by 20%.

To calculate the link specific cost parameter c_{ij}^T, for onshore pipelines universal operating cost of 0.3 mn €/bcm/100km is assumed. For offshore pipelines operating cost is 50% higher to account for higher pressure and increased difficulties of maintenance. These coefficients are then multiplied with the distance between the nodes to obtain the link specific operating cost as shown in column 3 of Table A.3 and A.4.

After we have specified the production cost by c^P and Δ_i, and the link specific transportation cost by c_{ij}^T, the only free parameter is the 'typical' transport cost $\bar{c}^T$. The optimization program (1.1) is run for the grand coalition to find that $\bar{c}^T = 19$ mn €/bcm yields a solution f_{ij}^* which closely replicates the empirical data on consumption and flows in the system.

A.1.4 LNG

In the model liquefied natural gas (LNG) is considered as nonstrategic since the market share of a single LNG exporter in the Eurasian gas trade is small relative to the market power of the suppliers of pipeline gas. Incorporation of the global LNG market into a cooperative game would be challenging. Since the LNG gas is a common source, actions of players outside of the considered coalition would have to be taken into account. They will form alternative coalitions which may tap the LNG supply and change the availability of LNG. Since the focus of the paper is on pipeline gas, the LNG market is not modeled explicitly.

Table A.5: Network: LNG regasification plants

Links		Capacity	Flow	Cost[a]	needed
				$c_p + \Delta_i$	for access
from	to	[bcm/a]	[bcm/a]	[mn €/bcm]	
BalkanLNG	Balkan	0.8	0.8	$2c_p$	Balkan
BelgiumLNG	Belgium	3.	3.	$2c_p$	Belgium
FranceLNG	France	10.1	10.1	$2c_p$	France
CenterLNG	Center	0.	0.	$2c_p$	Center
ItalyLNG	Italy	2.9	2.9	$2c_p$	Italy
NetherlandsLNG	Netherlands	0.	0.	$2c_p$	Netherlands
PolandLNG	Poland	0.	0.	$2c_p$	Poland
TurkeyLNG	Turkey	6.1	6.1	$2c_p$	Turkey
UKLNG	UK	10.1	10.1	$2c_p$	UK

[a]The global parameter c_p is set equal to 20 mn €/bcm. The unit cost is given for flows up to 75% of the capacity. For the remaining 25% of capacity the numbers are increased by 20%.

The LNG regasification plants, also called terminals, are represented as LNG links with capacities limited to imports through them in 2009. LNG regasification capacities and imports through them are compiled from GIE (2010), IEA (2010a), and IEA (2011a). According to Tables 13.5 and 13.6 in IEA (2009), the total cost of the LNG chain (i.e., the sum of production, liquefaction, transportation, and regasification costs) is assumed as $2c^P$. Similar to the cost of production and transportation, the total cost of the LNG chain is assumed to be piecewise constant : $T_{ij}(f) = 2c^P(\min[f, 0.75 * k_{ij}] + 1.2 \max[f - 0.75 * k_{ij}, 0])$. Figures for the LNG links are given in Table A.5.

A.1.5 New Projects

Information about the pipeline projects is obtained from various public sources. We supplement cost estimates of the project consortia by own estimates if figures are unavailable, outdated or subject to review. A rather high discount rate of 15% is used to translate capital expenditures into annualized capacity cost. This rate is a

Table A.6: Network: New pipelines

Links from	Links to	Capacity[a] old + new [bcm/a]	Flow[b] [bcm/a]	Operation Cost [€/tcm]	Capacity Cost [bn €]	required for for access
Nord Stream						
RussiaN	Center	$0 + 55$	0	6.9	12	Russia
South Stream						
RussiaS	Balkan	$0 + 63$	0	5.6	8.6	Russia
Center-EastSS	BalkanSS[c]	$1.7 + 30$	0.	3.3	3.5	Russia
Balkan	Italy	$0 + 10$	0	3.9	3.4	Russia
Nabucco						
Turkmenistan	Azerbaijan[d]	$0 + 30$	0	0.9	2.3	Azerbaijan, Turkmenistan
Azerbaijan	TurkeyE	$8.8 + 45$	4.5	2.4	7.5	Azerbaijan, Turkey
Iran	TurkeyE	$13.7 + 15$	7.2	1.2	5.4	Iran, Turkey
Iraq	TurkeyE	$0 + 10$	0	1.7	1.2	Iraq, Turkey
TurkeyE	Turkey	$20 + 30$	11.8	2.4	2.5	Turkey
Balkan	Turkey[e]	$16.3 + 30$	8.9	1.8	1.9	Turkey
Center-East	Balkan[c]	$1.7 + 30$	1	3.3	3.5	-

[a] Existing capacity as compiled from ENTSOG (2010) and public sources + planned capacity.

[b] Data is compiled from IEA (2010a) and IEA (2011a).

[c] Currently gas flows from Center-East to Balkan. The projects plan to revert the flow.

[d] This part of the project is referred to as Trans Caspian.

[e] Currently gas flows from Balkan to Turkey. The project plans to revert the flow.

common hurdle rate in the gas industry and reflects the real option nature of investment and depreciation. Table A.6 collects the parameters for the new pipelines.

A.2 Tables for the Nucleolus

The following tables (A.7 to A.9) give the results for the nucleolus. They correspond to tables 1.1 to 1.3 in the main text. The results are discussed in section 1.3.4.

Table A.7: Nord Stream, Nucleolus

Players	Nucleolus [%]		
	without Nord Stream	with Nord Stream	difference
Russia	0.8	0.8	−0.1
Ukraine	8.5	8.4	0.
Belarus	7.9	7.9	0.
Norway	1.2	1.2	0.
Netherlands	0.4	0.4	0.
UK	1.7	1.7	0.
Center	28.1	28.2	0.
Center-East	14.5	14.5	0.
Italy	5.4	5.4	0.
Poland	2.9	2.9	0.
France	11.2	11.2	0.
Belgium	5.1	5.1	0.
Balkan	1.5	1.5	0.
Turkey	10.8	10.8	0.
Iraq	0.	0.	0.
Iran	0.	0.	0.
Azerbaijan	0.	0.	0.
Turkmenistan	0.	0.	0.

Table A.8: South Stream, Nucleolus

	without Nord Stream		*with Nord Stream*			
	Nucleolus [%]	Impact[a] OS, NW, SW	Nucleolus [%]	Impact of pipeline sections[b] OS	OS, NW	OS, NW, SW
Russia	0.8	0.	0.8	0.	0.	0.
Ukraine	8.4	0.	8.4	0.	0.	0.
Belarus	7.9	0.	7.9	0.	0.	0.
Norway	1.2	0.	1.2	0.	0.	0.
Netherlands	0.4	0.	0.4	0.	0.	0.
UK	1.7	0.	1.7	0.	0.	0.
Center	28.1	0.	28.2	0.	0.	0.
Center-East	14.5	0.	14.5	0.	0.	0.
Italy	5.4	0.	5.4	0.	0.	0.
Poland	2.9	0.	2.9	0.	0.	0.
France	11.2	0.	11.2	0.	0.	0.
Belgium	5.1	0.	5.1	0.	0.	0.
Balkan	1.5	0.	1.6	0.	0.	0.
Turkey	10.8	0.	10.8	0.	0.	0.
Iran	0.	0.	0.	0.	0.	0.
Azerbaijan	0.	0.	0.	0.	0.	0.
Turkmenistan	0.	0.	0.	0.	0.	0.

[a]difference to column 1 table A.7

[b]difference to column 2 table A.7

Table A.9: Nabucco, Nucleolus

	without South Stream				*with South Stream*	
	Nucleolus [%]	Impact of pipeline sections[a] TC, ES	WS	TC, ES, CS, WS	Nucleolus [%]	Impact[b] TC, ES, CS, WS
Russia	0.6	−0.2	−0.1	−0.2	0.6	−0.2
Ukraine	8.3	−0.1	0.	−0.1	8.3	−0.1
Belarus	7.9	0.	0.	0.	7.9	0.
Norway	1.2	0.	0.	0.	1.2	0.
Netherlands	0.4	0.	0.	0.	0.4	0.
UK	1.7	0.	0.	0.	1.7	0.
Center	28.	−0.1	0.	−0.1	28.	−0.1
Center-East	14.5	−0.1	0.	−0.1	14.4	−0.1
Italy	5.4	0.	0.	0.	5.4	0.
Poland	2.9	0.	0.	0.	2.9	0.
France	11.1	0.	0.	−0.1	11.1	−0.1
Belgium	5.1	0.	0.	0.	5.1	0.
Balkan	1.6	0.1	0.1	0.1	1.6	0.1
Turkey	11.1	0.3	0.1	0.3	11.1	0.3
Iraq	0.	0.	0.	0.	0.	0.
Iran	0.1	0.1	0.	0.1	0.1	0.1
Azerbaijan	0.1	0.1	0.	0.1	0.1	0.1
Turkmenistan	0.	0.	0.	0.	0.	0.

[a] difference to column 2 table A.7

[b] difference to column 3 table A.8

A.3 Robustness

The results reported in the main text depend on a number of parameter assumptions and we will briefly discuss, how robust they are. All tables are given in appendix A.4.

A.3.1 Demand Intercept and Surplus

The power index, as measured by the relative Shapley Value, depends largely on the architecture of the current network and access rights. It is quite robust with respect to a proportional change of surplus in all regions or a uniform modification of production cost of all suppliers. Our conclusions about the strategic viability of additional pipelines, however, compare absolute cost to absolute gains. To check the robustness of our conclusions, we reduced the surplus by uniformly decreasing the demand intercept for the customers to its one third (500 mn €/bcm) while adjusting the slope to replicate consumption in the reference year (see tables A.10-A.12.). More pipelines and pipeline sections become strategically unviable, but the relative merits of the different projects do not change much. The benefit to cost ratio remains by far highest for Nord Stream. For the EU Nabucco has the lowest benefit to cost ratio, and South Stream remains the least attractive proposition for its consortium.

Our conclusions derived by the absolute as well as relative nucleolus are robust with respect to the reduction in surplus. Nord Stream and South Stream alter the power structure barely, and gains accruing from Nabucco to its consortium falls short to cover the project's large cost (see tables A.13-A.15.).

A.3.2 Access Right Regime

Next, we reconsider our assumption of free third party access within the EU. When the EC started its policies to ensure a common market for natural gas in the late 1990s, the situation was indeed very different. Most countries had a 'national champion' who monopolized the high pressure transportation grid, hence long distance transport. One might argue that it is still a long way to overcome this fragmentation of the market. In a fragmented market, a region in the EU enjoys exclusive access to its trunk-pipelines and can derive power by blocking gas shipments through its network. As a rule, in a fragmented market compared to an integrated one the European regions, which neighbor a producer or a transit country, gain transit power while importers without non-European borders suffer (see Hubert and Orlova (2014) for a detailed analysis).

A change in the access right regime alters the power structure quite substantially. When assessed with the Shapley value, Nord Stream has still the highest benefit to cost ratio for its consortium, but the pipeline's impact on the European regions is heterogeneous. It benefits Center, but harms the regions in Eastern Europe. Hence, we cannot conclude that the project is a common European interest. Benefits accruing from South Stream to its consortium doubles, barely covering the project's cost, but Center, the largest European consumer, encounters losses. Nabucco is still the least attractive project for the EU. Turkey shares its large gains with the European members of its consortium, but Center loses power although it was one of the initiators of the project (see tables A.16-A.18.).

The nucleolus is still in stark contrast with the Shapley value. In a fragmented European market Nord Stream and Nabucco have some strategic value while South Stream has again minute impact on the power structure. Nord Stream alters the power structure significantly. The project is strategically viable for the EU, but not for its respective consortium since large losses accrue to Russia, the initiator of the project. Nabucco brings larger benefits to the members of its consortium, but in total their gains are still lower than the project's cost (see tables A.19-A.21.).

A.4 Tables for Robustness

A.4.1 Decreased Demand (Surplus) : Shapley Value

Table A.10: Nord Stream, Shapley Value, Decreased Demand

Players	Shapleyvalue [%] without Nord Stream	Shapleyvalue [%] with Nord Stream	Shapleyvalue [%] difference
Russia	13.	16.	3.
Ukraine	9.3	6.9	−2.4
Belarus	6.6	5.8	−0.8
Norway	14.	11.6	−2.4
Netherlands	6.2	5.3	−0.9
UK	2.	2.	0.
Center	16.2	17.6	1.4
Center-East	8.6	9.3	0.7
Italy	3.	3.3	0.3
Poland	1.6	1.8	0.2
France	6.5	7.1	0.6
Belgium	3.	3.3	0.3
Balkan	0.8	0.8	0.
Turkey	7.4	7.3	0.
Iraq	0.	0.	0.
Iran	1.	1.	0.
Azerbaijan	0.6	0.5	0.
Turkmenistan	0.2	0.2	0.

Table A.11: South Stream, Shapley Value, Decreased Demand

	without Nord Stream		*with Nord Stream*			
	Shapley value [%]	Impact[a] OS, NW, SW	Shapley value [%]	Impact of pipeline sections[b] OS	OS, NW	OS, NW, SW
Russia	15.9	2.8	16.8	0.3	0.8	0.8
Ukraine	6.9	−2.4	6.	−0.3	−0.8	−0.9
Belarus	5.9	−0.7	5.6	0.	−0.2	−0.2
Norway	12.1	−2.	11.1	0.	−0.5	−0.6
Netherlands	5.5	−0.7	5.1	0.	−0.2	−0.2
UK	1.9	0.	2.	0.	0.	0.
Center	17.3	1.1	18.1	0.	0.4	0.5
Center-East	9.2	0.6	9.5	0.	0.2	0.2
Italy	3.3	0.3	3.4	0.	0.1	0.1
Poland	1.8	0.1	1.8	0.	0.	0.
France	7.	0.5	7.3	0.	0.1	0.2
Belgium	3.3	0.2	3.4	0.	0.1	0.1
Balkan	1.	0.2	1.	0.2	0.2	0.2
Turkey	7.4	0.	7.4	0.1	0.1	0.1
Iran	0.9	−0.1	0.9	−0.1	−0.1	−0.1
Azerbaijan	0.5	−0.1	0.5	−0.1	−0.1	−0.1
Turkmenistan	0.2	0.	0.2	0.	0.	0.

[a]difference to column 1 table A.10

[b]difference to column 2 table A.10

Table A.12: Nabucco, Shapley Value, Decreased Demand

	without South Stream				*with South Stream*	
	Shapley value [%]	Impact of pipeline sections[a] TC, ES	WS	TC, ES, CS, WS	Shapley value [%]	Impact[b] TC, ES, CS, WS
Russia	13.	−2.3	−0.1	−3.1	13.5	−3.3
Ukraine	6.2	−0.1	−0.5	−0.7	5.6	−0.4
Belarus	5.7	0.	0.	−0.1	5.5	0.
Norway	10.8	−0.5	0.3	−0.8	10.3	−0.7
Netherlands	5.	−0.2	0.1	−0.3	4.8	−0.3
UK	1.9	0.	0.	−0.1	1.9	−0.1
Center	17.8	0.	−0.1	0.2	18.3	0.2
Center-East	9.4	0.	0.	0.1	9.6	0.1
Italy	3.3	0.	0.	0.	3.5	0.
Poland	1.8	0.	0.	0.	1.9	0.
France	7.2	0.	0.	0.1	7.3	0.1
Belgium	3.4	0.	0.	0.	3.4	0.
Balkan	1.1	0.1	0.2	0.2	1.1	0.1
Turkey	10.3	1.9	0.6	2.9	10.1	2.7
Iraq	0.4	0.5	0.	0.4	0.4	0.4
Iran	1.1	0.	−0.2	0.1	1.	0.2
Azerbaijan	1.3	0.6	−0.1	0.8	1.3	0.8
Turkmenistan	0.4	0.	0.	0.1	0.4	0.1

[a]difference to column 2 table A.10

[b]difference to column 3 table A.11

A.4.2 Decreased Demand (Surplus) : Nucleolus

Table A.13: Nord Stream, Nucleolus, Decreased Demand

Players	Nucleolus [%] without Nord Stream	Nucleolus [%] with Nord Stream	Nucleolus [%] difference
Russia	2.2	2.1	−0.1
Ukraine	8.3	8.2	−0.1
Belarus	7.6	7.6	0.
Norway	3.5	3.4	−0.1
Netherlands	1.1	1.	0.
UK	1.6	1.6	0.
Center	26.8	26.9	0.1
Center-East	13.8	13.9	0.
Italy	5.	5.1	0.
Poland	2.8	2.8	0.
France	10.6	10.7	0.
Belgium	4.9	4.9	0.
Balkan	1.2	1.3	0.1
Turkey	10.2	10.2	0.
Iraq	0.	0.	0.
Iran	0.1	0.1	0.
Azerbaijan	0.1	0.1	0.
Turkmenistan	0.1	0.1	0.

