RUSSIA'S STRATEGIC NATURAL GAS EXPORT POLICY: THE CASE OF GAZPROM'S "BYPASS" PIPELINES

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Declaration

This dissertation is the result of my own work and includes nothing which is the outcome of work done in collaboration except where specifically indicated in the text.

This dissertation has not been submitted for a degree or diploma of other qualification at any other university. The dissertation does not exceed the PhD dissertation word limit of the Judge Business School.

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Dành cho cha mẹ tôi và gia đình của tôi

Abstract

Recent gas disputes between Russia and Ukraine have triggered policy responses by EU member states and investments into gas infrastructure to improve supply security. In response, Gazprom, the largest gas exporter to Europe, has proposed two pipeline projects, Nord Stream and South Stream, which together, as planned, would be able to transport around one quarter of Europe's annual gas consumption. These projects would improve Europe's security of supply by bypassing transit countries such as Ukraine.

A large-scale equilibrium gas simulation model of Eurasia was developed to analyze the economics of these projects. Project finance analysis and Monte Carlo simulations were used to investigate the full transport costs of these projects and the uncertainties affecting those costs.

The analysis of Nord Stream found that the unit cost of shipping Russian natural gas through Nord Stream is clearly lower than using the Ukrainian route. Under various scenarios of gas market development, investment in Nord Stream was found to have a positive economic value for Gazprom. The maximum potential economic value of Nord Stream was disaggregated into project economics (cost advantage), strategic value (increased bargaining power vis-à-vis Ukraine) and security of supply value (insurance against disruption of the Ukrainian transit corridor). The economic fundamentals of the project account for the bulk of Nord Stream's positive value in all analysed scenarios. Another major contribution to the value of the system is its strategic value, which could add between 24-31% on top of the core value, depending on demand growth in Europe. However, the security value of Nord Stream is quite low (roughly 3% of the maximum achievable value).

Unlike the Nord Stream case, South Stream was found not to be a cost competitive pipeline project when compared to the Ukrainian route. Thus, South Stream investment has a negative value in low and moderate demand expansion scenarios in Europe. Only when demand in Europe grew at more than 2.1% p.a. through to 2030 was the economic value of South Stream investment positive, albeit rather marginally (US$ 1.1 bn over 25 years). Moreover, the risks of transit interruptions through Ukraine did not justify the construction of the South Stream pipeline because under all transit disruption scenarios analysed the economic value of South Stream is negative. It was shown that only if Ukraine increased its transit fee considerably, the economic value of South Stream investment would range between US$ 1 bn and 10 bn, depending on the assumed demand growth rate in Europe. Thus, as insurance against Ukraine's future bargaining over higher transit fees or lower import prices, South Stream has far greater value than its value as insurance against transit interruptions and/or its value as a demand-driven project.

The key conclusion from this research is that Gazprom's bypass strategy is not so much about meeting future demand in Europe while eliminating transit risks but about eliminating Ukraine's transit monopoly while keeping the value of Ukraine's gas market as high as possible without risking its gas supplies to Europe.

Keywords: Natural gas pipelines, Gazprom, security of gas supply, Russia, Ukraine, Nord Stream, South Stream, equilibrium modelling, Cournot, Stackelberg games.

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List of Abbreviations

BASF	Badische Anilin- und Soda-Fabrik
bcm	Billion cubic metres
bcm/y	Billion cubic metres per year
bn	Billion
bn/y	Billion per year
CAGR	Compound Annual Growth Rate
CAPEX	Capital Expenditure
CIS	Commonwealth of Independent States
DCF	Discounted Cash Flow model
DOE	US Department of Energy
EC	Commission of the European Communities
EIA	Energy Information Administration
ENI	Ente Nazionale Idrocarburi
EU	European Union
FSU	Former Soviet Union
GDF	Gaz de France (Suez)
GDP	Gross Domestic Product
IEA	International Energy Agency
IEO	International Energy Outlook
IT	Information Technology
JAGAL	Jamal-Gas-Anbindungsleitung
KKT	Karush-Kuhn-Tucker optimality conditions
km	Kilometres
LNG	Liquefied Natural Gas
LRMC	Long-Run Marginal Cost
LTC	Levelized Transport Cost
MCP	Mixed Complementarity Problem
mn	Million
mn/y	Million per year
NEL	Norddeutsche Erdgas-Leitung
NPT	Nadym-Pur-Taz region

NPV	Net Present Value
O&M	Operation and Maintenance
OECD	Organisation for Economic Co-operation and Development
OPAL	Ostsee-Pipeline-Anbindungs-Leitung
OPEX	Operational Expenditure
p.a.	per annum
p.p.	percentage point
PGNiG	Polish Petroleum and Gas Mining
RPR	Reserve-Production Ratios
SNAM	Società Nazionale Metanodotti
SRMC	Short-Run Marginal Cost
STEGAL	Sachsen-Thüringen-Erdgas-Anbindungsleitung
tcm	thousand cubic metres
ToP	Take-or-pay
US$	United States Dollars
USSR	Union of Soviet Socialist Republics
WEO	World Energy Outlook

CHAPTER 1

Introduction

1.1. Research Background

1.1.1. Natural Gas in Europe

According to forecasts by the International Energy Agency, IEA, global natural gas demand is expected to expand during the next two decades (IEA, 2009).[1] Although most of the predicted demand expansion will take place in non-OECD regions (such as the Middle East and Asia), the mature gas markets of North America and Europe will remain the largest gas markets, with their combined share in global gas consumption accounting for about 37% (IEA, 2009). In terms of the international gas trade, the European Union, EU, will remain the most important gas market for international gas players, since by 2030 half of all global net gas exports are expected to be to this region (IEA, 2009).[2]

Competition, decarbonisation and security of supply are the main principles of European energy policy (EC, 2006; EC, 2008a). Thus, the importance of natural gas in the EU is expected to increase since natural gas, as an energy carrier, has relatively low carbon content compared to other fossil fuels (such as coal or oil).[3] In 2009, natural gas consumption in the EU totalled 503 billion cubic metres, bcm, (or about a quarter of total primary energy consumption) (IEA, 2010a). By 2030, consumption was projected to grow at an average annual growth rate of +0.6% (EC, 2008b) or +0.7% (IEA, 2009).[4]

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[1] In the IEA's *Word Energy Outlook* (2009) reference case, the global average annual demand growth rate is expected to be 1.5%. However, there are many uncertainties in these forecasts. Past gas demand predictions made by major international energy organizations were optimistic (Noël, 2009) and have consistently been downscaled.

[2] By 2030 net gas imports by the EU are expected to be 516 bcm, while global net gas exports are projected to be 1069 bcm (IEA, 2009) .

[3] Natural gas is in a favourable position in the European electricity generation industry, especially in the context of regulating greenhouse gas emissions. Gas-fired power plants emit roughly half the CO_2 per KWh of electricity output compared to coal-fired power plants.

[4] Although, on average, annual growth in gas consumption in Europe during the past twenty years exceeded the annual growth of energy consumption, experts are skeptical that this demand growth will continue in the future (see e.g., (Noël, 2009)).

On the other hand, indigenous gas production in Europe has been in steady decline[5] and, as of 2009, gas production accounted for about 39%[6] of total consumption. EU reliance on imported gas will increase over time, since the decline in indigenous gas production is expected to continue at 2.2% per annum (p.a.) and, by 2030, European gas production is forecasted at 112 bcm, or half of the production in 2009 (IEA, 2010b). Thus, by 2030 net imports are expected to increase by more than 200 bcm and total 516 bcm, which is about 83% of Europe's total primary gas demand (IEA, 2009).

In order to meet the expected increase in gas consumption and import requirements, substantial investment in existing and new infrastructures will need to be undertaken in the EU. By 2030, cumulative investment in exploration and development, transmission and distribution and LNG regasification in the EU is expected to be US$ 484 bn, or about US$ 23 bn p.a. (IEA, 2009). Apart from financing investment in the EU, substantial investment must be committed by non-EU gas producers with substantial gas reserves to serve growing demand.

Natural gas is predominantly exported either by large-diameter pipelines or by LNG ships.[7] The EU gas market has traditionally been dominated by imported pipeline gas. In 2009, more than three-quarters of all imported gas was conveyed through pipelines, while the rest was imported via LNG (BP, 2010a).[8] Due to the asset specificity of major gas infrastructures (e.g., LNG and pipelines) and demand uncertainties, their construction is usually based on long-term take-or-pay contracts (ToP). These contracts link sellers and buyers for a long period (about 25-30 years) into a bilateral monopoly with predefined obligations for both parties.[9] Such a long duration provides a secure environment in which producers can invest in field developments and gas transportation facilities.

[5] Between 2000 and 2009, indigenous gas production in Europe declined by 60 bcm, or 3.2% per annum on average (BP, 2010a).

[6] Own calculations based on (BP, 2010a; IEA, 2010a).

[7] LNG, or liquefied natural gas, is gas super cooled at about -260 degrees Celsius. At this temperature natural gas becomes liquid and can be easily transported via special LNG tankers (similar to oil tankers). The liquefaction is called a LNG 'train'. In order to use LNG it must be regasified for final consumption (transformed back to gaseous form) at a consumption (importing) node.

[8] However, the situation is expected to change due to substantial investment in LNG regasification terminals with an increase in total capacity of some 80 bcm by 2015 (Noël, 2009).

[9] Under the ToP conditions, purchasers are required to pay for a pre-specified gas quantity, irrespective of whether or not gas is actually taken off. The gas price under these contracts is indexed to prices of alternative fuels (such oil and oil products). Price indexation to competing fuels protects the buyer of gas on a long-term basis against prices above those for competing fuels. Long-term gas contracts are said to allocate risks along the gas chain in such a way that the buyer bears the volume risk and the seller the price risk.

There are many constraints and risks associated with constructing new pipelines (or LNG) to serve growing gas markets. Apart from demand-side risks, natural gas trading by pipelines has constraints on the supply side, such as sizes of reserves and technological and geographical constraints. For example, to export gas via a 36 inch pipeline with a length of about 3000 km a gas producer must have at least 250 bcm of natural gas available for at least 20 years. The minimum required reserve base goes sharply up when a larger diameter pipeline or longer lifetime is expected, and can exceed 1 tcm for 56 inch pipelines (Nitzov, 2003).

1.1.2. Natural Gas in Russia

Russia holds the largest conventional gas reserves in the world. As of 2009, its proven reserves account for around a quarter of the total world proven gas reserves (BP, 2010a). Gazprom, Russia's state-owned, vertically integrated oil and gas company, has shares in the global and Russian proven gas reserves amounting to 17% and 70%, respectively (Gazprom, 2010g). Moreover, Gazprom owns and operates the Russian gas transmission system and has a legal monopoly over gas exports (Gazprom, 2010d). Due to this comparative advantage, Gazprom is the largest gas exporter in the world, with its share in global gas trade (both pipe gas and LNG) accounting for some 20% in 2009 (BP, 2010a). However, most of Gazprom's gas exports have been destined for the EU market. Currently, Gazprom supplies around one quarter of the EU's natural gas consumption, or 6.2% of the bloc's primary energy supplies (BP, 2010a).[10]

Russian natural gas exports to Europe are crucial to its national economy. During the Soviet era, natural gas exports were one of the main sources of hard currency and, since the dissolution of the USSR, these earnings have, to a certain extent, helped Russia to overcome the economic collapse and eased the transition from an administrative to a market-based economy. In 2009, Russia's gas exports to European markets generated around 4.0% of Russia's GDP, or 42% of Gazprom's total revenue.[11] Tax receipts from gas exports to Europe amounted to one quarter of Russia's defence budget.[12]

[10] Europe's dependence on Russian gas is not evenly distributed –Eastern European countries are highly dependent on Russian gas (the dependence is over 60% on average), while Western European countries are moderately or only slightly dependent on Russian gas (only about 20% on average) (Noël, 2009).
[11] This includes revenues from all the commercial activities (gas, oil, electricity, transportation and others) of Gazprom and its affiliates.
[12] Author's own calculations based on (Gazprom, 2010b; Russian Federal State Statistics Service, 2010a).

Apart from direct economic benefits to the national economy and to the state budget, natural gas exporting provides Russia with an important role in the international arena. Due to infrastructural rigidity, the gas trade between Russia and the EU member states has been based on long-term ToP contracts; therefore, the gas trade ties Russia and consuming countries to long-lasting (commercial) relationships. Moreover, since Gazprom is a state-owned company, the natural gas trade provides Russia with an important (economic) dimension in bilateral political relations between Russia and the governments of consuming countries.

Russian President Medvedev has declared that the country needs to diversify its economy beyond oil and gas towards an innovative and service-based (such as IT, telecoms and aerospace industries) economy (Medvedev, 2009). In this sense, earnings from natural gas exports may, if effectively used, help Russia to diversify its economy and modernise its military and industrial complex (Balzer, 2005). Therefore, commercializing natural gas reserves in the most effective way and ensuring secure gas exports to Europe is crucial for the future of the Russian state.

Although it may seem that Russia is in good position to supply Europe's growing import requirements (because of its gas reserves and well-established gas trade with the EU), several other factors will determine whether Russia will be able to sustain and expand its position in the European gas market.

Firstly, during the next decade, Gazprom's gas supplies will be constrained by: (*i*) a decline in production from its traditional gas fields, (*ii*) its ability to contract gas from Central Asia and (*iii*) its obligation to supply growing domestic demand.[13] Therefore, Gazprom's ability to increase exports to Europe depends on the company's financial and technical ability to develop new gas production in remote and technically-challenging fields, such as on the Yamal Peninsula.

Secondly, Gazprom's position in Europe is being challenged by Europe's diversification away from Russian gas, due to the perceived insecurity of Russian gas exports, and by intense competition from overseas LNG suppliers.[14]

During the Soviet era, natural gas transit through the republics of the Soviet Union was not an issue at all because the pipeline system was under uniform management. However, with the dissolution of the USSR, the environment of Russian gas exports to

[13] Although the recent global economic crisis has moderated the gas demand growth observed during the economic expansion in Russia

[14] The recent global economic crisis and the successful development of unconventional gas in the U.S. have created a gas surplus in Europe.

Europe has been altered substantially. In particular, two major problems for Russian gas exports have emerged.

First, the single pipeline system, developed during the Soviet era, was split and came under the control and management of the newly independent states (such as Ukraine and Belarus). This has created transit issues for Russian gas exports to Europe. In 1991-2000 (before the first gas shipments through the Yamal-Europe pipeline), Ukraine transported about 106 bcm/y, which was roughly 93% of all Russian gas exports to European countries (excluding transit through Ukraine to CIS countries).[15]

Secondly, the collapse of the Soviet Union has caused economic hardship in many former Soviet Union (FSU) republics. This has created a cycle of non-payments for gas bills and debt accumulation, which has led to constant haggling between Russia, as the dominant gas supplier, and Ukraine over debt settlement, prices and transit fees. Since Ukraine has historically held a monopoly on the transit of Russian gas to Europe, any dispute over the terms of the gas trade puts European gas supplies at risk. The first gas dispute between Russia and Ukraine over the gas trade was reported as early as 1992 (Killen, 1992). Ukraine's first attempt to divert Russian gas transits to Europe was in 1993, when Russia stopped supplies to Ukraine during another gas dispute (Pirani, 2007). Recurrent disputes between Russia and Ukraine over the terms of the gas trade have continued, culminating in a major gas transit disruption in January 2009, which was the most severe gas disruption since the beginning of gas exports from Russia to Europe.[16]

Therefore, the question of the availability of a reliable transport route connecting Russia with major customers in the EU has become a top priority for the Russian government and Gazprom, and the next section reviews Gazprom's attempts to diversify away from the Ukrainian corridor.