Table A.14: South Stream, Nucleolus, Decreased Demand

	without Nord Stream		*with Nord Stream*			
	Nucleolus [%]	Impact[a] OS, NW, SW	Nucleolus [%]	Impact of pipeline sections[b] OS	OS, NW	OS, NW, SW
Russia	2.2	0.	2.1	0.	0.	0.
Ukraine	8.2	−0.1	8.1	−0.1	−0.1	−0.1
Belarus	7.6	0.	7.6	0.	0.	0.
Norway	3.5	0.	3.4	0.	0.	0.
Netherlands	1.1	0.	1.	0.	0.	0.
UK	1.6	0.	1.6	0.	0.	0.
Center	26.8	0.	26.9	0.	0.	0.
Center-East	13.8	0.	13.9	0.	0.	0.
Italy	5.1	0.	5.1	0.	0.	0.
Poland	2.8	0.	2.8	0.	0.	0.
France	10.6	0.	10.7	0.	0.	0.
Belgium	4.9	0.	4.9	0.	0.	0.
Balkan	1.3	0.1	1.3	0.	0.	0.
Turkey	10.2	0.	10.3	0.	0.	0.
Iran	0.1	0.	0.1	0.	0.	0.
Azerbaijan	0.1	0.	0.1	0.	0.	0.
Turkmenistan	0.1	0.	0.1	0.	0.	0.

[a] difference to column 1 table A.13

[b] difference to column 2 table A.13

Table A.15: Nabucco, Nucleolus, Decreased Demand

	without South Stream				*with South Stream*	
	Nucleolus [%]	Impact of pipeline sections[a] TC, ES	WS	TC, ES, CS, WS	Nucleolus [%]	Impact[b] TC, ES, CS, WS
Russia	1.5	−0.6	−0.4	−0.6	1.5	−0.6
Ukraine	8.	−0.2	−0.1	−0.2	8.	−0.1
Belarus	7.5	−0.1	0.	−0.1	7.5	−0.1
Norway	3.4	0.	0.	0.	3.4	0.
Netherlands	1.	0.	0.	0.	1.	0.
UK	1.6	0.	0.	0.	1.6	0.
Center	26.6	−0.3	0.	−0.3	26.6	−0.3
Center-East	13.7	−0.2	0.	−0.1	13.7	−0.2
Italy	5.	−0.1	0.	−0.1	5.	0.
Poland	2.8	0.	0.	0.	2.8	0.
France	10.5	−0.1	0.	−0.1	10.5	−0.1
Belgium	4.8	−0.1	0.	−0.1	4.8	−0.1
Balkan	1.6	0.3	0.3	0.3	1.6	0.3
Turkey	11.	0.8	0.2	0.8	11.	0.8
Iraq	0.1	0.1	0.	0.1	0.1	0.1
Iran	0.3	0.2	0.	0.2	0.3	0.2
Azerbaijan	0.3	0.3	0.	0.3	0.4	0.3
Turkmenistan	0.1	0.	0.	0.	0.1	0.

[a] difference to column 2 table A.13

[b] difference to column 3 table A.14

A.4.3 Fragmented Market: Shapley Value

Table A.16: Nord Stream, Shapley Value, Fragmented Market

Players	Shapleyvalue [%]		
	without Nord Stream	with Nord Stream	difference
Russia	15.1	18.3	3.1
Ukraine	8.7	6.9	−1.8
Belarus	5.2	4.7	−0.5
Norway	10.5	8.	−2.6
Netherlands	5.4	4.3	−1.1
UK	2.	1.8	−0.2
Center	20.3	23.4	3.1
Center-East	8.2	7.8	−0.4
Italy	2.	2.3	0.3
Poland	2.2	1.8	−0.3
France	5.8	6.2	0.4
Belgium	4.4	4.4	0.
Balkan	0.9	0.9	0.
Turkey	7.2	7.2	0.
Iraq	0.	0.	0.
Iran	1.2	1.2	0.
Azerbaijan	0.7	0.6	0.
Turkmenistan	0.1	0.1	0.

Table A.17: South Stream, Shapley Value, Fragmented Market

	without Nord Stream		*with Nord Stream*			
	Shapley value [%]	Impact[a] OS, NW, SW	Shapley value [%]	Impact of pipeline sections[b] OS	OS, NW	OS, NW, SW
Russia	16.6	1.5	19.3	0.3	0.8	1.1
Ukraine	6.7	−2.1	5.6	−0.3	−1.2	−1.3
Belarus	5.1	−0.2	4.6	0.	−0.1	−0.1
Norway	9.6	−0.9	7.6	0.	−0.3	−0.3
Netherlands	5.1	−0.3	4.2	0.	−0.1	−0.1
UK	2.	0.	1.8	0.	0.	0.
Center	20.1	−0.2	22.8	0.	−0.5	−0.6
Center-East	8.8	0.6	8.1	0.	0.6	0.3
Italy	2.4	0.4	2.5	0.	0.	0.2
Poland	2.	−0.1	1.8	0.	0.	0.
France	5.9	0.1	6.3	0.	0.	0.1
Belgium	4.4	0.	4.4	0.	0.	0.
Balkan	2.4	1.5	1.9	0.3	0.8	1.1
Turkey	7.2	0.	7.2	0.	0.	0.
Iraq	0.	0.	0.	0.	0.	0.
Iran	1.1	−0.1	1.1	−0.1	−0.1	−0.1
Azerbaijan	0.6	−0.1	0.6	−0.1	−0.1	−0.1
Turkmenistan	0.1	0.	0.1	0.	0.	0.

[a]difference to column 1 table A.16

[b]difference to column 2 table A.16

Table A.18: Nabucco, Shapley Value, Fragmented Market

	without South Stream				*with South Stream*	
	Shapley value [%]	Impact of pipeline sections[a] TC, ES	WS	TC, ES, CS, WS	Shapley value [%]	Impact[b] TC, ES, CS, WS
Russia	15.3	−2.4	0.	−3.	16.1	−3.2
Ukraine	6.3	0.1	−0.2	−0.6	5.5	−0.1
Belarus	4.7	0.	0.	0.	4.6	0.
Norway	7.6	−0.1	0.	−0.4	7.3	−0.3
Netherlands	4.1	−0.1	0.	−0.2	4.	−0.2
UK	1.8	0.	0.	0.	1.8	0.
Center	22.9	−0.2	−0.1	−0.5	22.5	−0.3
Center-East	8.2	0.	0.1	0.4	8.4	0.3
Italy	2.2	0.	0.	0.	2.5	0.
Poland	1.8	0.	0.	0.	1.8	0.
France	6.3	0.	0.	0.	6.3	0.
Belgium	4.4	0.	0.	0.	4.4	0.
Balkan	1.8	0.4	0.1	0.9	2.6	0.7
Turkey	9.5	1.9	0.1	2.3	9.2	2.1
Iraq	0.5	0.5	0.	0.5	0.5	0.5
Iran	1.1	−0.2	0.	−0.1	1.1	−0.1
Azerbaijan	1.3	0.4	0.	0.6	1.2	0.6
Turkmenistan	0.2	0.	0.	0.1	0.2	0.1

[a]difference to column 2 table A.16

[b]difference to column 3 table A.17

A.4.4 Fragmented Market: Nucleolus

Table A.19: Nord Stream, Nucleolus, Fragmented Market

Players	Nucleolus [%] without Nord Stream	with Nord Stream	difference
Russia	4.9	4.3	−0.7
Ukraine	7.	6.8	−0.2
Belarus	7.6	7.8	0.2
Norway	1.7	1.	−0.6
Netherlands	0.3	0.3	0.
UK	1.8	1.8	0.
Center	28.2	28.3	0.1
Center-East	14.3	14.4	0.1
Italy	4.6	5.	0.4
Poland	2.7	2.9	0.2
France	10.5	11.1	0.6
Belgium	5.1	5.1	0.
Balkan	0.8	0.8	0.
Turkey	10.3	10.3	0.
Iraq	0.	0.	0.
Iran	0.	0.	0.
Azerbaijan	0.	0.	0.
Turkmenistan	0.	0.	0.

Table A.20: South Stream, Nucleolus, Fragmented Market

	without Nord Stream		*with Nord Stream*			
	Nucleolus [%]	Impact[a] OS, NW, SW	Nucleolus [%]	Impact of pipeline sections[b] OS	OS, NW	OS, NW, SW
Russia	4.5	−0.4	4.4	0.	0.1	0.1
Ukraine	6.9	−0.2	6.8	0.	−0.1	0.
Belarus	7.7	0.1	7.8	0.	0.	0.
Norway	1.1	−0.5	1.	0.	0.	0.
Netherlands	0.3	0.	0.3	0.	0.	0.
UK	1.8	0.	1.8	0.	0.	0.
Center	28.3	0.	28.3	0.	0.	0.
Center-East	14.2	−0.1	14.2	0.	0.	−0.2
Italy	5.	0.3	5.	0.	0.	0.
Poland	2.9	0.2	2.9	0.	0.	0.
France	11.	0.5	11.1	0.	0.	0.
Belgium	5.1	0.	5.1	0.	0.	0.
Balkan	0.8	0.	0.9	0.	0.	0.
Turkey	10.3	0.	10.3	0.	0.	0.
Iraq	0.	0.	0.	0.	0.	0.
Iran	0.	0.	0.	0.	0.	0.
Azerbaijan	0.	0.	0.	0.	0.	0.
Turkmenistan	0.	0.	0.	0.	0.	0.

[a] difference to column 1 table A.19

[b] difference to column 2 table A.19

Table A.21: Nabucco, Nucleolus, Fragmented Market

	without South Stream				*with South Stream*	
	Nucleolus [%]	Impact of pipeline sections[a] TC, ES	WS	TC, ES, CS, WS	Nucleolus [%]	Impact[b] TC, ES, CS, WS
Russia	1.7	−2.	−0.2	−2.6	1.9	−2.5
Ukraine	7.7	0.4	0.	0.8	7.6	0.8
Belarus	7.7	0.	0.	0.	7.7	0.
Norway	1.	0.	0.	0.	1.	0.
Netherlands	0.3	0.	0.	0.	0.3	0.
UK	1.8	0.	0.	0.	1.8	0.
Center	28.2	−0.1	0.	−0.1	28.2	−0.1
Center-East	14.5	0.	0.	0.2	14.4	0.2
Italy	5.	0.	0.	0.	5.	0.
Poland	2.9	0.	0.	0.	2.9	0.
France	11.1	0.	0.	0.	11.1	−0.1
Belgium	5.1	0.	0.	0.	5.1	0.
Balkan	1.7	0.8	0.2	0.8	1.7	0.8
Turkey	11.	0.8	0.	0.8	11.	0.8
Iraq	0.	0.	0.	0.	0.	0.
Iran	0.1	0.1	0.	0.1	0.1	0.1
Azerbaijan	0.1	0.1	0.	0.1	0.1	0.1
Turkmenistan	0.	0.	0.	0.	0.	0.

[a]difference to column 2 table A.19

[b]difference to column 3 table A.20

Chapter 2

Central Asian Gas in the Eurasian Power Game

Cobanli, O. (2014). Central Asian gas in Eurasian power game. *Energy Policy*, 68 (0): 348 – 370.

Chapter 3

LNG: a Game Changer in Europe?

Abstract

Liquefied natural gas (LNG) promises to alter the power structure in the global gas trade considerably. To study the interplay between the global LNG market and the Eurasian natural gas trade through pipelines, I extend the disaggregated quantitative model of Hubert and Cobanli (2014) and consider LNG as a strategic instrument. Following their approach, I design the global gas trade as a cooperative game and use the Shapley value to analyze the power structure in the network. Given the expansion of the European LNG import capacities, I investigate how a demand growth in Asia Pacific and LNG exports from the United States impact the interaction among the players and hence the power structure. Significant benefits accrue to the European consumers and the overseas exporters of LNG, at the cost of the suppliers in the European near geography. However, Russia maintains its dominance in the Eurasian gas trade.

Keywords: Bargaining Power, Network, Natural Gas, LNG
JEL class.: C71, L5, L95, O22

3.1 Introduction

As the second largest gas consumer in the world, Europe relies on imports to serve two thirds of its natural gas demand. Since the European indigenous production in permanent decline, the continent's dependency on non-European suppliers is expected to increase further. Pipelines stand for 80% of the European imports, but they link only a few major suppliers such as Russia, Norway, and North Africa to the continent's markets. Russia alone serves one third of the European imports and hence one fifth of the continent's consumption while half of Russian shipments to Europe has to be carried through Ukrainian transmission pipelines. Liquefied natural gas (LNG) from overseas suppliers constitutes only one fifth of the European imports and plays a minor role in the continent's supply portfolio.

Concerned about the European dependency on a few suppliers and transit countries, European policymakers take strong interest in major infrastructure projects such as pipelines and LNG terminals to diversify the continent's supplier base and transit routes. As matter of fact, the diversification achieved by pipelines would be limited. The both ends of a pipeline, i.e., a supplier and an importer, are mutually dependent on each other since a pipeline cannot be moved or used for other purposes. Carrying gas from remote regions, a pipeline may have to cross through transit countries. A large number of parties involved in the gas trade complicates a long-lasting agreement and threatens perpetuity of gas deliveries to consumers. If the transit country cannot commit to stick to the agreement after the inauguration of the pipeline, its ex-post opportunism may lead to the hold-up problem, i.e., an inefficient investment in pipelines.[37]

LNG promises to be an attractive alternative to pipeline gas. The LNG chain is composed of three steps: liquefaction, transport, and regasification. Liquefaction terminals liquefy gas and load it to special ships which transport LNG to overseas markets. At the final destination, regasification terminals process LNG and serve gas to the onshore pipeline network. In contrast to pipelines, the LNG chain is free of transit countries. Special ships can carry gas to distances as far as 7000 km

[37] As an example, in the 1990s Russia invested in the Yamal pipeline through Belarus and Poland instead of in the modernization of the Ukrainian transmission pipeline network although the latter was considerably cheaper than the former. The Russia-Ukraine disputes compelled Russia to look for an alternative route to avoid an ex-post renegotiation of the rent sharing with Ukraine. For the Russia-Ukraine disputes see Pirani et al. (2009).

and enlarge the supplier base of consumers. Since several suppliers may serve a regasification terminal, the chain's both ends are less dependent on each other. Hence, consumers may respond easily to supply disruptions as well as price differences within suppliers.