1.1.3. Gazprom's Pipeline Investment Strategy: "Bypassing" Ukraine

Immediately after the fall of the USSR, to reduce its dependence on Ukraine, Gazprom began planning the construction of a pipeline that would pass through Belarus and Poland to Germany (the so-called Yamal-Europe pipeline). In 1994, the construction

[15] Author's own calculations based on (Naftogaz of Ukraine, 2010a; Stern, 2005).
[16] The 2009 gas interruption was a complete cut-off of gas supplies through Ukraine and lasted for two weeks in the middle of the winter, affecting millions of gas consumers in South-Eastern Europe and the Western Balkans (Pirani et al., 2009; Kovacevic, 2009; Silve and Noël, 2010).

of the Yamal-Europe pipeline began simultaneously in Russia, Germany and Poland. The initial plan for the Yamal-Europe project in Russia was to develop three giant gas fields on the Yamal Peninsula – Bovanenkovo, Kharasavey and Kruzenshtern - and to create a pipeline system connecting these fields with the Belarus section of the Yamal-Europe pipeline (Ingersoll, 1995).[17] However, these fields on the Yamal Peninsula have not been developed yet. Therefore, since its operation began, the Yamal-Europe pipeline has transported gas from existing production fields in the Nadym-Pur-Taz (NPT) region.

The construction of the Yamal-Europe pipeline in Belarus began in 1996 and was carried out by Belarus' state-owned gas company, Beltransgaz (Beltransgaz, 2010). Since Gazprom was the sole financier of the Belarus section, it retains full ownership (Gazprom, 2010j). The basis for the construction of the Polish section of the Yamal-Europe pipeline was an intergovernmental agreement signed between Poland and Russia in 1993 (Europol Gaz s.a., 2010a). Accordingly, a joint venture (Europol Gaz) between Gazprom (48%), the Polish national oil and gas company, PGNiG (48%), and Gas-Trading S.A. (4%) was set up to finance, construct and operate the Polish section of the Yamal-Europe pipeline. In Germany, Wingas, a joint venture between Gazprom and Wintershall (BASF's oil and gas arm), was responsible for the construction of the JAGAL pipeline (about 350 km), which would connect the Yamal-Europe pipeline (near Frankfurt/Oder) to Wingas' gas grid in Germany.

The initial plan was to install two 56 inch pipelines along the route with a total capacity of 63 bcm/year (Europol Gaz s.a., 2010c). However, due to market conditions in Europe the project was scaled back and only one 56 inch pipeline was installed, with a total transport capacity of 32.9 bcm. The total length of the pipeline is over 2000 km, and 14 compressor stations were installed along the route. Commercial flows through the Yamal-Europe pipeline started in 2000 and the pipeline reached its design capacity (32.9 bcm) only in 2006 (Gazprom, 2010j).

Although one of the reasons for building the Yamal-Europe pipeline was to reduce Gazprom's reliance on the Ukrainian route, according to Victor and Victor (2006), this was not the decisive factor that ultimately allowed the project to go ahead. These authors pointed out that the principal reasons for investment in the Yamal-Europe pipeline were: (*i*) competition between downstream suppliers in Germany (Wintershall v. Ruhrgas), (*ii*) Gazprom's interest in obtaining higher margins and diversifying away

[17] Because of this initial plan, the pipeline bears the name of the intended gas source – the Yamal Peninsula - and of the final market – Europe.

from its traditional importer in Germany – Ruhrgas, and (*iii*) anticipated growth in gas demand in Germany and along the route (particularly Poland) (Victor and Victor, 2006). Therefore, the argument that the Yamal-Europe pipeline was principally built to avoid a troublesome Ukraine is not the full story. In the early 1990s, even before the commitment to construct the Yamal-Europe pipeline through Belarus, Gazprom had several gas disputes with Belarus over gas supplies, prices and debt settlement, which indicated that Belarus would not be a better option for secure gas exports to Europe than Ukraine. Nevertheless, the pipeline was built, albeit with a lower transport capacity than initially planned. The security of supply argument was helpful in keeping the project sponsors focused on the project as it allowed the project to be portrayed as improving the reliability of gas exports from Russia to Europe by avoiding Ukraine (Victor and Victor, 2006).

After cementing the legal and commercial basis for the construction of the Yamal pipeline, Gazprom's attention turned to southern Europe where Turkey, Gazprom's fourth largest market at that time, was expected to expand its demand considerably. Thus, in December 1997, the governments of Russia and Turkey signed an intergovernmental agreement outlining Turkey's interest in boosting gas imports from Russia through the new, yet to be built, pipeline under the Black Sea, connecting Russia directly with Turkey (the Blue Stream pipeline). Based on this intergovernmental agreement, a long-term supply contract was signed between Gazprom and the Turkish national gas company, Botas. Under this contract, Gazprom would supply 365 bcm to Turkey over 25 years (Gazprom, 2010a). In early 1999, an agreement was signed between Gazprom and the Italian oil and gas major, ENI, on joint implementation of the Blue Stream project. The two companies set up a joint venture, the Blue Stream Pipeline Company B.V., to finance, construct and operate the offshore pipeline under the Black Sea (Gazprom, 2010a). The capacity of the Blue Stream pipeline is 16 bcm/year and the total cost of the system was estimated at US$ 3.7 bn (Ivak et al., 2003). The pipeline was commissioned in October 2002 and commercial gas flows through the Blue Stream pipeline began in February 2003.

Before the construction of the Blue Stream pipeline, Russian gas supplies to Turkey were delivered through Ukraine, Moldova, Romania and Bulgaria (the so-called 'Trans-Balkan' corridor) under a 25-year long-term supply contract signed between the Soviet Union and Turkey in 1986 (ECT, 2007). The off-take volume agreed under this supply contract was 6 bcm/y. In early 1998, Russia and Turkey signed another contract for the supply of 8 bcm/y of natural gas over 25 years. The delivery point is the Bulgarian-Turkish border (through the Trans-Balkan route). Therefore, to accommodate additional gas supplies through the Trans-Balkan route, the existing pipeline from Bulgaria to Turkey was increased from 6 bcm to 14 bcm (Semerdjieva, 1999). Total Russian gas exports to Turkey under these three contracts are 30 bcm/y; however, the first contract (signed in 1986) will expire in 2011.

When the Blue Stream project was initiated, and the 1997 supply agreement between Gazprom and Botas was signed, the projection of gas demand in Turkey was rather optimistic. Botas estimated that by 2010 gas demand in Turkey would be 66 bcm, an almost 7-fold increase compared to gas consumption in 1999 (10 bcm) (WGI, 1999; Semerdjieva, 1999). Based on this optimistic view of gas demand expansion, Botas contracted around 45 bcm by 2010, with two-thirds coming from Russia and the rest piped from Iran or imported as Algerian or Nigerian LNG. In addition to these contracts, Botas was eager to close the import gap by contracting gas from Azerbaijan and Turkmenistan.[18] These potential new supplies have created pressure on Gazprom's position in the Turkish market. Therefore, one of Gazprom's major motivations behind the Blue Stream pipeline was to outpace its rivals in the fast-growing Turkish gas market and to preserve its monopoly position there.

Despite the overly optimistic demand projection, in reality gas consumption in Turkey in 2009 was less than half of the projected amount – 32 bcm (BP, 2010a). Therefore, the Blue Stream pipeline has been heavily underutilized since it began operation. Between 2006 and 2009, Gazprom transported, on average, around 9.2 bcm/y through the Blue Stream pipeline to Turkey, which is about 57% of its design capacity (Gazprom, 2010a). Moreover, in April 2003, Botas completely stopped importing gas through the Blue Stream pipeline (just two months after commercial supplies began through the pipeline), demanding that Gazprom reduce the price or the minimum off-take quantity through the new pipeline (Yenukov, 2003).[19] Victor and Victor (2006) argued that, in general, the Blue Stream project is perceived to be more of

[18] Botas has contracted to import 6.6 bcm per year from Azerbaijan for 15 years (ECT, 2007). Based on this, BP has constructed the South Caucasus Pipeline to Turkey to supply gas from the Shah Deniz field. Initially it was planned to start operations in 2005; however, due to demand conditions, shipments were postponed until 2006 (Platts, 2002). The contract with Turkmenistan to import about 16 bcm/y for 30 years was also suspended indefinitely (ECT, 2007).

[19] Even before the pipeline began operation, Gazprom reportedly made a concession reducing the off-take quantity in 2003 by half (2 bcm/y instead of 4 bcm/y) and reduced the price by 9% (Yenukov, 2003). Similarly, in 2001, Botas refused to take all of the gas under its contract with Iran under the take-or-pay condition on a pretext of gas quality problems (Iran supplied gas to Turkey under the 25-year contract signed in 1996 for 10 bcm per annum) (Kommersant, 2003).

a technological breakthrough (part of the pipeline was laid at a depth of 2150 metres, lower than any other offshore pipeline) than a commercially successful project (Victor and Victor, 2006). Despite lower-than-expected gas demand in Turkey, had Gazprom not invested in the project it could have lost its market share in Turkey. Therefore, Blue Stream might have a strategic pre-emptive investment value to Gazprom.[20] Moreover, the Blue Stream pipeline is a shorter and more secure route to Turkey than the Trans-Balkan route. However, given its location, in contrast to the Yamal-Europe pipeline Ukraine's unreliability as a transit country was employed less by Gazprom as a means of mobilising public support for the Blue Stream project. The risks to the security of Russian gas supplies along the Trans-Balkan route have only worsened Gazprom's competitiveness in the Turkish market and have pushed Turkey to diversify away from importing Russian gas.[21] Therefore, in order to preserve and boost its position in the Turkish market (and effectively exclude possible competition from other suppliers), Gazprom was in desperate need of a more reliable transport option to convince Botas and Turkish politicians that Russian gas would be secure (Stern, 2005).

In early 2000, after the first commercial gas flows through the Yamal-Europe pipeline, Gazprom announced that the company was studying the construction of another pipeline running from Belarus (near the city of Kobrin) to Slovakia (near the city of Veľké Kapušany), passing through Poland (Interfax, 2000d). This pipeline (the Polish-Slovak bypass connector) would allow Gazprom to divert gas from the Ukrainian route and thus would provide no net increase in Russian export capacity to Europe. The Polish-Slovak bypass connector was expected to have a capacity of 30-60 bcm/y (21%-42% of Ukraine's transit capacity).[22] In October 2000, Gazprom and its four largest European customers (GDF, Wintershall, Ruhrgas and SNAM Spa) signed a memorandum of understanding on the construction and operation of the bypass connector (Interfax,

[20] Specifically, the construction of the Blue Stream pipeline should counter the strong American support for both the Trans-Caspian pipeline from Turkmenistan and Azeri gas supplies from the Shah Deniz field to Turkey and further to Europe (Stern, 2005).
[21] In the early 1990s Turkey experienced two gas supply disruptions: (*i*) in early 1994 daily deliveries of Russian gas through the Trans-Balkan route were reduced by 50% due to transit problems with Ukraine, and (*ii*) in March 1995, one of the existing gas-fired power plants had to switch all its input to fuel oil and two fertiliser plants were put on stand-by (IEA, 1997).
[22] It is not entirely clear whether the Polish-Slovak bypass pipeline described was Gazprom's revised version (route) of the second pipeline of the Yamal-Europe pipeline project (the Yamal-II pipeline) or an entirely new project. (Stern)Stern (2005: footnote 95, p.89) noted that the Polish-Slovak bypass pipeline is not the same as the Yamal-II pipeline. However, at that time, the Polish-Slovak bypass pipeline was usually referred to in media reports as the alternative to the Yamal-II pipeline (PNB, 2000b; Polityka, 2000; CTK, 2000).

2000f). The total cost of the pipeline was estimated at US$ 1-2 bn (Davydova, 2000; EIU, 2000).

One of the main reasons why Gazprom pushed for the Polish-Slovak bypass connector was that between 1998 and 2000 Ukraine reportedly siphoned off 9-15 bcm of the Russian gas transited to Europe (Stern, 2005). Part of this gas (2.5-3 bcm/y) was re-exported by Ukraine to Romania, Hungary and Poland at low prices (Gorst, 2000). Therefore, Gazprom's reasoning was that, since Ukraine's gas theft and re-exporting cost Gazprom around US$ 1 bn/y, the bypass pipeline would pay for itself very quickly (Stern, 2005). However, the project was delayed for several reasons, among them:

1. when the project was proposed by Gazprom, the Polish government was opposed to participating in the project because it viewed the bypass as likely to hurt Ukraine's economic interests and therefore it would jeopardize Polish-Ukrainian strategic relations (PNB, 2000a).
2. Gazprom was not in a position to finance the project alone. During 1998-2000, Gazprom faced a very difficult financial situation. The huge non-payment problem in the Russian domestic market (because of Russia's economic crisis of 1998) and in the CIS markets (e.g. Ukraine), combined with record low oil prices in the international market, dramatically reduced Gazprom's revenue (e.g., in 1998 gas sales to Russian and CIS customers fell by 20% and 30% respectively compared to those of 1997).[23] Additionally, Gazprom was in the process of financing the Yamal-Europe pipeline. Therefore, Gazprom was looking for financial support from its European customers. European companies might have agreed to finance the project but only if Gazprom had agreed to share the capacity of the bypass pipeline; however, sharing the capacity of the pipeline was not in Gazprom's business strategy at that time (Stern, 2005).[24]

In addition to difficulties in financing the project, one of the major obstacles behind the Polish-Slovak bypass seemed to be Polish opposition to the project.[25] At first, Poland's refusal to participate in Gazprom's bypass pipeline was grounded on strategic reasons. However, by mid-2001 Poland had shifted its view and adopted a more

[23] Author's own calculations based on (Gazprom, 1998)
[24] It should be noted that Ukrainian government officials believed that it would be difficult for Gazprom to finance the project and they viewed Gazprom's plan to bypass Ukraine as part of Russian political strategy aimed at restoring its domination over Ukraine (EIU, 2000).
[25] Even then the Ukrainian Prime Minister, Yuschenko, admitted that the financial side of the bypass pipeline would not necessarily be decisive in reaching a final decision (Interfax, 2000c).

pragmatic stance towards the bypass project (Interfax, 2001). Poland's objectives were: (*i*) to bargain for a longer route (and thus higher transit fee) and (*ii*) to use its position to re-negotiate the supply contract signed with Gazprom in 1996.

On the other hand, Russia used various means to convince the Polish government to participate in the Ukraine bypass project including:

1. threatening to withhold planned governmental visits to Poland and therefore slow down the rapprochement between Russia and Poland (WPS, 2000);
2. threatening to construct a bypass pipeline under the Baltic Sea connecting Russia directly with Germany (Nord Stream) and therefore bypassing Poland, Ukraine and Belarus altogether (Interfax, 2000e).

Despite Poland's hostility towards the bypass pipeline proposal, Gazprom's threat to bypass Ukraine temporarily 'normalized' Ukraine's relations with Russia over gas trading and transit. First, the bypass threat forced Ukraine to immediately stop siphoning off gas from export pipelines and re-exporting gas to Europe.[26] Secondly, the threat induced Ukraine to sign the 2001 intergovernmental agreement (IGA) with Russia, which regularized their import and transit arrangements (Stern, 2005: p.90).[27] The agreement stipulated that the importing of Russian gas to Ukraine would be in lieu of transit fees. The agreement also introduced mechanisms for payment when extra gas was removed from transit pipelines and stated that Ukraine's re-exports would have a very high export duty imposed (Pirani, 2007). Thirdly, substantial progress seemed to be made between Russia and Ukraine on joint management of Ukraine's transit system. The idea of joint management of Ukraine's pipelines was first put forward in 2000. However, due to ownership issues (Russia wanted a controlling stake in the venture), the proposal was not welcomed by Ukraine at that time.[28] However, in June 2002, as a result of Russo-Ukrainian 'normalization', an international pipeline consortium was agreed between the presidents of the two countries with the aim of managing and

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[26] Then Ukrainian President Kuchma admitted that Ukraine was unable to pay its gas bill (Interfax, 2000c) and that gas theft did indeed take place (Semenenko, 2000).