To exploit LNG's favorable qualities, Europe expands its regasification capacities. Gas Infrastructure Europe (GIE) reports that over the period 2009-2017 regasification terminals under construction are going to increase the European LNG import capacities by one third to 230.7 bcm/a (billion cubic meters per annum) (GIE (2013a)). An increase in LNG's share will diversify the continent's suppliers as well as transit routes and hence strengthen the European supply security.

However, demand competition in the global LNG market may dampen the European ambitions. The global LNG market is supply constrained. Almost fully utilized, liquefaction capacities amount to only 40% of regasification capacities. A strong increase in demand, e.g., in Asia Pacific, can congest liquefaction terminals and lead to an increase in LNG prices. Demand competition within LNG importers might intensify, and less LNG might be available to European consumers.

The shale gas revolution in the United States can address the concerns over a tight LNG market.[38] In the last decade, shale gas has flooded the United States' markets and driven down the spot price in the country's Henry Hub to as low as 2.8 \$/MMBtu (U.S. dollars per million Btu) in 2012 while the prices in Europe and Asia Pacific were considerably higher, 9.5 \$/MMBtu in UK's Heren NBP, 11 \$/MMBtu for German imports via pipelines, and 16.8 \$/MMBtu for Japanese LNG imports (BP (2013b)). These large price differences between the overseas markets create large arbitrage opportunities and thus an incentive to export gas. Following the recent Crimea crisis between Russia and Ukraine, the United States has overcame its reluctance to export the country's abundant supplies and initiated a new era of energy diplomacy. The country's Department of Energy (DoE) has sped up its approval of liquefaction terminals and export permits. Exporting gas to the European markets, the United States aims to mitigate its European allies' dependence on Russian gas and hence to weaken the Russian position in the Eurasian gas trade.

In this paper I investigate the interplay between the global LNG market and the

[38] Shale gas is one of the many unconventional sources of natural gas. The gas trapped in shale gas formations is extracted with a mix of innovative technologies such as horizontal drilling and hydraulic fracturing. See EIA (2014) for an introduction to shale gas and the industry in the United States.

Eurasian gas trade through pipelines and question LNG's role as a game changer in Europe. It is worth to emphasize that the investment decisions in the European regasification terminals have been made. I consider only those which are already under construction and are going to be operational in 2017. Given the European regasification capacities in 2017, I analyze the major demand and supply developments and their impact on the power structure in the mid term: *the growth in Asia Pacific's LNG imports*, and *the United States' LNG exports*, respectively. These two developments are likely to materialize in 2017, but they are not certain.

The paper uses the disaggregated quantitative model of the Eurasian gas trade presented in Hubert and Cobanli (2014), and Hubert and Orlova (2014).[39] They consider only the Eurasian gas trade through pipelines and do not account for the global LNG market. They regard LNG as non–strategic although it is a major factor in the gas–to–gas competition. Adding the global LNG market to the model, I extend the geographical scope from Eurasia to the globe. Thereby, LNG becomes strategic, and the interaction between LNG and imports through pipelines is taken into account.

Following Hubert and Cobanli (2014) and Hubert and Orlova (2014), the paper uses cooperative game theory to analyze the power structure in the global gas trade. The value function takes into account essential characteristics of the global gas trade and captures the interdependencies among the players. The Shapley value, which I interpret as (bargaining) power here, assigns a share of the surplus to the players. A change in the architecture of the network, demand or supply will alter the interdependencies among the players. Thereby, it yields a new value function and hence a new Shapley value. The change in a player's Shapley value gives then the impact on the player's power.

For the analysis of the global gas trade, cooperative game theory is well suited.[40]

[39]Their geographical scope comprises the European countries including Turkey and the suppliers in the European near geography such as Russia, Norway, North Africa, the Caspian Sea region, and the Middle East. Cobanli (2014) extends the pipeline network eastwards and includes China to the model's geographical scope to investigate the competition within Europe, China, and other regional powers for Central Asian gas.

[40]The paper stands out from other studies in the area which apply non-cooperative game theory to the Eurasian gas trade via pipelines, e.g., Grais and Zheng (1996), Boots et al. (2004), Von Hirschhausen et al. (2005), Egging and Gabriel (2006), and Holz et al. (2008), and to the global gas trade, e.g., Egging et al. (2010), and Hartley and Medlock (2006). Hubert and Ikonnikova (2011b) explains strengths of the cooperative approach over its non-cooperative counterpart in the analysis

Firstly, with its distinct stages of production, transmission, and distribution the global gas trade resembles a vertical structure. The large differences in regional gas prices, which cannot be explained by transport cost within markets, hint to market power and strategic behavior at different stages of the vertical structure, such as Russia in production and Ukraine in transit. To avoid double marginalization and inefficiencies in the network, long term contracts are widely used in the trade of pipeline gas as well as LNG. These comprehensive contracts impose price and quantity of gas shipped from a supplier to a consumer as well as tariffs to transit countries. In conformity with long term contracts, the cooperative approach assumes that players use the network efficiently. Secondly, in the global gas trade the bargaining process within parties is recondite and does not follow a transparent procedure. The cooperative approach avoids any assumption about the bargaining process and considers a player's contribution to coalitions of other players. Thereby, it derives the player's power endogenously from its role in the global gas trade.

The expansion of the European regasification capacities facilitates European consumers' access to the global LNG market and hence supply competition in the European markets. *The United States' LNG exports* increases LNG supply and complements *the expansion of European regasification capacities*, benefiting European consumers. However, *the growth in Asia Pacific's LNG imports* drains LNG supplies and countervails the previous developments. When the developments are considered together, the diversification of supplies brings significant gains to the European consumers at the cost of the established suppliers in the continent's near geography. However, Russia suffers only marginal losses and maintains its dominance in the Eurasian gas trade.

The rest of the paper is organized as follows. Section 3.2 describes the developments in the global LNG market. Section 3.3 presents the model while Section 3.4 discusses the results. Section 3.5 delivers a short summary and concludes. While Appendix B.1 describes the model and the calibration of the parameters in detail, Appendix B.2 provides the robustness of the conclusions.

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of the gas trade.

3.2 The Major Developments in the Global LNG Market

The section presents the major developments in the global LNG market. It opens with *the expansion of the European regasification capacities*. Then, the section turns to the demand and supply developments in the global LNG market, i.e., *the growth in Asia Pacific's LNG imports*, and *the United States' LNG exports*, respectively.

3.2.1 Europe: the Expansion of the Regasification Capacities

Although the European demand is expected to increase only modestly in the near future, several major infrastructure projects to carry additional supplies to the European markets are under construction or development. Over the period 2009-2017 alone the regasification terminals under construction are going to add 56.2 bcm/a to the European import capacities and increase the total European regasification

Table 3.1: European LNG imports and regasification capacities

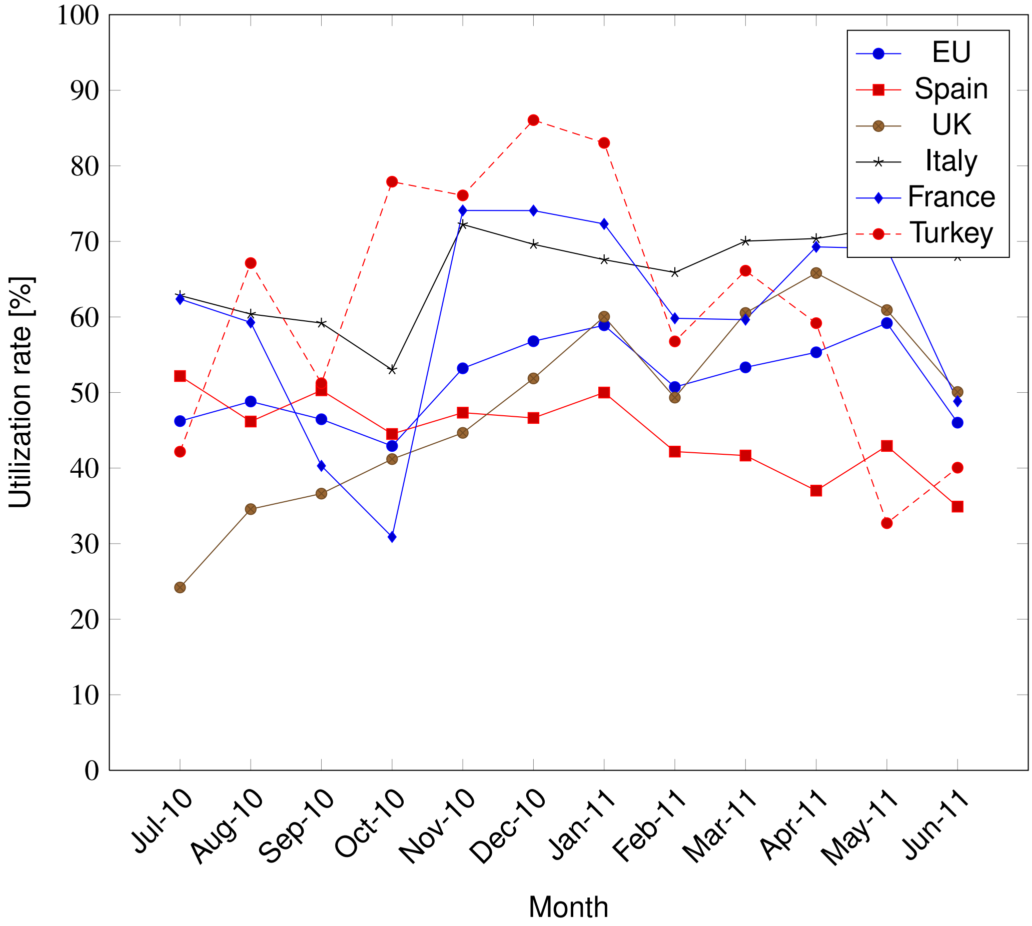
Country	Capacity[a] 2009 [bcm/a]	Imports[a] 2009 [bcm]	Util.[b] rate [%]	Capacity[c] 2017 [bcm/a]
Belgium	9.5	6.6	69.5	12.
Denmark	–	–	–	–
Germany	–	–	–	–
Greece	5.3	0.8	15.1	7.3
France	25.1	10.9	43.4	36.8
Italy	11.9	2.9	24.4	14.7
Netherlands	–	–	–	16.
Spain	63.3	27.2	43.	71.9
Poland	–	–	–	5.
Portugal	5.5	2.7	49.1	7.9
UK	53.9	10.1	18.7	59.1
Turkey	12.9	6.2	48.1	12.9
EU	174.5	61.2	35.1	230.7
EU+Turkey	187.4	67.4	36.	243.6

[a]Data for 2009 is compiled from IEA (2011a).

[b]Utilization rate = Imports/Capacity in 2009.

[c]The figures show the capacities of the regasificafication terminals, which already exist or are going to be operational in 2017. Data is taken from GIE (2013a).

Figure 3.1: Utilization Rates of the European Regasification Terminals (Monthly)



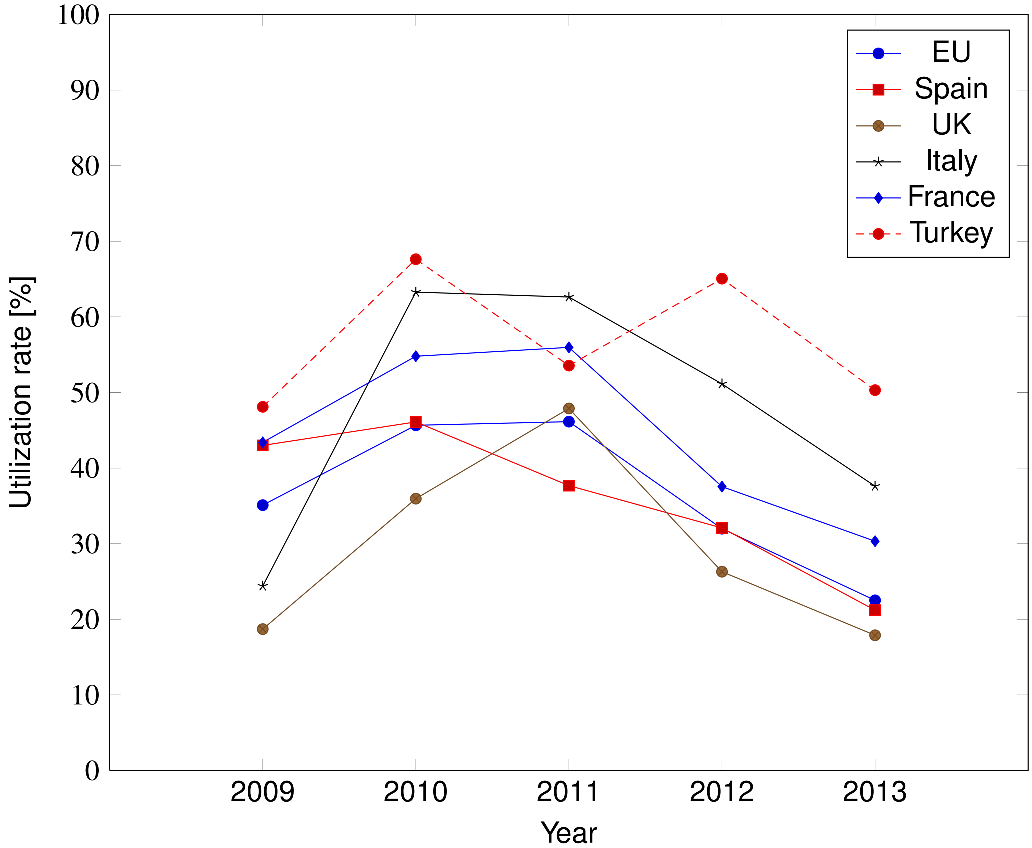
Source: Data is taken from IEA (2014). Maximum regasification capacities are supplemented with GIE (2013b).

capacities from 174.5 bcm/a to 230.7 bcm/a (GIE (2013a)).[41] Table 3.1 presents the investments in the European regasification terminals in detail.

The expansion of the European regasification capacities cannot be explained in narrow economic terms because the current capacities are underutilized. At first glance, the seasonality of gas demand promises to explain the low utilization rates of the European regasification terminals. Similar to pipelines, regasification terminals are used at high capacity in winter because of increased heating demand, and they are relatively idle in the rest of the year. In winter regasification terminals might become congested and limit annual LNG imports. Figure 3.1 presents the monthly utilization rates of the European regasification terminals from July 2010 to June 2011. In the winter of 2010–2011 the European LNG imports reached their highest

[41] If planned investments in the LNG regasification terminals are considered as well, the European regasification capacities will increase by an additional 19.6 bcm/a.

Figure 3.2: Utilization Rates of the European Regasification Terminals (Yearly)



Source: Data for 2009 is compiled from IEA (2011a). Data for 2010–2013 is taken from IEA (2014).

level in the last decade. However, the European regasification terminals were not fully utilized and did not constrain the European LNG imports. Over the period the European average utilization rate was under 60%. In Europe, France and Italy had the highest utilization rates, but one quarter of their regasification capacities were still idle.

Relative prices of LNG and imports through pipelines may elucidate the under-utilization. Figure 3.2 displays the annual utilization rates of the European LNG terminals over the period 2009-2013. The utilization rates of the European regasification terminals vary considerably within the countries as well as over time. The European average utilization rate increased from 35% in 2009 to 45% in 2010, as a result of LNG's price advantage over imports via pipelines. After a short plateau, the European average utilization rate decreased gradually to 22% in 2013. High LNG prices in the Asia Pacific region strengthened demand competition for spot LNG shipments and decreased the availability of LNG for Europe.[42]

[42]Over the period the European gas demand decreased due to the Eurozone crisis and the con-

These observations suggest that there would be enough spare regasification capacities to serve a modest increase in the European demand as well as to compensate short disruptions of imports via pipelines, such as during the Russia-Ukraine gas dispute in 2009. Hence, the expansion of the regasification capacities is not needed to transport additional volumes of LNG. However, in strategic terms the expansion of the regasification capacities will strengthen the European bargaining position vis–a–vis the established suppliers, especially Russia. They will not be used at full capacity, but the option to import large volumes of LNG from overseas suppliers will soften the Russian dominance in Europe.