[27] The 2001 intergovernmental agreement between Russia and Ukraine was the last of its kind (Pirani, 2007). Since 2006 gas relations between the two countries have been governed by commercial contracts between private companies (Gazprom and Naftogaz).

[28] Ukraine was ready to concede only 49% of its transit system. For this proposal, a draft law was submitted in September 2000 to the Ukrainian parliament on partial privatization (49%) of its gas transport system. The sale of 49% of the transport system was intended to be in exchange for the accumulated gas debt to Gazprom. Ukraine's reasoning was that partial ownership of the pipelines would convince Gazprom that there would be no gas theft and/or re-exports of Russian gas in the future (Interfax, 2000b). However, Russia would only agree to a controlling stake (51%) in the transit system, which was not acceptable to Ukraine (i.e., it would be extremely difficult to pass the law through the Ukrainian parliament) (UNIAN, 2000).

refurbishing transit pipelines in Ukraine (Stern, 2005: p.91).[29] Taking into account Poland's relations with Russia and the 'normalization' of gas relations between Russia and Ukraine, the Polish-Slovak bypass pipeline was shelved indefinitely from mid-2002 onwards, and Gazprom's attention shifted towards the idea of an international consortium (the original plans envisaged partnership between Gazprom, Naftogaz of Ukraine and European, specifically German, companies) to manage Ukraine's transit pipelines.

Despite the optimism that followed the creation of the international consortium, few concrete advances were made thereafter, primarily due to political disagreements between the governments of Russia and Ukraine (Pirani, 2007). By 2004, the idea of an international pipeline consortium was scaled back and reduced to a proposal to construct and jointly manage a new pipeline from Bogorodchany to Uzhgorod (the Ukrainian-Slovak border) to convey additional gas from Central Asia to Ukraine and further on to Europe (Pirani, 2007). Moreover, by mid-2005 it became clear that the concept of the Russo-Ukrainian pipeline consortium had completely collapsed (Stern, 2006). This was primarily due to the abrupt deterioration in gas relations between Russia and Ukraine since late 2004, when a change in political regime had taken place in Ukraine (the so-called 'Orange Revolution'). In the context of these worsening bilateral relations, negotiations over gas supplies and transit broke down and, on the 1st January 2006, Russia famously cut gas supplies to Ukraine for three days (1-3 January).[30]

It is evident that Gazprom has had a 'difficult' experience in dealing with the newly created transit countries, most notably Ukraine and, to a lesser extent, Belarus. Therefore, by 2004, Gazprom's focus on ensuring reliable gas exports to Europe completely shifted towards the construction of offshore pipelines; that is, the Nord Stream and South Stream pipelines.

The Nord Stream pipeline will go under the Baltic Sea and will connect Russia directly with Germany. The Nord Stream project is a partnership between Gazprom and its largest European clients (E.ON Ruhrgas, BASF/Wintershall, Gasunie, GDF Suez). The Nord Stream project will have two pipelines running under the Baltic Sea with a total capacity of 55 bcm. Construction of the first pipeline began in April 2010 and the entire project is meant to be finished by the end of 2012.

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[29] The 'normalization' of gas relations evidenced by the signing of the 2001 intergovernmental gas agreement was at least in part due to general economic/political rapprochement between Russia and Ukraine since Putin had become the Russian president.

[30] For a detailed analysis of Russo-Ukrainian gas relations see(Stern, 2005; Stern, 2006; Pirani, 2007; Pirani et al., 2009).

The idea of constructing a pipeline under the Baltic Sea connecting Russia with Western Europe was initially conceived of as a Soviet-British joint venture called Sovgazco in early 1990, as part of the Soviet-British effort to boost their bilateral trade (Petroleum Economist, 1991). Several routes were examined for this project; however, the project was abandoned due to the perceived risks of involving Gazprom as a major partner in the project (Victor and Victor, 2006).

Several years later, the Baltic pipeline was revived in Gazprom's investment plan. In 1997, North Transgas Oy was formed by the Finnish oil and energy group Neste Oy (later Fortum) and Gazprom to plan, construct and operate the North European Gas Pipeline from Russia to Northern Germany across the Baltic Sea (Fortum, 2005). In May 2005, Fortum sold its 50% stake in North Transgas Oy to Gazprom due to changes in Fortum's business strategy (Fortum, 2005). By the end of 2005, Gazprom had signed an agreement with E.ON and BASF on the construction of the Baltic pipeline, and the North European Gas Pipeline Company (later renamed 'Nord Stream AG') became responsible for the construction and operation of the pipeline.

In June 2007, Gazprom and the Italian oil and gas company, ENI, signed an agreement stipulating cooperation between the two companies in designing, financing, constructing and operating the offshore part of the South Stream pipeline. The pipeline is meant to go under the Black Sea and connect Russia directly with Bulgaria. From Bulgaria, one branch of the pipeline will go to Southern and Central Europe, while the second branch will pass through Greece and end in South Italy. The total capacity of the South Stream system is intended to be 63 bcm.[31] Once operational, the Nord Stream and South Stream pipelines would, together, have a total capacity larger than the average volume of gas being transported through Ukraine to Europe since the fall of the USSR.[32] Therefore, as argued by Gazprom and its large western European clients, these projects should increase the security of gas supplies to Europe (Gazprom, 2010e; E.ON, 2010; BASF, 2010b; GDF SUEZ, 2010; Gasunie, 2010; Gazprom, 2010h; ENI, 2007; EDF, 2010).[33] If both projects are built as designed, their total export capacities would

[31] A detailed presentation of the South Stream system can be found on the official website – www.south-stream.info.

[32] The average Russian gas transit through Ukraine to Europe during 1991-2008 was 109 bcm (the peak of transit through Ukraine was 122 bcm in 2005), while the total capacity of Nord Stream and South Stream is 113 bcm.

[33] After the most severe transit interruption through Ukraine in January 2009, Nord Stream and South Stream gained additional support from European gas importers and Gazprom.

constitute a quarter of the EU's annual consumption, or about 40% of the EU's total gas imports.

Since the breakup of the Soviet Union, Gazprom has consistently attempted to reduce its reliance on Ukrainian pipelines, and the Nord Stream and South Stream pipelines are a natural continuation of this strategy.

To date, Gazprom's quest for route diversification has resulted in a reduction of its reliance on Ukraine by around 25% (Figure 1.1). However, this reduction was re-distributed to the Belarusian route and consequently Gazprom's reliance on Belarus has increased. Therefore, Gazprom's transit dependence has not been significantly reduced (see Figure 1.1).