In Section 3.4.2 I expand the European regasification capacities and the global LNG shipping capacities by 56.2 bcm/a and 16.9 bcm/a, respectively. The increase in the latter corresponds to 30% of the former's expansion since the global average utilization rate of regasification terminals is around 30%.

3.2.2 Asia Pacific: the Growth in LNG Imports

As the world's largest importer of LNG, the Asia Pacific region (i.e., China, India, Japan, South Korea, and Taiwan) accounts for 70% of the global LNG trade while LNG serves 95% of the region's imports and 60% of its consumption. To reduce their dependence on LNG, the countries in the region invest in their indigenous production as well as international pipeline projects to import gas from their near geography, such as Russia and Central Asia.[43] However, these investments cannot keep pace with the Asia Pacific region's rapidly growing demand, and the region's LNG imports are expected to increase further.

Over the period 2007–2012 the region's aggregate gas consumption expanded tremendously by 54.4% from 248.9 bcm to 384.3 bcm (BP (2013b)). In the region China and Japan were the fastest growing markets. As an emerging economy,

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sequential slowdown of the economy. However, the decline in the European LNG demand was in excess of the decrease in the continent's gas demand.

[43] In the Asia Pacific region China is the only country, which is connected through a pipeline to a major supplier. The Turkmenistan-China pipeline links China to rich fields in Central Asia. At present the A and B lines of the pipeline have a capacity of 30 bcm/a. The C line, which is expected to be inaugurated in October 2014, will increase the pipeline's capacity to 55 bcm/a. China seeks to enlarge the pipeline's capacity further to 80 bcm/a in 2020 (Platts (2014)). In March 2014 Russia and China signed a major gas deal. According to the deal, Russia will deliver gas to China as of 2018 and expand its shipments gradually to 38 bcm/a (Reuters (2014a)).

China is expected to lead the growth in the region's gas consumption. According to its 12th Five-Year Plan, China aims to increase the share of gas in its primary energy consumption to serve the country's rapidly growing energy demand as well as to address pollution caused by dirty fuels such as coal. The International Energy Agency (IEA) forecasts that the country's LNG imports will reach to around 50 bcm in 2015 (IEA (2012a)), a sixfold increase from 2009.

In Japan the Tohoku earthquake and the consequent Fukushima Daiichi nuclear disaster in March 2011 boosted gas demand. Following the disaster, Japan shut down all of its nuclear power plants and has relied on LNG imports and power savings to serve the country's energy demand. The rush to LNG raised Japanese LNG imports from 88.8 bcm to 116.7 bcm over the period 2007–2012 (BP (2008), BP (2013b)), and the IEA forecasts that Japanese LNG imports will reach to 129 bcm in 2017 (IEA (2012a)). However, a possible restart of nuclear power plants may ease the country's demand for LNG , indicating a drop to levels before the Fukushima Daiichi nuclear disaster (Reuters (2014b)).

In Section 3.4.3, *the growth in Asia Pacific's LNG imports* represents the demand development in the global LNG market. I amplify the Asia Pacific region's demand and hence LNG imports by 61.6 bcm/a to 180.6 bcm/a. I expand the global LNG shipping capacities by 72.5 bcm/a to prevent a possible congestion in the transport of LNG within regional markets.

3.2.3 The United States: LNG Exports

As the largest gas consumer in the world, the United States has been traditionally a net importer gas, but the shale gas revolution in the last decade has altered the country's role in the global gas trade. Over the period 2007–2012 the United States' gas production increased remarkably from 545.6 bcm to 681.4 bcm, and the country became the largest gas producer in the world, surpassing Russia. The U.S. Energy Information Administration (EIA) forecasts that the United States will turn into a net LNG exporter in 2016 and a net gas exporter in 2018 (EIA (2013)).

However, at present the United States' poor liquefaction capacities (1.9 bcm/a) preclude export of the country's abundant supplies to overseas markets. The export of gas has became a major political controversy in the United States. On the one hand, opponents argue that LNG exports will increase gas prices in the country and eliminate a crucial subsidy for domestic industries in form of cheap energy. American companies will lose their competitive advantage in international markets, which will cost jobs at home. On the other hand, proponents claim that LNG exports will benefit the United States and its allies such as Europe in several forms. At home LNG exports will generate an income stream. The increase in gas demand will boost domestic production and create new jobs in the upstream gas sector. In the global LNG market, American supplies will provide liquidity, interlink regional markets, and decrease LNG prices. In Europe, LNG exports from the United States will intensify supply competition and hence soften the European dependence on established suppliers of pipeline gas, such as Russia (Ebinger et al. (2012)).

Currently, several prospective exporters wait for the DoE's approval to build liquefaction terminals and hence to ship gas to overseas markets. In February 2014, the DoE's latest approval for Cameron LNG terminal has increased the United States' prospective LNG export capacities up to 82.5 bcm/a (Reuters (2014c)).[44] It is expected that the country's prospective LNG export capacities will be capped at 120 bcm/a, which is mentioned as the upper threshold in DoE-commissioned studies (Ebinger and Avasarala (2013)).

In Section 3.4.4, *the United States' LNG exports* stands for the supply development in the global LNG market. Taking into account the commissioning dates of the liquefaction terminals under construction, I expand the United States' liquefaction capacities by 60 bcm/a. I raise the global LNG shipment capacities by 43.4 bcm/a since the average utilization rate of liquefaction terminals is around 85%.

3.3 The Model

3.3.1 The Network Game

I extend the disaggregated quantitative model of the Eurasian gas trade presented in Hubert and Cobanli (2014), and Hubert and Orlova (2014). The extended model illustrates the global LNG market explicitly and regards LNG as a strategic instrument. Here, I restate the model as well as the cooperative approach for completeness.

[44] The other approved liquefaction terminals are Sabine Pass (22.5 bcm/a), Freeport (14.3 bcm/a), Lake Charles (20.4 bcm/a), and Dominion Cove Point (7.9 bcm/a).

Network

The network is composed of sets of links L and nodes R. A link $l = \{i, j\},\ i \neq j \in R$ connects node i with j. f_{ij} signifies a flow from node i to j while a negative value infers a flow in the reverse direction. Gas flow f_{ij} through a link is constrained by its capacity k_{ij} and has link specific transportation cost $T_{ij}(f_{ij})$. A typical region consists of a production field R_P, a consumer market R_C, and a transit hub R_T. Nodes R_P and R_C are connected with a dedicated link to R_T, and flows through these links have to be positive ($f_{ij} \geq 0,\ \forall i \in R_P$ or $\forall j \in R_C$). If $i \in R_P$, $T_{ij}(f_{ij})$ contains production cost as well. $p_j(f_{ij})$ is the inverse demand in consumption node $j \in R_C$ while $f_{ij},\ j \in R_C$ is the flow to the consumption node.

The players are linked with each other onshore through the Eurasian transmission network and/or offshore through the global LNG market. The Eurasian transmission network is represented by bidirectional links connecting transit hubs R_T. The global LNG market is composed of two nodes, R_{LNGliq} and R_{LNGgas}, and a set of links. While links $l = \{i, j\}, i \in R_T, j \in R_{LNGliq}$ represent liquefaction terminals, links $l = \{i, j\}, i \in R_{LNGgas}, j \in R_T$ stand for regasification terminals. The link connecting R_{LNGliq} to R_{LNGgas} illustrates LNG ships carrying gas from liquefaction to regasification terminals. Since gas can flow only from liquefaction to regasification terminals, all links composing the global LNG market are unidirectional and flows through these links have to be positive ($f_{ij} \geq 0,\ \forall i \in R_T, \forall j \in R_{LNGliq}$ or $\forall i \in R_{LNGgas}, \forall j \in R_T$).

Game

The value function $v : 2^{|N|} \rightarrow R_+$ maximizes the surplus which a subset of the players, i.e., a coalition, $S \subseteq N$ generates by participating in the global gas trade. The access right regime determines to which links $L(S) \subseteq L$ the coalition has access. Access to $\{i, j\},\ i \in R_P$ means that the coalition can produce gas at node i. If the coalition has access to $\{i, j\},\ j \in R_C$, it can serve gas to consumer node j. Similarly, access to links composing the transmission network $\{i, j\},\ i, j \in R_T$ and the global LNG market $\{i, j\},\ i \in R_{LNGgas}$ or $j \in R_{LNGliq}$ determines gas flows within the coalition's members. Hence, the value function takes the most important characteristics of the global gas trade into account, such as demand for gas, production capacities, regulatory framework, transportation cost via different routes, etc. The value function is calculated as:

$$v(S) := \max_{\{f_{ij}|\{i,j\}\in L(S)\}} \left\{ \sum_{\{i,j\}\in L(S),\, j\in R_C} \int_0^{f_{ij}} p_j(z)dz - \sum_{\{i,j\}\in L(S)} T_{ij}(f_{ij}) \right\} \tag{3.1}$$

subject to

$$\begin{aligned} \textstyle\sum_i f_{it} &= \textstyle\sum_j f_{tj}, & &\forall\, t \in R_T(S) & &\text{(node-balancing)} \\ |f_{ij}| &\leq k_{ij}, & &\forall\, \{i, j\} \in L(S) & &\text{(capacity constraints)} \\ f_{ij} &\geq 0, & &\forall\, i \in R_P \text{ or } j \in R_C \text{ or } i \in R_{LNGgas} \text{ or } j \in R_{LNGliq} & &\text{(non-negativity)} \end{aligned}$$

Solution

Among various solution concepts I choose the Shapley value to solve the game.[45] Hubert and Cobanli (2014) analyze strategic investments in the Eurasian gas network and compare the explanatory power of established solution concepts such as the Shapley value, nucleolus, and core. They conclude that the Shapley value can explain real investment patterns in pipeline projects while the nucleolus and core fail to replicate empirical evidence.

The Shapley value's definition is intuitive. A player's Shapley value, interpreted as (bargaining) power here, is the player's weighted contribution to all possible coalitions. Hence, it increases with the player's importance for other players. Moreover, the Shapley value is a fair division since the players contributions are balanced, i.e., the loss player i can impose on j by leaving a coalition is the same as its loss when j leaves the coalition.

3.3.2 Specification

Players & Geographical Scope

The number of optimization problems and hence the computation time increase exponentially with the number of the players. Therefore, countries showing similar characteristics are merged to *regions*, and consumers and suppliers which are

[45] For a detailed presentation of solution concepts in cooperative game theory see Myerson (2004), and Peleg and Sudhölter (2007).

strategically irrelevant for the considered developments are left out.

The model covers around 80% of the global LNG trade. *Qatar*, *Nigeria*, and *Australia* (including Indonesia and Malaysia) are the suppliers of LNG. Thanks to its shale gas revolution, *the United States* is a major prospective supplier. *Asia Pacific* (composed of Japan, China, South Korea, India, and Taiwan) consumes 70% of LNG supplies and dominates the global LNG market. These regions may trade gas only via the global LNG market.

In the Eurasian gas trade through pipelines *Russia*, *Norway*, and *North Africa* (Algeria and Libya) are the major suppliers. They are minor actors in the global LNG market since they have relatively small liquefaction capacities. *UkrBel* formed by Ukraine and Belarus is the transit region for Europe-bound Russian gas. In Europe, each region is illustrated by two players, i.e., a national *champion* and *consumers*. As an idealized- representation of a dominant midstream gas firm, a *champion* owns local production as well as transmission and distribution networks in a European region.[46] *Central & Eastern Europe* stands for Central Europe (Germany, Netherlands, Switzerland, Denmark, and Luxembourg) and Eastern Europe (Austria, Czech Republic, Hungary, Slovakia, and Poland). The region is the largest consumer and producer of gas in Europe and does not possess any LNG terminals. While Central Europe's consumption is well diversified with imports from the non-European suppliers and its own production, Eastern Europe relies highly on Russia, but also transits westbound Russian gas. *Iberia*, composed of Spain and Portugal, has the largest European regasification capacities, but the region is poorly linked to other European markets. *UK* has the second largest consumption, production, as well as regasificiation capacities in Europe. The region is well connected to the global LNG market as well as the Eurasian gas market. *Italy* is the third largest European consumer and has historically the highest wholesale prices in Continental Europe. *Western Europe* represents France and Belgium. *South-Eastern Europe* is composed of the Balkans and Turkey. Isolated from other European markets, the region relies mostly on Russian gas, but has access to the suppliers in the Caspian region and the Middle East.

[46]GdF in France, OMV in Austria, and Eni in Italy are examples for dominant midstream gas firms. In Germany there are two champions. E.ON and Wintershall share ownership of distribution and transmission networks.

Access Rights

The access right regime defines the players needed to access consumer markets, production fields, LNG facilities, as well as transmission pipelines. Hence, it decides the relative importance of a player vis–a–vis others in the global gas trade.

The European regulatory framework promotes open third party access to the continent's bottleneck facilities. It obliges the operators of pipelines, i.e., the champions, to open their transmission and distribution networks, as well as regasification terminals to third parties (EU (2009a), EU (2009b)). So, I assume that the European markets are "liberalized". The national champions are reduced to local producers. Gas flows freely within national markets, and all suppliers, European or non-European, of pipeline gas or LNG, compete for consumers under non-discriminatory conditions. In other words, consumers can freely choose their suppliers.

Table 3.2: European Access Rights

	Players needed	
	The European market is	
Access to	integrated	liberalized
Markets	*champion, consumers*	*consumers*
Production	*champion*	*champion*
Transm. network	-	-
LNG terminals	-	-

However, the European regulatory reforms are still in progress. Some national champions and their respective governments resist the liberalization of the European markets. One might argue that the European gas market is at best "integrated". In this case, gas can flow within the European national markets under non-discriminatory conditions, but the champions control access to distribution networks and hence to their respective consumer markets. Section B.2.1 checks the robustness of the results for this alternative set-up. Table 3.2 shows players needed to access the European network under different regimes.

Outside Europe, every player controls access to its consumer market, production fields, LNG facilities, as well as transmission network, i.e., gas shipments through its territory. A player may gain bargaining power by blocking access of other players to these. Access to LNG vessels is open to all players.

Time Scope

Hubert and Ikonnikova (2011b) distinguish between the short–sighted and far–sighted views. In the short–sighted view the time window is long enough to ignore the seasonality of demand and to undertake minor investments to make the current transmission network bidirectional. However, it is too short for major investments in pipeline projects, LNG facilities, and production fields or an enlargement of existing ones. Thereby, the short–sighted view regards the network as static and waives benefits from options to invest. It ignores reactions of the players to the developments and determines each development's impact in isolation.

In the far–sighted view the pipeline and LNG networks become flexible, and the players may respond to the developments in the global LNG market by altering the network architecture and hence the power structure to their favor. Here I consider the short–sighted view. In Section B.2.2 I employ the far–sighted view and discuss the robustness of the results when investment options are taken into account.

Data

I consulted several sources to collect data for 2009. Production and consumption data is compiled from IEA (2010a) and IEA (2011a). Capacities of transmission pipelines are taken from ENTSOG (2010) and supplemented by public sources. Liquefaction and regasification capacities are collected from IEA (2011a). Gas trade flows through European terminal points (IEA (2010a)), LNG trade flows within the players (BP (2010)), and wholesale prices in major markets (EC (2013b)) serve as benchmark for the calibration.