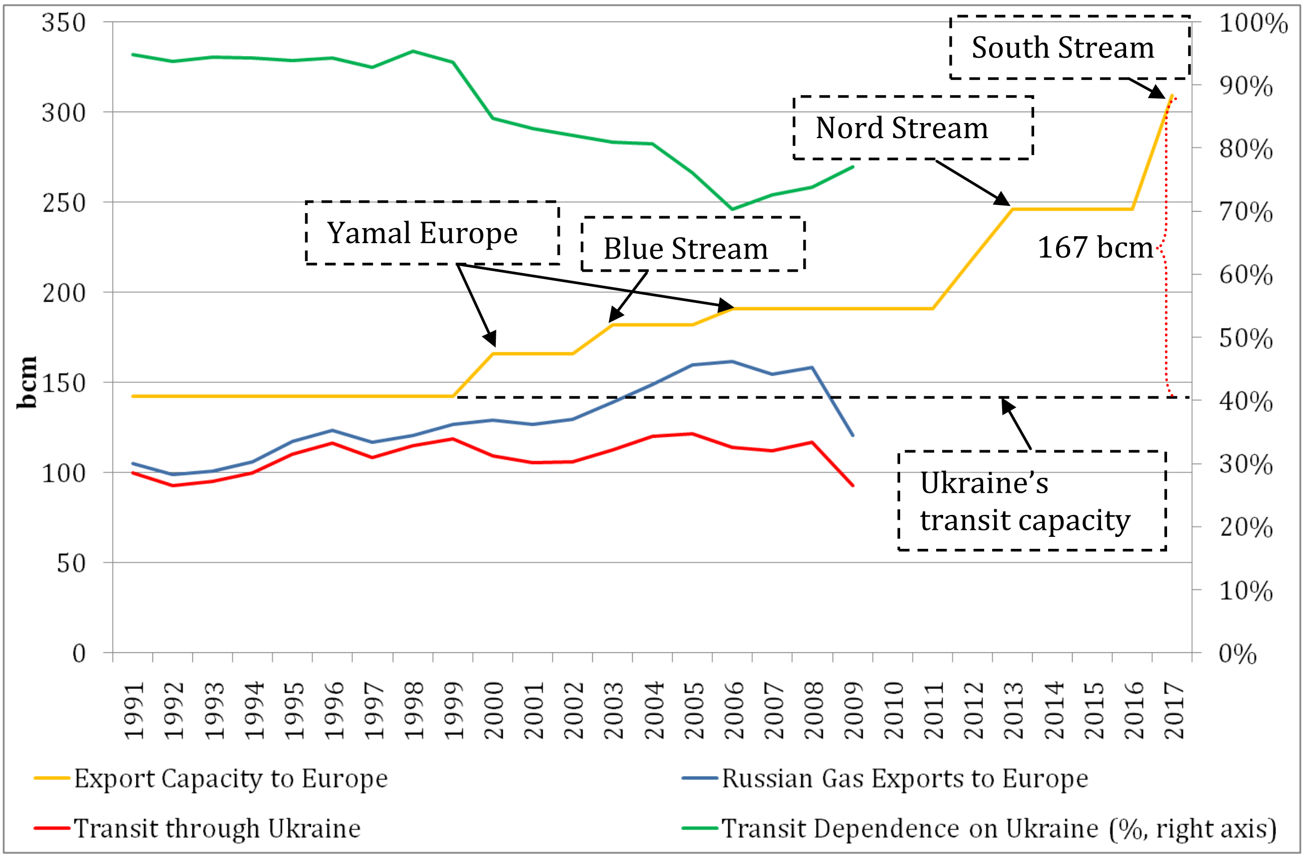

Figure 1.1: Bypassing Ukraine

Note: Export Capacity to Europe does not include the Russian-Finland connector. Transit Dependence on Ukraine is transit through Ukraine divided by Russian gas exports to Europe; Export capacity to Europe includes the capacities of the Yamal-Europe I pipeline, the Blue Stream pipeline and the Ukrainian transit system.

Source: Russian gas exports to Europe: 1991-2004 (Stern, 2005), 2005-2009 (Russian Federal State Statistics Service, 2010b). Transit through Ukraine: (Naftogaz of Ukraine, 2010a). Ukraine's Transit Capacity: (Naftogaz of Ukraine, 2010b).

Based on this historical overview of Gazprom's attempts to reduce its reliance on the Ukrainian route, the logic of Gazprom's strategic pipeline investments from 1992-2005 can be described as:

1. The expectation of higher gas demand was one of the major drivers for building the Yamal-Europe and Blue Stream pipelines. However, as purely capacity expansion projects, they appeared to be too expensive, and expanding the Ukrainian pipelines would be a much cheaper option.
2. If Russia had not invested in the Yamal-Europe and Blue Stream pipelines, it would have had to expand capacity through Ukraine by 2003, since by that time Russian exports to Europe would have exceeded existing Ukrainian transit capacity (Figure 1.1). However, expanding the Ukrainian pipelines was not viewed as acceptable to Gazprom since this would increase Gazprom's dependence on Ukraine and grant bargaining power to Ukraine.
3. From a security of supply perspective, investment in the Yamal-Europe pipeline was not especially attractive since transporting gas through Belarus was also problematic for Gazprom, but at least it diversified the transit routes.[34] Investment in Blue Stream seemed to be Gazprom's best option because the pipeline improved Russia's security of gas supply to Turkey and was a pre-condition for the Turkish government to import more gas from Russia. Having these two pipelines in operation also reduced Gazprom's losses in cases of transit interruptions through Ukraine, such as those in 2006 and 2009. Therefore, Gazprom's additional export capacity served as insurance against possible disruptions on the Ukrainian route.
4. Gazprom's unrealized pipeline projects (e.g., the Polish-Slovak bypass connector and the Russo-Ukrainian pipeline consortium) further reveal the strategic nature of bargaining between Russia and Ukraine. Gazprom's threat to build the Polish-Slovak bypass altered Ukrainian behaviour: Ukraine stopped gas thefts and agreed to grant access to its pipelines through the pipeline consortium with Gazprom. However, the pipeline consortium was short-lived because the new Ukrainian government believed that giving up control over its pipeline system was tantamount to giving up sovereignty since Ukraine was already highly dependent on Gazprom as a supplier of some 70% of its annual gas consumption. Therefore, Ukraine's preference has been to use its transit monopoly to bargain with Gazprom for lower gas import prices; thus, joint control over its pipelines was not seen as being in Ukraine's strategic interests.

[34] In February 2004 Gazprom cut off gas supplies to Belarus for about 18 hours due to dispute with the Belarusian government over ownership of Belarusian pipelines, gas theft, and import prices to Belarus (Victor and Victor, 2006).

Gazprom's investment in bypass pipelines could only be justified by a combination of factors. For example, Gazprom's investment in the Yamal-Europe and Blue Stream pipelines involved a combination of anticipated demand growth, a desire to break up traders' monopsony, concern over security of supply and improving its bargaining position with transit countries. Investing in pipelines to bypass Ukraine purely on grounds of Ukraine's unreliability always seemed too costly for Gazprom (e.g., the Polish-Slovak bypass project).

In light of these complexities, the key questions are whether Nord Stream and South Stream will be built at their planned capacities and whether investment in these projects is economically justifiable. These questions have been hotly debated by researchers and policy makers in Europe and in the FSU countries since the inception of these projects. While substantial research has already been devoted to the analysis of Russian gas exports to Europe (see among others: (Stern, 2005; Victor and Victor, 2006; Finon and Locatelli, 2008; Sagen and Tsygankova, 2008)), there has been limited economic analysis of Gazprom's investment in Nord Stream (see e.g., (Hubert and Ikonnikova, 2003; Hubert and Suleymanova, 2008)) and South Stream (Smeenk, 2010) in order to bypass Ukraine. The economics of these two projects deserve greater scrutiny and are the topic of this enquiry.

1.2. Research Objective and Questions

Gazprom's investment in the Nord Stream and South Stream pipelines will have a long-term impact on both Russia and the energy landscape of Eurasia, with both economic and geopolitical consequences. Therefore, the objective of this research is to:

> **Systematically analyse the economics of Gazprom's pipeline investment strategy in the context of the security of natural gas transit through Ukraine to Europe.**

To fulfil this objective, the following research questions were examined in order to develop an understanding of the economics of Gazprom's investment in bypass pipelines:

1. How much will it cost Gazprom to bypass Ukraine with the Nord Stream and South Stream projects? Are the Nord Stream and South Stream routes cost competitive compared to Gazprom's existing export routes, particularly compared to the Ukrainian route?
2. How do different scenarios of gas demand in Europe affect the economics of the Nord Stream and South Stream projects?
3. What is the economic value of Nord Stream and South Stream as insurance against transit interruptions through Ukraine?
4. Given that Nord Stream is already under construction, how relevant is South Stream to the negotiations between Russia and Ukraine over the terms of the gas trade?

The research questions were mainly motivated by the historical overview of Gazprom's bypass strategy discussed above. The answers to these questions may help us to better understand the economic rationale (if it exists) of Gazprom's investment strategy in bypassing Ukraine.

1.3. Research Methodology

The research methodology involves: (*i*) building a large-scale, strategic natural gas market model that will help us to simulate different market scenarios, and (*ii*) an economic and financial (levelized transport cost) analysis of the Nord Stream and South Stream projects. This section briefly discusses major modelling techniques that can be applied to the analysis of natural gas markets and the cash-flow model applied to the detailed analysis of pipeline investment.

1.3.1. Modelling Approaches in Natural Gas Research

1.3.1.1. The Complementarity Approach

Since the path-breaking paper by Lemke and Howson (1964) and the seminal work by Scarf and Hansen (1973), the computation of economic and game theoretic equilibria has gained considerable interest (Harker and Pang, 1990).

The complementarity approach is widely used in economic modelling because it allows one to represent equilibria in both a general framework and in non-cooperative games. The complementarity problem for the natural gas market equilibrium model is derived from a combination of the first-order conditions of each market participant's optimization problem and market clearing conditions (such as supply equals demand). Therefore, the objective of modelling the gas market system from this perspective is to find a unique solution that *simultaneously* satisfies each market participant's first-order conditions for profit maximization and market clearing conditions in the model. Given certain assumptions about objective functions and constraints, this solution is a Nash equilibrium of the market game embodied in the model. This approach and its application to our gas market model are discussed in greater detail in Chapter 2.

1.3.1.2. The Optimization Approach

In general, optimization, or mathematical programming, is concerned with the study of the maximization and minimization of mathematical functions. Optimization can involve linear or non-linear functions that describe a set of alternatives, called an objective function. Thus, the goal of a linear (non-linear) optimization problem is to find maximum or minimum linear (non-linear) functions with one or more variables under certain equality or inequality constraints. Linear programming was developed in the late-1940s, when G. B. Dantzig invented the simplex algorithm (in 1947). Advances in linear programming are driven mainly by its applications to economics and management.

Linear and non-linear optimization has been used extensively for applications in industrial processes (e.g., a classical application in manufacturing is the "product mix" problem), and also in modelling commodity markets and, specifically, natural gas markets (see e.g., (Boucher and Smeers, 1985; Beltramo et al., 1986; Boucher and Smeers, 1987; Boucher and Smeers, 1996; Lochner and Dieckhöner, 2010)). Usually, in these models, producers and consumers are described by supply and demand functions. Given the assumption that the market is perfectly competitive, the arising market equilibrium problem is to maximize the sum of producer and consumer surplus, i.e. the welfare maximization problem (Samuelson, 1952). However, if markets are imperfectly competitive, the equilibrium problem might not be solved using the optimization approach (Harker, 1993).

1.3.1.3. The System Dynamics Approach

System dynamics is a computer simulation approach that is widely applied to dynamic problems arising in complex social, managerial, economic or ecological systems which are characterized by interdependence, mutual interaction, information feedback and circular causality (Sterman, 2000). The development of the approach was based on the seminal work by Jay W. Forrester of MIT in the early 1960s (Forrester, 1961).

The primary focus of the system dynamics approach is on the feedback structure of the system under analysis (Sterman, 2000). The structure of the analysed system is formalised using a simulation model consisting of a network of two elements: stocks and flows. The inertia of the system is captured by the stocks. The rate of changes in stocks is regulated by in- and out-flows to the stocks. The approach has traditionally been used in the analysis of management processes such as supply chain management (e.g., the Bullwhip Effect). Beginning in the 1970s, system dynamics was the basis for extensive energy-economy models of the U.S. (various versions of COAL and FOSSIL models) (see e.g., (Naill, 1973; Naill, 1977; Sterman et al., 1988; Ford, 1997)).

Formally, the system dynamics simulation model is a system of coupled, nonlinear, first-order differential (or integral) equations (Sterman, 2000). The relationships between the components of the model (stocks and flows) are described using pre-defined functions, which are based on empirical observations (e.g., econometric estimations). The relationships expressed via the (customized) functions are assumed to be the same throughout the period of analysis. Thus, the implicit assumption of this approach is that the modelled system may be in disequilibrium. This is one of the major differences from the equilibrium-based modelling framework, where the existence of and convergence to an equilibrium state is a central concept.

1.3.2. Detailed Project Analysis: Cash Flow Model and Levelized Transport Costs

The aim of project-based analysis is to derive total investment costs for the Nord Stream and South Stream systems and then use these costs to calculate levelized transport costs (LTC). In essence, the calculation of levelized unit transport costs is based on a standard discounted cash flow (DCF) model. The DCF model is widely used in corporate finance for project appraisal (Brealey and Myers, 2002) and values a project by discounting the project's expected cash flows over a project's lifetime at a risk-adjusted discount rate. In general, the levelized cost represents the present value of the total cost of building and operating a facility over its economic life, converted to equal annual payments (EIA, 2010b). Therefore, the levelized transport cost per unit of natural gas (e.g., one tcm of natural gas transported through a pipeline) is derived as the present value of the total costs of building and operating a gas pipeline divided by the present value of total shipments over its economic life. The levelized cost methodology is widely used in the energy industry and, in particular, has been applied to calculate the cost of electricity generation (see among others: (Previsic et al., 2004; Sevilgen et al., 2004; Falk, 2008b; Falk, 2008a)).

Financing and constructing large-scale gas pipelines involve many uncertainties such as financial costs (e.g., interest rates on loans) and construction cost-overruns (e.g., the cost of construction materials). The most important uncertainties that may affect total project costs are dealt with using Monte Carlo simulation.

1.4. Thesis Overview

This thesis is structured around a strategic computational gas market model and its application to two case studies – Gazprom's investment in the Nord Stream and South Stream pipelines. This section summarizes the three chapters (see Table 1.1) and gives short summaries of each chapter.

CHAPTER	TITLE	OBJECTIVE	MAIN RESULTS
2	Strategic Eurasian Natural Gas Model for Energy Security and Policy Analysis	- To develop a modelling tool that would facilitate a systematic economic analysis of Gazprom's investment in bypass pipelines	- A model has been developed that has a detailed representation of the Former Soviet Union gas region. This is a major contribution compared with existing gas models. The validation of the model with historical data shows that the model's results are in line with actual market outcomes and that the behaviour of the model is consistent with economic intuition. The sensitivity analysis shows that the model's results are fairly robust in terms of major structural assumptions. - The model's capability was shown by carrying out an analysis of investment in Nord Stream and its implications for overall market efficiency. Thus, it was found that investment in Nord Stream has a positive impact on social welfare in all analysed market power scenarios. The higher the competition between market participants, the larger the benefit to society of Nord Stream investment.
3	The Economics of the Nord Stream Pipeline System	- Derive costs of the Nord Stream project - Uncertainty analysis of major factors affecting investment cost of the project - Derive the economic value of Nord Stream investment to Gazprom under various scenarios of market developments	- The Nord Stream route is cost competitive relative to the Ukrainian route. - The positive economic value of Nord Stream investment was disaggregated into major components, such as cost competitiveness, strategic value and security value.
4	The Economics of the South Stream Pipeline in the Context of Russo-Ukrainian Gas Bargaining	- Derive costs of the Nord Stream project - Uncertainty analysis of major factors affecting investment cost of project - Derive the economic value of South Stream investment to Gazprom under various scenarios of market developments and in the context of gas bargaining between Russia and Ukraine	- The South Stream route is more expensive than the Ukrainian route. - Security of supply value does not justify South Stream investment. - The main value of South Stream investment for Gazprom is as insurance against future bargaining by Ukraine.