Calibration

I represent demand in a consumption node by a linear function and adjust its intercept to replicate the wholesale gas price in the respective consumer market. Hence, each consumption node has a customized demand intercept which reflects differences in consumers' willingness to pay for gas.[47] I assume a piecewise constant common supply cost which I adjust for each production node to have a more

[47] Hubert and Cobanli (2014), Hubert and Orlova (2014), and Cobanli (2014) assume a uniform demand intercept for all consumption nodes.

realistic picture of regional differences (see Table 13.5 and 13.6 in IEA (2009)). Given the customized demand intercept and the common supply cost, I calculate the slope parameter to replicate the consumption in 2009. Appendix B.1 presents the calibration in detail.

3.4 Results

Table 3.3 shows the impact of the developments (i.e, *the expansion of the European regasification capacities*, *the growth in Asia Pacific's LNG imports*, and *the United States' LNG exports*) on the power structure. Column 1 displays the benchmark, i.e., the power structure in 2009. Column 5 presents the net change in the power structure if the three developments occur jointly, a highly probable case in 2017. To identify the causalities in detail, columns 2–4 show the impact of the each mid term development separately as a counterfactual scenario. Figures in columns 2-5 are in differences with respect to the benchmark. All figures are given in bn €/a.

The Shapley value takes into account the players' interdependencies in the global gas trade and assigns each player a share of the total surplus. Since I want to analyze the power structure in the global gas trade, I subtract a player's standalone value, i.e., what the player can achieve alone without any participation in the global gas trade, from its share in the total surplus. Thereby, the benchmark in column 1 shows the players' shares in the trade surplus, i.e., their gains from cooperation with the other players. I interpret a player's share in the trade surplus as its power in the global gas trade.

However, a player's standalone value depends on how the actors in the global gas trade are aggregated to the players. Therefore, the figures in column 1 tell little about the power structure in the global gas trade. As an example, in the benchmark the Russian share in the trade surplus amounts only to 20.1 bn €/a although the country is the second largest producer and the third largest consumer in the world. Represented by one player, Russia's share results from its contribution to the global gas trade as the dominant supplier to Europe, but not from its consumption. Central & Eastern Europe, which has the largest indigenous production and consumer market as well as imports in Europe, is represented by two players: the consumers and the local producer.[48] The region's share of 91.3 bn €/a reflects its

[48] From here on I refer to a European region's national monopolist a.k.a. champion as (local) pro-

contribution to the global gas trade through its imports as well as its consumption and production. If only one player would stand for Central & Eastern Europe, the region's share would be far smaller since its power would arise only from the region's imports. The consideration of the players' standalone values would change the figures in the benchmark, but not the figures in columns 2–5 since they are given in differences with respect to the benchmark. Hence, figures in columns 2-5 have a sensible interpretation.

The European players' power (including Turkey) sums up to 220.7 bn €/a, which amounts to around half of the surplus generated by the global gas trade. The European producers account only for 16.5% of the continent's aggregate power. While a producer's power increases with its production capacities, consumers' power grounds on the size of their market and their willingness to pay for gas. Central & Eastern Europe alone stands for around 40% of the European aggregate power. South-East Europe, Italy, and UK are the other major regions.

The net exporters of gas may be arranged in two groups: *the pipeline suppliers* (Russia, Norway, and North Africa), and *the LNG suppliers* (Australia, Nigeria, and Qatar). The pipeline suppliers and Europe are well linked via pipelines and hence are strongly dependent on each other. The pipeline suppliers serve 80% of the European imports and around 55% of the continent's consumption. Europe consumes around 70% of the Russian and North African, and almost all Norwegian exports. The pipeline suppliers' joint power amounts to 47.3 bn €/a, and the largest gain accrues to Russia (20.1 bn €/a). Ukraine and Belarus, the transit countries for Europe-bound Russian shipments, receive a larger share than Russia, 24.6 bn €/a. They benefit from the transit as well as consumption of Russian gas while Russia derives benefits only from gas exports. Although North African deliveries to Europe amounts to half of Norwegian shipments, the former's gains are larger than the latter's since North Africa is active in the global LNG market as well.[49]

The LNG suppliers account only for 20% of European imports, but they are more flexible than the pipeline suppliers and may ship their gas to overseas markets

ducer. In the "liberalized" European market a champion controls only the local production and has to open its distribution and transmission networks to third parties.

[49]The pipeline suppliers export LNG through their liquefaction terminals as well. However, their liquefaction capacities sum up to 46.3 bcm/a, which is only one fifth of the LNG suppliers' joint liquefaction capacities. Among the pipeline suppliers Algeria has the largest liquefaction capacities, 27.5 bcm/a.

Table 3.3: Impact of Developments on Power Structure

Players	Shapley Value [bn €/a]				
	Bench-mark	Impact of developments *(difference to column 1)*			
		European LNG regas.	LNG demand in Asia Pacific	LNG exports from the U.S.	All developments
Europe	220.7	0.7	−1.9	2.8	1.8
producers	36.5	−0.9	2.2	−2.1	−1.3
customers	184.2	1.6	−4.	4.9	3.1
Continental Eur.[a]	91.3	0.2	−0.1	0.6	0.8
producer	14.2	−0.8	1.3	−1.2	−0.9
customers	77.2	1.	−1.3	1.8	1.7
West Eur.[b]	19.9	0.3	−0.4	0.5	0.4
producer	0.1	0.	0.	0.	0.
customers	19.7	0.3	−0.4	0.5	0.4
Iberia[c]	9.2	−0.2	−0.8	0.7	−0.2
producer	0.	0.	0.	0.	0.
customers	9.2	−0.2	−0.8	0.7	−0.2
UK	30.7	0.	0.2	−0.1	0.1
producer	6.7	0.1	0.8	−0.8	0.
customers	24.	−0.1	−0.6	0.8	0.1
Italy	34.	0.3	−0.5	0.7	0.6
producer	1.4	−0.1	0.1	−0.1	−0.1
customers	32.6	0.4	−0.6	0.8	0.6
South-East Eur.[d]	35.6	0.1	−0.4	0.4	0.1
producer	14.1	−0.3	0.	0.	−0.2
customers	21.4	0.3	−0.4	0.3	0.3
Pipeline supp.	47.3	−1.4	10.7	−6.9	−0.4
Russia	20.1	−0.9	4.7	−2.9	−0.5
Norway	13.5	−0.5	1.8	−1.5	−0.5
North Africa[e]	13.7	0.	4.2	−2.5	0.6
Ukraine & Belarus	24.6	−0.3	0.8	−0.2	0.
LNG supp.	55.8	1.8	32.6	−15.9	9.5
Australia[f]	23.2	0.8	14.5	−6.8	4.3
Nigeria	9.	0.3	3.8	−2.2	0.9
Qatar	23.7	0.8	14.4	−6.8	4.3
USA	0.6	0.	0.2	11.8	18.3
Asia Pacific[g]	136.9	−0.8	55.8	8.5	69.

[a]Germany, Netherlands, Denmark, Switzerland, Austria, Hungary, Check Republic, Slovakia, and Poland.

[b]France, and Belgium.

[c]Spain, and Portugal.

[d]Bulgaria, Romania, Greece, and Turkey.

[e]Algeria, and Libya.

[f]Australia, Indonesia, and Malaysia.

[g]Japan, China, South Korea, India, and Taiwan.

with high prices, e.g., Asia Pacific. Therefore, their gains aggregate to 55.8 bn €/a and surpass the pipeline suppliers' joint share in the trade surplus. An LNG supplier's power increases with its liquefaction capacities. Qatar, the largest LNG supplier, gains 17.9 bn €/a while Nigeria, a smaller LNG exporter, receives 6.7 bn €/a. The United States is a prospective major LNG supplier. Although the country is the largest consumer and producer of gas in the world, it has only a share of 0.6 bn €/a. The United States serves its demand by its indigenous production, and the country's small liquefaction capacities hinder its participation in the global gas trade.[50] Asia Pacific's large LNG imports (70% of the global LNG supply) as well as high willingness to pay for gas are reflected on its power of 136.9 bn €/a.

3.4.1 All Developments

In column 5 of Table 3.3 *the expansion of the European regasification capacities* as well as the demand and supply developments materialize jointly, a highly probable case in 2017. The figures in column 5 differ from the sum of the figures presented in columns 2-4 since *the expansion of the European regasification capacities* and *the United States' LNG exports* are complementary, and they reallocate the power in the opposite direction of *the growth in Asia Pacific's LNG imports*.

Large gains accrue to Asia Pacific and the United States, 69 and 18.3 bn €/a, respectively. While the LNG suppliers benefit by 9.5 bn €/a, the aggregate losses of the pipeline suppliers are minute, -0.4 bn €/a. The United States' energy diplomacy is rendered abortive. The country's LNG exports fail to mitigate the power of Russia in the Eurasian gas trade notably (only by -0.5 bn €/a) since the growth in Asia Pacific's LNG imports absorbs the liquidity created by the United States in the global LNG market. Although North Africa is a pipeline supplier, positive benefits accrue to the region since its gains from LNG exports compensate its losses from supply competition in Europe.

The supply and demand developments in the global LNG market benefits Europe (1.8 bn €/a), especially the continent's consumers (3.1 bn €/a) at the cost of the champions (-1.3 bn €/a). However, Iberia is an exception. The region is poorly connected to the other European markets and relies largely on LNG imports to

[50] Remember that the model considers only the United States' gas trade through the global LNG market from a given set of players and ignores its gas trade with Canada and Mexico through pipelines.

meet its demand. Thus, Iberia suffers from demand competition in the global LNG market and cannot enjoy any benefit from supply competition within pipeline gas and LNG in Continental Europe.

3.4.2 Europe: the Expansion of the Regasification Capacities

The expansion of the European regasification capacities (by 56.2 bcm/a) improves access of the continent's consumers to the LNG suppliers, and vice versa. Thereby, in the global LNG market demand competition within the LNG importers intensifies, and in Europe supply competition within the suppliers of LNG and pipeline gas stiffens. As presented in column 2 of Table 3.3, demand competition in the global LNG market benefits the LNG suppliers (1.8 bn €/a in total) while harming LNG importers, such as Asia Pacific (-0.8 bn €/a). Supply competition in the European markets harms the pipeline suppliers, such as Russia (-0.9 bn €/a), and the transit countries for westbound Russian supplies, Ukraine and Belarus (-0.3 bn €/a). However, North Africa's power does not change since the region's export options are well diversified between the Europe-bound pipelines and the liquefaction terminals. Therefore, North Africa's gains in the global LNG market cancels out its losses in the European markets.

In Europe, the impact on the consumers depends on the share of LNG in their supply portfolio. The consumers of Iberia and UK, i.e., the two largest LNG importers in Europe, lose power due to demand competition for LNG (-0.2 and -0.1 bn €/a, respectively). The other consumers gain from supply competition in the continent. The largest gain (1 bn €/a) accrues to the consumers of Central & Eastern Europe although the region does not have any regasification terminals. The location of a regasification terminal, i.e., the injection point of LNG, matters little for the European consumers and the LNG suppliers. Thanks to the European liberalization reforms, the regasification terminals and the transmission pipelines are open to third party access. Hence, gas flows freely within the European markets.[51] The local producers suffer from supply competition. However, a positive gain of 0.1 bn €/a accrues to UK's producer, the second largest in Europe (62.1 bcm in 2009). Demand competition in the global LNG market decreases the availability of LNG

[51] In Europe the pipeline connections between France and Iberia (4.7 bcm/a) as well as between Balkan and Central Europe (1.7 bcm/a) are the major bottlenecks. Therefore, gas in these regions cannot be shipped to the other European markets as well as gas from the other European markets to these regions.

and hence supply competition faced by UK's producer.

Although the existing European regasification capacities are underutilized, their expansion brings positive gains to Europe. The option to import larger LNG volumes benefits the European consumers by 1.6 bn €/a while it harms the continent's producers by -0.9 bn €/a, resulting in a net European gain of 0.7 bn €/a. Considering the size of the capacity expansion (56.2 bcm/a), the net European gain of 0.7 bn €/a is translated into an average unit investment benefit of 153 $/ton. An average unit investment cost less than 153 $/ton would make the expansion of the regasification capacities feasible, and vice versa. However, the International Gas Union (IGU) reports a three year moving average unit investment cost with an upward trend, less than 90 $/ton in 2004, 145 $/ton in 2011, and 187 $/ton in 2013 (IGU (2013)).

3.4.3 Asia Pacific: the Growth in LNG Imports

The growth in Asia Pacific's demand and hence LNG imports adds value to the global gas trade and enhances the surplus of the grand coalition from 789.6 to 888 bn €/a, but also reallocates the power among the players. As shown in column 3 of Table 3.3, the growth in Asia Pacific's LNG imports boosts the region's power by 55.8 bn €/a, an increase of 40.8% compared to the benchmark. The LNG suppliers benefit from demand competition in the global LNG market (32.6 bn €/a). Their gains increase with their LNG liquefaction capacities. The tight global LNG market abates the supply competition between LNG and pipeline gas in the European markets. Thereby, the pipeline suppliers enjoy an increase of 10.7 bn €/a in their power. While Russia benefits by 4.7 bn €/a, 0.8 bn €/a accrues to the transit countries.

In Europe, weak supply competition harms the consumers, but benefits the producers. The larger production a producer has, the more it gains. The producers of Central & Eastern Europe and UK, the two largest in Europe, gain 1.3 and 0.8 bn €/a, respectively.[52] The interpretation of the consumers' power is less straightforward. As an example, the consumers of UK and Italy suffer 0.6 bn €/a each, but their consumption and regasification capacities differ considerably.[53] Demand

[52]Central & Eastern Europe includes the Netherlands, the largest producer in Europe. In 2009, Central & Eastern Europe and UK produced 113 bcm and 62.1 bcm, respectively.

[53]In 2009, UK and Italy consumed 90.5 and 75.6 bcm, respectively. UK's regasification capacities

competition in the global LNG market is the major reason for the decrease in the power of UK's consumers. However, Italy's consumers lose due to weak supply competition in the continent. The European consumers' losses aggregate to 4 bn €/a while a joint benefit of 2.2 bn €/a accrues to the producers, netting down in a European loss of 1.9 bn €/a.

3.4.4 The United States: LNG exports

The expansion of the United States' liquefaction capacities will link the country to the global LNG market. Thereby, the United States can ship its abundant and cheap supplies to overseas markets. Intuitively, the expansion of LNG supply impacts the power structure diametrically opposite to the growth in LNG demand, which is discussed in section 3.4.3. In contrast to the growth in LNG demand, the expansion of LNG supply does not add any value to the global gas trade. As a result of the model's calibration, given the willingness to pay for gas and costs of production and transmission, there is already sufficient gas to serve the consumers' demand efficiently. Therefore, the expansion of LNG supply redistributes only the power among the players.

As presented in column 4 of Table 3.3, the expansion of its liquefaction capacities benefits the United States by 11.8 bn €/a. An additional LNG supplier sharpens supply competition in the global LNG market and hence in Europe. Supply competition curtails Russia's power by 2.9 bn €/a while Ukraine and Belarus lose only 0.2 bn €/a. The aggregate losses of the LNG suppliers (-15.9 bn €/a) is considerably larger than the pipeline suppliers' losses (-6.9 bn €/a). While the LNG suppliers confront the United States in Europe as well as Asia Pacific, the pipeline suppliers compete with the country only in the former.

In Europe, the consumers enjoy the diversification of their suppliers while the producers suffer from supply competition. Among the European consumers the largest benefit accrues to Central & Eastern Europe (1.8 bn €/a), which is the largest importer of gas, instead of Iberia (0.7 bn €/a) and UK (0.8 bn €/a), which hold the largest regasification capacities. While consumers' gains total to 4.9 bcm/a, the producers' aggregate losses amount to -2.1 bn €/a, resulting in a net European gain of 2.8 bn €/a.

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were around fivefold of Italy's, 53.9 bcm/a compared to 11.9 bcm/a.

3.5 Conclusions

LNG promises to diversify European supplies and hence to mitigate the continent's dependence on the non-European suppliers of pipeline gas, especially on Russia. To investigate dynamics of the global LNG market and its interaction with the Eurasian gas trade, I apply cooperative game theory to a disaggregated quantitative model of the global gas trade. I consider three major developments in the global LNG market, i.e., *the expansion of the European regasification capacities*, *the growth in Asia Pacific's LNG imports*, and *the United States' LNG exports*, in isolation as well as altogether. The discussion may be useful for policymakers interested in the diversification of European gas supplies as well as in the impact of the global LNG market on the regional trade of pipeline gas.

The expansion of the European regasification capacities facilitates access of the European consumers to the global LNG market. Consequently, demand competition in the global LNG market as well as supply competition in the European markets intensify. *The United States' LNG exports* inundate the global LNG market with supplies and complements *the expansion of the European regasification capacities*. However, *the growth in Asia Pacific's LNG imports* drains supplies in the global LNG market and counters the previous developments. Thereby, it mitigates supply competition in the European markets.

The developments altogether bring significant benefits to the European consumers at the cost of the continent's producers, netting down a positive European gain. While large benefits accrue to the overseas suppliers of LNG, supply competition in Europe curtails the power of the established suppliers. However, the decrease in the power of Russia is minute. The United States' new energy diplomacy, i.e., the export of LNG to Europe, fails to abate the Russian dominance in the Eurasian gas trade considerably since the growth in Asia Pacific's LNG imports take up LNG supplies from the United States.

Appendix B

LNG: a Game Changer in Europe?

B.1 Calibration

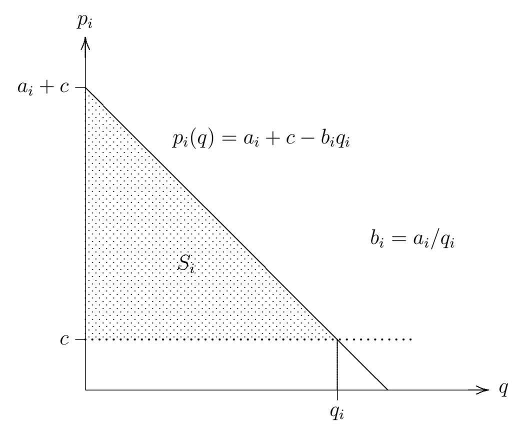
The appendix presents the parameters used for calculation of the value function (equation (3.1) in the main text) and their calibration. The calibration of the parameters follows the approach described in Hubert and Cobanli (2014) and Hubert and Orlova (2014) closely since the model used here is an extension of theirs. There are two important differences: (i) the replication of the wholesale market prices through an individual demand intercept in each consumer node, and (ii) the consideration of LNG as a strategic instrument.

The calibration of the parameters aims that f_{ij}^*, i.e., the result of the equation (3.1) when maximized for the grand coalition, converges the empirical data on consumption, production and flows reasonably. The calibration exploits a basic feature of the cooperative approach that the players use the network efficiently. Therefore, at a consumption node marginal willingness to pay for gas $p_i(q)$ is equal to marginal cost of supplying gas $c_i(q)$, i.e., nodal cost. Based on this assumption, first the inverse demand and then cost of supply and transport are calibrated.

B.1.1 Demand

As a first approximation, I ignore any difference within nodal costs and introduce a common cost parameter c which is composed of common supply cost c^P and typical transporting cost $\bar{c}^T$. Demand in each consumption node i is illustrated by a linear inverse demand function. As discussed in the main text, wholesale gas prices in regional markets differ considerably, and the disparity in wholesale gas prices cannot be explained with transportation cost within regional markets. Therefore, in contrast to Hubert and Cobanli (2014) and Hubert and Orlova (2014), I customize the demand intercept a_i of each consumption node i to replicate the average wholesale price p_i in the respective consumer market. To calibrate a_i, I follow a simple iterative approach of four steps:

Figure B.1: Surplus (S_i)



(i) Assuming initial values for a_i, the value function v_0 is calculated. Then, the Shapley value $\phi_i(v_0)$ solves the game and assigns to each player a share of the total surplus generated by the grand coalition.

(ii) As illustrated by the gray triangle in Figure B.1, the surplus S_i generated in a consumption node depends on the demand intercept a_i and the consumption q_i, but not on c. The level of c is irrelevant for the solution to the program in (3.1) since the linear inverse demand curve is shifted by c. Thus, S_i remains unchanged. The area of the gray triangle $(a_i + c - c) * q_i/2$ gives S_i.

(iii) The Shapley value $\phi_i(v_0)$ of the consumer i is smaller than its S_i. The difference between S_i and $\phi_i(v_0)$ is interpreted as the rent transferred to other players since the consumer i has to share its S_i with producers and transit countries to access supplies. The payment to other players per unit volume of gas, i.e., the average wholesale price, is given by $p_i = (CS_i - \phi_i(v_0))/q_i$.

(iv) p_i is compared with the actual average wholesale price in the consumption node i. As seen in Figure B.1, when c and q_i are kept constant, S_i and ϕ_i, as well as their difference increase with a_i. Therefore, a_i is increased if p_i is smaller than the actual average wholesale price, and vice versa.

Then, returning to the first step, for new values of a_i the value function v_1 is calculated. The same steps are repeated till p_i converges to actual average wholesale price in the consumption node i reasonably. Table B.1 displays p_i for the regions considered in the model.

Table B.1: Wholesale prices

Consumers	Wholesale price p_i	
	[€/MWh]	[$/MMBtu]
Continental Eur.[a]	24.	9.4
Iberia[b]	18.5	7.3
UK	16.9	6.6
Italy	28.7	11.3
South-East Eur.[c]	34.3	13.5
Asia Pacific	38.8	15.2

[a]Germany, Netherlands, France, Belgium, Denmark, Switzerland, Austria, Hungary, Check Republic, Slovakia, and Poland.

[b]Spain, and Portugal.

[c]Bulgaria, Romania, Greece, and Turkey.

For the calibration of the wholesale prices I assume that the European markets are "integrated", which represents the state of the European regulatory framework in 2009. Section B.2.1 portrays the "integrated" European market and discusses how the access right regime alters the power structure in the global gas trade.

Given a_i and q_i, the calibration of the slope parameter b_i is straightforward. Since the players use the network efficiently, $p_i(q) = a_i + c - b_i q_i$ equals to c. So, a_i/q_i gives b_i. Table B.2 presents the parameters a_i and b_i, which ensure q_i.

After the calibration of demand, the appendix turns to production and transport (via pipelines and LNG) of gas. I abandon the common cost parameter c and introduce differences within nodal costs.

Table B.2: Consumption nodes

Consumption nodes	Consumption q_i [bcm]	Intercept a_i [€/tcm]	Slope b_i	Needed for access[a]
Center-C	104.6	950.	9.1	Continental Eur-C
Netherlands-C	48.3	700.	14.5	Continental Eur-C
CenterEast-C	41.4	1380.	33.3	Continental Eur-C
Poland-C	16.	1380.	86.3	Continental Eur-C
France-C	44.1	950.	21.5	West Eur-C
Belgium-C	16.9	700.	41.5	West Eur-C
Iberia-C	38.8	700.	18.	Iberia-C
UK-C	90.5	700.	7.7	UK-C
Italy-C	75.6	1150.	15.2	Italy-C
Balkan-C	20.2	1380.	68.4	SouthEast Eur-C
Turkey-C	36.4	1380.	37.9	SouthEast Eur-C
Russia-C	426.4	500.	1.2	Russia
Ukraine-C	53.3	1500.	28.1	UkrBel
Belarus-C	17.9	1500.	83.9	UkrBel
USA-C	584.7	500.	0.9	USA
Japan-C	65.5	3200.	48.8	Asia Pacific
Asia-C	53.5	3200.	59.8	Asia Pacific

[a] In Europe, the consumers control access to markets. C stands for a European region's consumers.

B.1.2 Production

IEA (2010a) and IEA (2011a) provide production data for 2009. I assume that the LNG suppliers, i.e., Australia, Nigeria, and Qatar, may produce as much as their liquefaction capacities since their liquefaction terminals are almost fully utilized. In the Eurasian gas trade Russia has slack production capacities while I cap production of other regions at their actual production in 2009. During the Eurozone crisis in 2009, the European consumers passed the decrease in their demand on their imports from Russia while their imports from other suppliers changed only slightly.

Since data on wellhead production cost of the suppliers is publicly unavailable, I introduce a common supply cost parameter c^P and customize it for each production node i by a specific adjustment parameter δ_i (see Tables 13.5 and 13.6 in IEA (2009)). I set c^P arbitrarily as 20 €/tcm. It is worth to emphasize that the level of c^P does not alter the results presented in the main text since consumers' demand curves are shifted with respect to any level of c^P. Table B.3 displays the parameters related to production in detail.

Table B.3: Production links

Links from	Links to	Capacity k_{ij} [bcm/a]	Flow [bcm/a]	Cost[a] $\delta_i \cdot c_p$ [€/tcm]	Needed for access[b]
Net Exporters					
Russia-P	Russia	650.8	556.7	c_p	Russia
Norway-P	Norway	100.3	100.3	$0.65c_p$	Norway
Algeria-P	Algeria	51.8	51.8	$0.4c_p$	NorthAfrica
Libya-P	Libya	15.9	15.9	$0.56c_p$	NorthAfrica
Australia-P	Australia	94.6	79.5	$c_p/2$	Australia
Nigeria-P	Nigeria	29.5	13.2	$0.15c_p$	Nigeria
Qatar-P	Qatar	94.1	49.1	$0.07c_p$	Qatar
USA-P	USA	583.1	583.1	$c_p/2$	USA
Net Importers					
Center-P	Center	23.7	23.7	$c_p/2$	Continental Eur-M
Netherlands-P	Netherlands	78.7	78.7	$0.78c_p$	Continental Eur-M
CenterEast-P	CenterEast	4.8	4.8	$c_p/2$	Continental Eur-M
Poland-P	Poland	5.8	5.8	$c_p/2$	Continental Eur-M
France-P	France	0.9	0.9	$c_p/2$	West Eur-M
Belgium-P	Belgium	0.	0.	$c_p/2$	West Eur-M
Iberia-P	Iberia	0.	0.	$c_p/2$	Iberia-M
UK-P	UK	62.1	62.1	$0.65c_p$	UK-M
Italy-P	Italy	8.1	8.1	$c_p/2$	Italy-M
Balkan-P	Balkan	10.8	10.8	$c_p/2$	SouthEast Eur-M
Turkey-P	Turkey	0.7	0.7	$c_p/2$	SouthEast Eur-M
Ukraine-P	Ukraine	21.9	21.9	$c_p/2$	UkrBel
Belarus-P	Belarus	0.2	0.2	$c_p/2$	UkrBel

[a]Global parameter c_p is set equal to 20 €/tcm. Unit cost is given for flows up to 75% of capacity. For remaining 25% of capacity numbers are increased by 20%.

[b]In Europe, national champions control access to production fields. M stands for a region's national champion, i.e., monopolist.

B.1.3 Pipeline network

Tables B.4 and B.5 display the links representing the Eurasian pipeline network and the related parameters in four groups: (i) transit into (out of) the EU, (ii) transit in the EU, (iii) transit outside of the EU, and (iv) transit out of the regional scope. For simplicity, all pipelines connecting two nodes are combined into a link, and the link's capacity equals to the aggregate capacities of the pipelines. I compile the flows in the links from IEA (2010a) and IEA (2011a) and take their capacities from ENTSOG (2010) and public sources. All data is for 2009. I assume that capacities of the links, which are connected to nodes outside of the geographical scope, are equal to actual flows in them in the benchmark year.

The total cost of transporting gas through a pipeline consists solely of operating cost

Table B.4: Transmission network A

Links from	Links to	Capacity [bcm/a]	Flow [bcm/a]	Operation cost:[a] c^T_{ij} [€/tcm]	Needed for access
Transit into (out of) the EU					
Algeria	Italy	30.2	25.4	6.1	North Africa
Algeria	Iberia	12.	9.2	4.5	North Africa
Balkan	Turkey	16.3	8.9	1.8	BalkanTR-M[b]
Belarus	Poland	33.	31.3	1.4	UkrBel
Libya	Italy	11.	9.	4.6	North Africa
Norway	Belgium	15.	12.2	5.2	Norway
Norway	France	18.2	15.	5.9	Norway
Norway	Center	46.	29.2	5.2	Norway
Norway	UK	46.4	24.	4.9	Norway
RussiaN	Center	55.	0.	6.9	Russia
UkraineE	Balkan	31.3	16.5	3.4	UkrBel
Ukraine	CenterEast	105.8	77.	1.9	UkrBel
Transit in the EU					
Belgium	France	30.	14.9	0.8	-
Belgium	Center	26.	1.	0.6	-
CenterEast	Balkan	1.7	1.	3.3	-
CenterEast	Center	77.8	18.4	2.4	-
CenterEast	Italy	37.	21.3	2.7	-
Center	France	28.	4.3	1.4	-
Center	Italy	20.2	9.1	3.4	-
France	Iberia	4.7	1.1	3.1	-
Netherlands	Belgium	53.	10.7	0.5	-
Netherlands	Center	80.	11.7	0.6	-
Netherlands	UK	15.3	7.	1.	-
Poland	Center	31.4	24.4	3.2	-
UK	Belgium	25.5	7.5	1.5	-

[a] Unit cost is given for flows up to 75% of capacity. For remaining 25% of capacity numbers are increased by 20%.

[b] M stands for a European region's national champion, i.e., monopolist.

and disregards the pipeline's capital cost since rational players do not account for sunk cost in their bargaining. Operating cost is composed of costs of management & maintenance as well as energy. Therefore, operating cost increases with the length of the pipeline and the volume of gas transported. I assume that onshore pipelines have the universal operating cost of 0.3 €/tcm/100km. Transport through offshore pipelines (here only Nord Stream, represented as a link from RussiaN to Center) costs 0.45 €/tcm/100km, which accounts for additional costs of higher pressure and maintenance under water. The product of the universal operating cost with the length of a link gives the link's operation cost, i.e., the link specific cost parameter c^T_{ij}. In order to replicate real flows in the network, I assume that operation

Table B.5: Transmission network B

Links from	Links to	Capacity [bcm/a]	Flow [bcm/a]	Operation cost:[a] c_{ij}^T [€/tcm]	Needed for access
Transit outside the EU					
Russia	Belarus	100.	49.2	2.1	Russia, UkrBel
Russia	RussiaN	165.	0.	2.2	Russia
Russia	RussiaS	240.	8.9	2.1	Russia
Russia	UkraineE	415.	109.1	2.	Russia, UkrBel
RussiaS	Turkey	16.	8.9	4.8	Russia, BalkanTR-M[b]
RussiaS	UkraineE	200.	24.6	1.2	Russia, UkrBel
TurkeyE	Turkey	20.	11.8	2.4	BalkanTR-M
UkraineE	Ukraine	122.	95.1	2.5	UkrBel
Transit out of regional scope					
Azerbaijan	RussiaS	0.	0.	3.8	Russia
Azerbaijan	TurkeyE	4.5	4.5	17.4	BalkanTR-M
Iran	TurkeyE	7.2	7.2	5.2	BalkanTR-M
Kazakhstan	Russia	0.	0.	28.5	Russia
Kazakhstan	RussiaS	32.3	32.3	27.	Russia

[a]Unit cost is given for flows up to 75% of capacity. For remaining 25% of capacity numbers are increased by 20%.

[b]M stands for a European region's national champion, i.e., monopolist.

cost is piecewise linear : $T_{ij}(f) = c_{ij}^T(\min[f_{ij}, 0.75 * k_{ij}] + 1.2\max[f_{ij} - 0.75 * k_{ij}, 0])$. In case of a production link, $\delta_i \cdot c^P$ substitutes c_{ij}^T. It is worth to emphasize that a change in the level of the universal operating cost or the shape of the cost curve will alter the results and the conclusions presented in the main text only marginally since the architecture of the network and the access rights are decisive for the power structure, rather than the assumptions about cost.

B.1.4 LNG network

Table B.6 presents the links composing the LNG network in three groups: liquefaction terminals, regasification terminals, and LNG vessels. IEA (2011a) provides capacities of liquefaction and regasification terminals, and BP (2010) delivers data on flows through terminals. All figures are for 2009. Since the average global utilization rate of regasification terminals is around 30%, I set the total capacity of LNG ships equal to 30% of the aggregate regasification capacities.

According to Tables 13.5 and 13.6 in IEA (2009), the total cost of the LNG chain (i.e., liquefaction, shipping and regasification) equals to $1.5c^p$. Liquefaction corresponds to half of the LNG chain's total cost ($0.75c^p$). Shipping and regasification

Table B.6: LNG network

Links from	Links to	Capacity [bcm/a]	Flow [bcm/a]	Operation cost:[a] c_{ij}^T [€/tcm]	Needed for access
Liquefaction terminals (Export)					
Australia	LNGliq	94.6	79.5	$0.75c_p$	Australia
Nigeria	LNGliq	29.5	13.2	$0.75c_p$	Nigeria
Qatar	LNGliq	94.1	49.1	$0.75c_p$	Qatar
USA	LNGliq	1.9	0.	$0.75c_p$	USA
Russia	LNGliq	13.	6.2	$0.75c_p$	Russia
Norway	LNGliq	5.8	3.1	$0.75c_p$	Norway
Algeria	LNGliq	27.5	20.9	$0.75c_p$	North Africa
Regasification terminals (Import)					
LNGgas	Center	0.	0.	$0.375c_p$	-
LNGgas	Netherlands	0.	0.	$0.375c_p$	-
LNGgas	Poland	0.	0.	$0.375c_p$	-
LNGgas	France	25.1	10.6	$0.375c_p$	-
LNGgas	Belgium	9.5	6.3	$0.375c_p$	-
LNGgas	Iberia	68.8	19.5	$0.375c_p$	-
LNGgas	UK	53.9	7.8	$0.375c_p$	-
LNGgas	Italy	11.9	2.8	$0.375c_p$	-
LNGgas	Balkan	5.3	0.5	$0.375c_p$	-
LNGgas	Turkey	12.9	5.5	$0.375c_p$	South-East Eur.M[b]
LNGgas	USA	157.9	1.6	$0.375c_p$	USA
LNGgas	Asia	140.2	53.5	$0.375c_p$	Asia Pacific
LNGgas	Japan	264.2	65.5	$0.375c_p$	Asia Pacific
LNG vessels					
LNGliq	LNGgas	224.9	173.9	$0.375c_p$	-

[a]Unit cost is given for flows up to 75% of capacity. For remaining 25% of capacity numbers are increased by 20%.

[b]M stands for a region's national champion, i.e., monopolist.

cost $0.375c^p$ each (Kavalov et al. (2009)). In contrast to operation cost of pipelines, I assume that shipping cost is independent of the distance between liquefaction and regasification terminals because the share of shipment cost in the total cost of the LNG chain is small compared to the aggregate cost of liquefaction and regasification.

After the common supply cost parameter c^P, the supplier specific adjustment parameter δ_i, and the link specific transportation cost c_{ij}^T are defined, the last step is to determine the typical transporting cost $\bar{c}^T$. When $\bar{c}^T$ equals to 16.5 €/tcm, the solution of the program in (3.1) for the grand coalition reproduces the empirical data on consumption, production and flows closely.

B.2 Robustness

B.2.1 Access Right Regime

The access right regime is decisive for the power structure since it defines the players' interdependences in the global gas trade. In the main text, I assume that the European gas market is ”liberalized”. In this section I reexamine the European access right regime and check the robustness of the conclusions for an ”integrated” European market.[54]

Table B.7 has the same structure as Table 3.3 in the main text. In the former the European market is ”integrated” while in the latter it is ”liberalized”. The comparison of the both tables shows that the power structure and hence the conclusions under ”liberalized” and ”integrated” access right regimes differ considerably.

In column 1 of Table B.7 the power structure is shifted in favor of the European champions at the cost of the continent's consumers and the non-European suppliers. In Europe, the expansion in the champions' power is more than enough to compensate the decline in the consumers' power, leading to an increase in the continent's aggregate power. When considered jointly (column 5), the developments alter the European aggregate power barely, and the power of the pipeline suppliers, such as Russia, increases. When considered in isolation (columns 2-4), the developments' impact on Europe is robust, but the figures for the champions and consumers are aligned.

B.2.2 Investment Options

Following Hubert and Ikonnikova (2011b), the main text uses the short–sighted view. In this section I extend the time scope to the far–sighted view and consider investment options in the network. Thereby, the players might react to the developments and alter the network and hence the power distribution.[55] The setting allows investment in the European transmission pipelines, pipeline projects carrying Russian gas to the European markets (i.e., Yamal, Nord Stream, South Stream, and the modernisation of the Ukrainian pipeline network), as well as LNG terminals and

[54] For a description of the access rights in the ”liberalized” as well as ”integrated” European markets see Section 3.3.

[55] See Section 3.3 for a detailed description of the short–sighted and far–sighted views.

ships.[56]

It is worth to emphasize that the grand coalition composed of all players will not invest in any pipeline and LNG terminal since the current capacities are sufficient to carry gas from production fields to consumer markets efficiently, thanks to the calibration of the model presented in Section B.1. Thus, the values generated by the grand coalition in the short–sighted as well as far–sighted views are the same. However, a smaller coalition may want to alter the network architecture since its members may lack in supplies, transit routes, and/or consumer markets.

Table B.8 shows the power structure and the impact of the developments in the far–sighted view. I compare it to Table 3.3 in the main text, which uses the short–sighted view to assess the power structure. In the far–sighted view, consumers are less captured by the established suppliers of gas and the transit countries since they can invest in pipelines and LNG facilities to gain access to alternative suppliers and transit routes. Similarly, Russia can invest in alternative transit routes to bypass Ukraine. Therefore, the European consumers and Russia have higher shares in column 1 of Table B.8 than of Table 3.3. In Table B.8 *The expansion of the European regasification capacities* (column 2) alters the power structure negligibly since these investment options have already been taken into account in the benchmark (column 1). The joint impact of the developments on the power structure (column 5) is robust in direction, but differs in magnitude. In absolute terms, the net impact on Europe and the pipeline suppliers is larger while the LNG suppliers undergo a smaller change.

[56]The capacities of the liquefaction terminals in Australia, Nigeria and Qatar cannot be expanded since they equal to the production capacities of the respective country. There is no investment in production capacities.

Table B.7: Robustness: Access Right Regime

Players	Benchmark	European LNG regas.	LNG demand in Asia Pacific	LNG exports from the U.S.	All developments
	Shapley Value [bn €/a]	Impact of developments *(difference to column 1)*			
Europe	255.5	0.5	−3.	2.	0.1
producers	129.5	0.3	−1.2	0.7	0.1
customers	125.9	0.2	−1.8	1.3	0.1
Continental Eur.[a]	130.9	0.4	−1.	0.8	0.3
producer	66.1	0.2	−0.4	0.3	0.1
customers	64.9	0.2	−0.6	0.5	0.2
Iberia[b]	11.8	−0.1	−1.	0.5	−0.3
producer	5.9	0.	−0.5	0.2	−0.1
customers	5.9	0.	−0.5	0.2	−0.1
UK	33.3	0.	−0.1	0.1	−0.1
producer	17.3	0.	0.1	−0.1	0.
customers	16.	−0.1	−0.2	0.1	−0.1
Italy	41.3	0.2	−0.5	0.4	0.2
producer	20.8	0.1	−0.2	0.2	0.1
customers	20.5	0.1	−0.3	0.2	0.1
South-East Eur.[c]	38.1	0.1	−0.4	0.3	0.
producer	19.4	0.	−0.2	0.1	0.
customers	18.7	0.1	−0.2	0.2	0.
Pipeline supp.	22.3	−0.6	9.5	−4.8	1.3
Russia	9.	−0.4	3.9	−2.	0.3
Norway	5.	−0.2	1.4	−0.9	0.
North Africa[d]	8.3	0.	4.2	−2.	1.
Ukraine & Belarus	23.2	0.	0.4	0.1	0.3
LNG supp.	43.4	0.3	33.8	−14.2	10.3
Australia[e]	18.	0.1	14.9	−6.2	4.6
Nigeria	6.9	0.1	4.	−1.9	1.1
Qatar	18.5	0.1	14.8	−6.2	4.6
USA	0.5	0.	0.2	8.8	15.
Asia Pacific[f]	141.3	−0.2	57.5	8.1	71.3

[a] Germany, Netherlands, France, Belgium, Denmark, Switzerland, Austria, Hungary, Check Republic, Slovakia, and Poland.

[b] Spain, and Portugal.

[c] Bulgaria, Romania, Greece, and Turkey.

[d] Algeria, and Libya.

[e] Australia, Indonesia, and Malaysia.

[f] Japan, China, South Korea, India, and Taiwan.

Table B.8: Robustness: Investment Options

Players	Shapley Value [bn €/a] Bench-mark	Impact of developments (difference to column 1) European LNG regas.	LNG demand in Asia Pacific	LNG exports from the U.S.	All developments
Europe	227.2	0.	−1.7	4.5	2.9
producers	35.1	−0.1	2.7	−4.6	−2.6
customers	192.2	0.1	−4.4	9.1	5.5
Continental Eur.[a]	92.9	0.	−0.2	1.3	0.9
producer	12.2	0.	1.6	−2.6	−1.5
customers	80.7	0.1	−1.8	3.9	2.4
West Eur.[b]	20.8	0.	−0.5	1.	0.6
producer	0.1	0.	0.	0.	0.
customers	20.6	0.	−0.5	1.	0.6
Iberia[c]	10.1	0.	−0.3	0.6	0.3
producer	0.	0.	0.	0.	0.
customers	10.1	0.	−0.3	0.6	0.3
UK	31.3	0.	0.2	−0.2	−0.1
producer	7.5	0.	0.9	−1.5	−0.9
customers	23.8	0.	−0.7	1.3	0.8
Italy	35.2	0.	−0.6	1.3	0.8
producer	1.2	0.	0.1	−0.2	−0.1
customers	34.	0.	−0.7	1.5	0.9
South-East Eur.[d]	37.	0.	−0.3	0.5	0.3
producer	14.	0.	0.1	−0.2	−0.1
customers	22.9	0.	−0.4	0.7	0.4
Pipeline supp.	49.6	−0.1	16.5	−13.2	−3.
Russia	23.1	−0.1	7.8	−6.8	−2.1
Norway	12.7	0.	2.5	−2.9	−1.2
NorthAfrica	13.7	0.	6.2	−3.4	0.3
Ukraine & Belarus	21.5	0.	0.1	0.6	0.6
LNG supp.	40.3	0.1	19.4	−10.8	1.2
Australia[e]	16.6	0.	8.5	−4.6	0.7
Nigeria	6.7	0.	2.5	−1.7	−0.2
Qatar	17.1	0.	8.4	−4.6	0.7
USA	1.2	0.	0.4	11.8	19.1
Asia Pacific[f]	146.	0.	63.7	7.1	77.6

[a]Germany, Netherlands, Denmark, Switzerland, Austria, Hungary, Check Republic, Slovakia, and Poland.

[b]France, and Belgium.

[c]Spain, and Portugal.

[d]Bulgaria, Romania, Greece, and Turkey.

[e]Australia, Indonesia, and Malaysia.

[f]Japan, China, South Korea, India, and Taiwan.

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Appendix C

Technical Documentation

We give a documentation of the gas sector model and related calculations. Together with the data-files and codes, available from ”http://www.ms-hns.de/research_gas”, it should help the reader to check and replicate the results of the following papers:

- Franz Hubert & Onur Cobanli: Pipeline Power (chapter 1) [pipe1]
- Onur Cobanli: Central Asian Gas in Eurasian Power Game (chapter 2) [pipe2]
- Franz Hubert & Ekaterina Orlova: Competition or Countervailing Power for the European Gas Market [reg1]
- Franz Hubert & Ekaterina Orlova: Network Access and Market Power [reg2]

While the papers differ in their economic focus and in many technical details, they all use variants of a model of the European gas-network and notions from cooperative game theory to analyze the power structure in the Eurasian gas trade. Each paper starts from a broad description of the network: its geographical scope, major players, etc. In this respect, we have four basic variants (pipe1, pipe2, reg1, reg2); one for each paper.

All four papers analyze how the bargaining power of the players is affected by various changes such as a new pipeline, liberalization of pipeline access, a merger, increase of demand, etc. Each of these scenarios correspond to a distinct cooper-

Files containing results

name	content
description of network optimization model	
`VN-parameters-Mathematica`	the parameters for the optimization problem in the format required for `calculateValueOneCoalition[]` .
`VN-parameters-General`	same as above in a simplified format for use with other optimization software.
value function	
`VN-value-Full`	explicit list of coalitions and values, as well as any errors reported from the calculation (very large).
`VN-value-Mathematica`	values in a compressed format, suitable for Mathematica's `Subsets[]` function.
`VN-value.nuc`	values in a compressed format, suitable for calculating the Nucleolus using Matlab code of Johannes Reijnierse.
cooperative solutions	
`VN-Shapley`	the Shapley Value
`VN-Nucleolus`	the Nucleolus
`VN-MinCore`	the minimal values players receive in the core
`VN-MaxCore`	the maximal values players receive in the core
technical files	
`VN-nucl.dat`	log and results from calculating the nucleolus
`VN-MinCore.dat`	log and results from calculating the minimal core
`VN-MaxCore.dat`	log and results from calculating the maximal core

ative game, for which we have a unique identifier, the *variant-name* or *VN*.[57] These games are formulated and solved using software written in Mathematica and Matlab, which are described in the following.

A cooperative game is characterized by a set of players N and a value function v. For each possible subset of players $S \in N$ (also called coalition), $v(S)$ gives the maximal joint payoff which the coalition S can achieve on its own. In other words, v is the result of a number of related optimization problems. These optimization prob-

[57]Typically the variant name consists of several parts referring to specific settings such as geographic scope, set of players etc. These variant names are used as identifiers to build file names for the results, e.g. the Shapley values are saved in a file `VN-Shapley`).

Directories

name	content
\EAGas-model	Mathematica notebooks and corresponding packages for setting up the network optimization problem, calculating the value function, solving for the Shapley value.
\games+tools	Mathematica and Matlab code to convert files, to calculate minimal and maximal values in the core.
\nucleolus HR	Matlab code provided by Hans Reijnierse for calculating the nuleolus.
\pipe1	special code and results related to Hubert & Cobanli: Pipeline Power.
\pipe2	special code and results related to Cobanli: Central Asian Gas.
\reg1	special code and results related to Hubert & Orlova: Competition or Countervailing Power.
\reg2	special code and results related to Hubert & Orlova: Network Access and Market Power.

lems share a common structure because they are derived from the same broad network model, but they differ in the sense that smaller coalitions have only access to parts of the whole network.

So the analysis proceeds in four steps.

1. We characterize the general network optimization problem of the cooperative game. For each variant we specify the instruments and parameters of the network optimization problem. These parameters include the specification of access rights, so that we can derive the embedded sub-network optimization problems of smaller coalitions. We refer to this representation of the game *VN-parameters*.

2. We calculate the numerical values of the value function by solving all sub-network optimization problems for a particular variant/game. We call this representation *VN-values*. Since we look at a large set of coalitions, this step is computationally the most demanding one.

3. Using the numerical value function, we calculate for each variant various solutions for cooperative games, such as Shapley value, nucleolus, core. We refer to the solutions as *VN-Shapley*, *VN-nucleolus*, etc.

4. Finally, we compare the solutions of different variants to assess the impact of pipeline investment, regulatory changes etc. and build the tables in the papers.

The code, which defines the parameters of the network optimization problem, calculates the value function and then the Shapley value is written in Mathematica (step 1-3). The code which calculates the Nucleolus and the minimum and maximum values of the core is written Matlab (step 3). Further evaluations of the results are again written in Mathematica (step 4). In the next sections, we give a brief overview on the main programming tools for each of these steps.

We save results to a number of files in plain text format. The following files contain results. VN stands for variant-name.

C.1 General Network Optimization Problem

All papers share a common data base from which the calibrations and definitions of their network optimization problems are obtained using two Mathematica notebooks, a common one `Gas Parameters` and an additional one which is individual for each paper. There are also packages to visualize the data base and the parameter settings.

All code of this section is written in Mathematica. The general network optimization problem is saved in files named `VN-parameters-*` where the * stands for different formats.

C.1.1 Data & Calibration

C.1.1.1 Definition of Data

The data is defined in **`Gas Data Base`** using a similar format as the data provided by Mathematica. All data, which are needed for the model specification and displays (tables and maps) are assigned to global variables by loading the Mathematica package `Gas Data Base` .
requires: nothing

Data Overview

package	function	needs
`Gas Data Base`	assignes data to global variables.	*nothing*
`Gas Data Visu`	defines functions for display of data.	`Gas Data Base` `FH Tools`
file output:	*none*	

C.1.1.2 Visualization of Data

`Gas Data Visu` defines functions for the display of the data.
requires: `Gas Data Base` , `FH Tools`

C.1.2 Set-up for Network Optimization

The topology of the network is defined by a set of nodes R and a set of directed links L (the geographical scope). Each link $\{i, j\} \in L$ connects two nodes, which might be R_P production nodes, R_C consumption nodes, or R_T transit nodes.[58] For each link we have (piecewise linear) cost reflecting transportation and/or production cost.

The game is defined by a set of players N and a value function v, mapping the set of subsets of N into real numbers. A coalition $S \subseteq N$ has access to $L(S) \subseteq L$ (the access regime). The value of a coalition S is obtained by maximizing the joint surplus (gross surplus from consumption s minus cost of transport and production T) using the gas-flows x_{ij} in the pipelines which are accessible:

$$v(S) = \max_{\{x_{ij} | \{i,j\} \in L(S)\}} \left\{ \sum_{\{i,j\} \in L(S),\, j \in R_C} s_j(x_{ij}) - \sum_{\{i,j\} \in L(S)} T_{ij}(x_{ij}) \right\} \qquad \text{(C.1)}$$

subject to

$$\begin{array}{rcll} x_{ij} & \geq & 0, & \forall\, i \in R_P \text{ or } j \in R_C \quad \text{(non-negativity)} \\ \sum_i x_{it} & = & \sum_j x_{tj}, & \forall\, t \in R_T(S) \quad \text{(balancing)} \\ |x_{ij}| & \leq & k_{ij}, & \forall\, \{i, j\} \in L(S) \quad \text{(capacity constraints)} \end{array}$$

The capacity constraint is dropped when we allow for investment. In this case T also accounts for investment cost.

[58] Production and consumption nodes are always linked to a transit node.

Parameters Overview

package	function	needs
`Gas Parameters`	defines functions for the assignment, saving and recovering of parameters, as well as parameters for some basic variants. → `reSetParTo[]` → `parameterToFile[]` → `fileToParameters[]`	`Gas Data Base`
`Gas Parameters *.m`	defines additional functions and all the variant names for the individual papers. (*: pipe1, pipe2, reg1, reg2)	`Gas Data Base` `Gas Parameters`
`Gas Parameters min`	collects functions needed for recovering the parameters-settings from the file and starting the optimization.	*nothing*

`Gas Parameters Visu`	defines functions for display of parameters after they have been assigned using `reSetParTo[]` .
	→ `showMainParCurrent`
	→ `showAllParCurrent`
		`Gas Data Base`
		`Gas Data Visu`
		`FH Tools`
		`Gas Parameters`

file output:	`VN-parameters-Mathematica` `VN-parameters-General`	
for illustration:	**`workspace parameters.nb`**	

→ : main functions defined in the package; VN : variant name

To keep the network optimization problem simple, we assume a linear demand (quadratic surplus function) and piece-wise linear cost functions.

C.1.2.1 Definition of Functions and some Variants

By loading **`Gas Parameters`** we define routines, which specify the functions and parameters of the optimization problem using data provided by `Gas Data Base` .

The complete specification of the general network optimization problem (all the technical and demand parameters as well as the access rights) are assigned to global variables by calling: `reSetParTo[`*`parameter-list`*`]`, which in turn calls: `setGeoScope[]`, `setPlayers[]`, `setPipeAccess[]`, `setLinkParameter[]`, `setDemandParameter[]`. These routines define the geographical scope of the network, players, access regime, parameters for the individual links and for demand. Different (but not all) versions of these settings can be combined. `selectVarList` allows for an interactive selection of predefined arguments for the subroutines.

`feasiblePipes[`*`coalition`*`]` returns the links to which a coalition has access.

In `Gas Parameters` we provide only the base variants, used in the different papers. To obtain the specific definitions for a paper, an additional file has to be loaded; e.g. `Gas_Parameters pipe1.m` or `Gas_Parameters reg2.m`. These define a unique *variant-name* (*VN*) for each network optimization (game) which will be part of the names of files for storing results etc. We also define `setVar[`*`VN`*`]` to return the arguments for `reSetParTo[]` .

`parametersToFile[`*`VN`*`, "Mathematica"]` saves the parameter settings of a game to a file with a name `VN-parameters-Mathematica` from which the settings can be recovered using `fileToParameters[`*`VN`*`, "Mathematica"]`. When writing "Mathematica" can be replaced by "General" to obtain a more compact format.

`Gas Parameters` and `Gas Parameters *.m` require `Gas Data Base` .

C.1.2.2 Visualization of Parameter Settings

`Gas Parameters Visu` defines functions for the display of the parameter setting, once they have been assigned by calling `reSetParTo[]`. There are tables and maps, some of them interactive. Various functions are collected in the commands: `showMainParCurrent`, `showAllParCurrent`, which display most of the settings.

requires: `Gas Data Base` , `Gas Data Visu` , `FH Tools` , `Gas Parameters` .

C.1.2.3 Starting from defined Games

`Gas Parameters min` collects those routines which are needed if the parameter settings are already saved to files `VN-parameters-Mathematica`. If loaded there is no need to load other notebooks.

C.1.2.4 Example

The Mathematica notebook `workspace parameters.nb` illustrates these steps.

Network Optimization Overview

package	function	needs
Gas Prog	finds accessible network for a given coalition of players and calls LinProg[] from Gas ProgLP to calculate the payoff (value). → calculateValueOneCoalition[]	Gas Parameters min Gas ProgLP
Gas ProgLP	creates a linear programming problem to calculate the optimal network usage for a given network configuration. → LinProg[]	Gas Parameters min
Gas Prog Visu	display of the optimal network usage using output created by calculateValueOneCoalition[] . needs parameters from reSetParTo[] . → displayResChartLP[] → displayResTableLP[]	Gas Data Base Gas Data Visu FH Tools Gas Parameters Gas Prog Gas ProgLP
file output:	none	
for illustration:	**workspace program.nb**	

→ : main functions defined in the package

C.2 Value Function

Given our assumption on functional forms, we obtain the value function by maximizing surplus (quadratic) minus cost (piece-wise linear) subject to balancing constraints for transit nodes and non-negativity constraints for production and consumption links.

C.2.1 Network Optimization

By loading Gas Prog and Gas ProgLP we define the functions used for solving the network optimization problem. calculateValueOneCoalition[] establishes the sub-network, which is accessible for a given coalition of players and calls LinProg[] from Gas ProgLP to calculate the payoff (value).

The general optimization routines coming with Mathematica turned out to be too slow. To speed up the process `LinProg[]` approximates the quadratic surplus functions by piece-wise linear functions and uses "LinearProgramming" to solve the resulting linear optimization problem.

C.2.2 Visualization of Results

`Gas Prog Visu` defines `displayResChartLP[]`, and `displayResTableLP[]` for the display of the optimal network usage using the output created by `calculateValueOneCoalition[]` . It needs the full parameter definitions from `reSetParTo[]` and requires `Gas Data Base` , `Gas Data Visu` , `FH Tools` , `Gas Parameters` , `Gas Prog` , and `Gas ProgLP` .

C.2.3 Calculating Value Function (and Shapley Value)

`Gas ValFuncShap` defines functions for the calculation of the value function. Using the unique variant-name VN we recover the parameters from the associated file `VN-parameters-Mathematica`. Then we calculate the value of all coalitions (repeatedly calling `calculateValueOneCoalition[]`). Depending on the number of players, this step may take a long time. The results are saved in two formats. `VN-values-Full` has the value, coalition, and possible error-messages and is very large. `VN-values-Mathematica` has only the numerical values ordered as the coalitions are ordered by Mathematica's `Subsets[]` command, i.e., $\{\}, \{a\}, \{b\}, \{c\}, \{a, b\}, \{a, c\}, \{b, c\}, \{a, b, c\}$.

As we have the value function already, it is convenient to invoke `FH Shapley` and write the Shapley value into `VN-Shapley`.

For some changes, i.e., if two players merge, it is not necessary to run all optimization problems again. The new value function can be obtained from the old one by re-matching values with coalitions. Suppose we start with a game $\{N, v\}$ and let players a and b merge. We define the new game as $\{N, w\}$ by making a a 'proxy' player and b a dummy player. The new value function w is obtained from v as

$$w(S) = \begin{cases} v(S \cup b) & \text{if} \quad a \in S, \quad b \notin S \\ v(S \setminus b) & \text{if} \quad a \notin S, \quad b \in S \\ v(S) & \text{else.} \end{cases}$$

In these cases we save only the original value function.

Calculating Value Function & Shapley Value

package	does	loads

`Gas ValFuncShap`	provides operations for the calculation of the value function (which may take a long time) and all Shapley values.
	→ `calcValFuncShap[]`
	→ `calcShapleyValue[]`
	→ `assignValueFunction[]`
		`Gas Parameters min`
		`Gas Prog`
		`Gas ProgLP`
		`FH Shapley`

file output:	`VN-value-Full`
	`VN-value-Mathematica`
	`VN-Shapley`	

for illustration:	**`workspace ValFuncShap.nb`**	

→ : main functions defined in the package ; VN : variant name

C.3 Solving the Game

We consider several solutions for the games defined by the different variants: the Shapley value, nucleolus, and core, which we characterize by the minimal and maximal values a player can achieve. The starting point is always the set of players and the value function as specified in `VN-value-Mathematica`.

We express the solutions as absolute values and as relative values (in per cent of the value of the grand coalition). In addition, we report the player's value when it is alone, and we give the solutions (absolute and relative) for the zero normalized game.

For the calculation of the nucleolus, as well as minimal and maximal values in the core, we use Matlab code.

C.3.1 Shapley Value

We calculate the Shapley value intermediately after calculating the value function (see section C.2.3). The function is defined in `FH Shapley` . In addition, we have some tools to rearrange and aggregate the players once the Shapley values are calculated.

Calculating Shapley Value

package	does	loads
`FH Shapley`	functions to calculate the Shapley value for a set of players and a value function. → `shapleyValue[]` → `allShapleyValues[]`	*nothing*
`FH Shapley tools`	functions to rearrange and aggregate players in the output of `FH Shapley` (or other solutions).	*nothing*
for illustration:	**`workspace ValFuncShap.nb`**	

→ : main functions defined in the package

C.3.2 Nucleolus

To calculate the nucleolus, we use Matlab code provided by Hans Reijnierse. It implements an algorithm described in Potters et al. (1996). The algorithm in turn is based on the characterization of the nucleolus as the lexicographical center of the game developed in Maschler et al. (1979).

We first convert `VN-value-Full` into `VN-value.nuc`. This file is used by Matlab program `calcNucleolus`, which invokes Reijnierse's command "nucleolus". The log and results are written into `VN-nucl.dat`. We switch back to Mathematica code to further process `VN-nucl.dat`, extracting the nucleolus, as well as those coalitions and their excesses which determine the solution.

Calculating the Nucleolus

package	does	loads
`convert-nucleolus`	prepares input for Matlab, reads Matlab output, and writes it to files: converts `VN-value-Full` into `VN-value.nuc`, extracts results from `VN-nucl.dat` (Matlab output) into Mathematica, and prepares the input for the tables. → `writeMatlabInputFunc[]` → `vectorNucleolusList[]` → `vectorPlayersNucleolus[]` → `writeToFileAllValues[]`	*nothing*
`calcNucleolus` (Matlab)	reads `VN-value.nuc`, calculates the nucleolus, and writes `VN-nucl.dat`.	`nucleolus`
`nucleolus` (Matlab)	package to calculate the nucleolus written by Potters et al. (1996).	

file output:	`VN-value.nuc`
	`VN-nucl.dat` (from Matlab)
	`VN-Nucleolus`	

for illustration:	**`workspace nucleolus.nb`** **`workStepsNucleolus.nb`**	

→ : main functions defined in the package ; VN : variant name

C.3.3 Core

As the core is characterized by a large number of inequalities, we restrict our attention to the extreme values, which a player can obtain in the core. For each player we find the minimal and the maximal value in the core.

As with the nucleolus we use Matlab to compute the values.

Characterizing the Core

package	does	loads
`convert-core`	creates matrices and writes "*.csv" files for the optimization in Matlab. extracts the values from Matlab output files, compares these values with the nucleolus and the Shapley value, prepares the input for the table. → `writeMatricesVariantsMatlab[]` → `readMatlabCore[]` → `ShapleyMinNuclMax[]` → `writeConceptsToFile[]`	`convert-nucleolus`
`calcMaxMinCore` (Matlab)	reads `variants.csv`, `matrices.csv` and `VN_matrixname.csv`, calculates the minimum and the maximum for each player, writes `VN-MinCore.dat` and `VN-MaxCore.dat`.	*nothing*

file output:	`VN_matrixname.csv`
	`variants.csv`
	`matrices.csv`
	`VN-MinCore.dat` (from Matlab)
	`VN-MaxCore.dat` (from Matlab)
	`VN-MinCore`
	`VN-MaxCore`
	`VN-Concepts`	

for illustration:	**`workspace core.nb`** **`workStepsCore.nb`**	

Declaration

Ich bezeuge durch meine Unterschrift, dass meine Angaben über die bei der Abfassung meiner Dissertation benutzten Hilfsmittel, über die mir zuteil gewordene Hilfe sowie über frühere Begutachtungen meiner Dissertation in jeder Hinsicht der Wahrheit entsprechen.

Berlin, den 29. July 2014 Onur Cobanli