Table 1.1: Structure of the Thesis

1.4.1. Chapter 2: Strategic Eurasian Natural Gas Model for Energy Security and Policy Analysis

Chapter 2 presents the gas simulation model which is developed to analyse the economics of security of supply pipelines in subsequent chapters. While large-scale gas simulation models have been formulated and used extensively in the analysis of the security of gas supplies to Europe, e.g., Holz (2007), Egging et al. (2008), Holz et al. (2009) and Lise et al. (2008), the model presented in Chapter 2 differs from earlier models in its detailed representation of the Former Soviet Union (FSU) gas sector. First, the market power of transit countries is modelled explicitly via the conjectured transit demand curve approach. Secondly, the transmission system of the FSU countries is represented in detail. Furthermore, Russian gas production is divided into that of its dominant producer - Gazprom - and that of independent gas companies, as well as by production region. This level of detail in the representation of the FSU "region" in a gas market model is unique and represents one of the major contributions of this research.

The validation of the model with historical data shows that in general the model's results are in line with actual market outcomes for the years 2008 and 2009, and that the behaviour of the model is consistent with economic intuition. The sensitivity analysis shows that the model's results are fairly robust in terms of major structural assumptions.

The model's capability was shown by carrying out an analysis of investment in Nord Stream and its implications for profits for individual market parties, as well as for overall market efficiency. Particularly, it was found that under the double marginalization case (i.e., producers and traders exert market power), the impact of Nord Stream investment on social welfare is US$ +1.5 bn/y over the next 25 years. Further, if transit countries exerted market power vis-à-vis Gazprom (the successive market power scenario), then the construction of Nord Stream would add US$ +1.8 bn/y to social welfare. The maximum possible impact of Nord Stream on social welfare is found under the perfect competition scenario. In this scenario, the impact of Nord Stream on social welfare is US$ +13.3 bn/y. Most of these gains are driven by the benefits of Nord Stream investment to consumers. Accordingly, the net benefit of Nord Stream to society under double marginalization is about 11% of the net benefit under the perfect competition case (US$ 1.5/13.3 bn). Further, the market power of transit countries adds another 2% on top of the 11%, and therefore, under the successive market power scenario, the net benefit of Nord Stream to society is 13% of the maximum possible value. If traders were competitive (the upstream oligopoly scenario), then the net benefit of Nord Stream investment to society would be US$ +3.9 bn/y. Thus, if only producers behave imperfectly the net benefit of Nord Stream to society is about 30% of the benchmark value.

In general, investment in Nord Stream has a positive impact on social welfare in all analysed market scenarios. The higher the competition between market participants, the larger is the benefit of Nord Stream investment to society. However, in the perfect competition scenario the impact of Nord Stream investment on Gazprom's profit is negative (US$ -5.0 bn/y). It is also interesting to note that when there is transit country market power Nord Stream investment is far more important for Gazprom than it is for society as a whole. When transit countries exert market power, investment in Nord Stream adds as much as 58% of the potential additional profits to Gazprom under the double marginalization case, whereas it only adds some 20% to society.

1.4.2. Chapter 3: The Economics of the Nord Stream Pipeline System

The Nord Stream project has been politically controversial since its inception, but there has not been any attempt – at least none that is publicly available – to examine the economics of the project in an in-depth manner. Existing papers (see e.g., (Holz et al., 2009; Egging et al., 2008)) suggest that Nord Stream is economically justifiable only if Gazprom needs additional export capacity. Explicitly or implicitly, this idea stands behind most claims that Nord Stream is a purely geopolitical project. This implies that shipping gas through Nord Stream would necessarily be more expensive than using the existing options, an assumption that the existing literature provides no analytical basis to support.

The analysis follows two steps: (*i*) using detailed analysis of the Nord Stream project, the total cost of the pipeline is derived and the levelised unit transportation costs through Nord Stream and the existing routes are compared; then (*ii*) the economic value of Nord Stream investment under various scenarios of gas demand in Europe is calculated using a computational game-theoretic model of the Eurasian gas trade.

The unit cost of shipping Russian natural gas through Nord Stream is shown to be clearly lower than using the Ukrainian route, and is only slightly above the unit cost of shipping through the Yamal-Europe pipeline. Under various scenarios of gas market development, Nord Stream investment is found to have a positive economic value. The maximum expected economic value of Nord Stream was disaggregated into project economics (cost advantage), strategic value (increased bargaining power vis-à-vis Ukraine) and security of supply value (insurance against disruption of the Ukrainian transit corridor). The economic fundamentals of the project (cost advantage) guarantee that investment in Nord Stream will yield the expected present value of at least US$ 2.3 bn, or 66% of the maximum expected value (US$ 3.5 bn), under the low demand scenario. Nord Stream's positive expected present value due to cost advantage increases sharply, reaching US$ 27.4 (7.8) bn if gas demand in Europe is expected to grow at 2.1% (0.8%) p.a. through to 2030. Another major contribution to the value of the system is its strategic value, which could add between US$ 1.1-2.5 bn on top of the core value (cost advantage), depending on demand growth in Europe; thus, under different demand scenarios, Nord Stream's strategic value contributes between 7-31% to the maximum expected value of the project. However, the security value of Nord Stream is relatively limited (roughly 3% of the maximum achievable value).

1.4.3. Chapter 4: The Economics of the South Stream Pipeline in the Context of Russo-Ukrainian Gas Bargaining

This chapter analyses the economics of South Stream, the second of the two pipelines, in the context of Russo-Ukrainian gas negotiations. South Stream, if realized, would allow Gazprom to completely bypass Ukraine. The project has received much publicity since its launch in 2007, and especially after the January 2009 gas dispute between Russia and Ukraine.

The policy literature is rather ambiguous regarding the South Stream project. Security of supply and competition with the EU-backed Southern Gas Corridor-related reasoning concerning motivation behind South Stream investment saturates both expert analysis and media commentary. Despite its importance, limited efforts have been invested in analysing the economic rationale of Gazprom's investment in South Stream in a systematic way.

South Stream's project sponsors argue that the major objective of the pipeline is meeting the additional demand for natural gas in Europe while eliminating transit risks (Gazprom, 2010h). The existing policy literature on South Stream also asserts that the risks of transit disruptions through Ukraine can justify investment in South Stream.

However, in this chapter, the risks of transit interruptions through Ukraine are not found to justify the construction of the South Stream pipeline because, under all analysed transit disruption scenarios, the economic value of South Stream is negative. Examining natural gas demand as a possible factor that could justify Gazprom's investment in South Stream, it was found that only when demand in Europe grew at more than 2.1% p.a. through to 2030 (which is highly unlikely), would the economic value of this investment be positive, albeit rather marginally (US$ 1.1 bn over 25 years).

It was shown that only if Ukraine increased its transit fee considerably, the economic value of South Stream investment would range between US$ 1 bn and 10 bn, depending on assumed demand scenarios.

Thus, as insurance against Ukraine's future bargaining over higher transit fees or lower import prices, South Stream has far greater value than as insurance against transit interruptions and/or as a demand-driven project. The expert analysis and media commentary concerning Gazprom's investment in South Stream largely miss this important dimension. Gazprom's bypass strategy is not primarily about meeting future demand in Europe while eliminating transit risks. Instead, its strategy is about eliminating Ukraine's transit monopoly while preserving the value of Ukraine's gas market at as high a level as possible without risking its gas supplies to Europe.

1.5. Conclusions and Discussion

In comparing the two case studies in Chapters 3 (Nord Stream) and 4 (South Stream) with each other, and also with Gazprom's past efforts to circumvent Ukraine, the competing rationales of cost competitiveness, security of supply and bargaining are examined. This allows us to draw conclusions regarding Nord Stream and South Stream in the context of Gazprom's overall route diversification strategy.

- *Cost competitiveness*

In spite of the costs involved in building the new pipeline, which includes the portion under the Baltic Sea, Nord Stream was found to be more cost competitive than the Ukrainian route because the latter route requires a longer distance to the main markets in Western Europe (such as Germany). Overall, this cost competitiveness creates the bulk of the economic value generated for Gazprom by investing in Nord

Stream - the results presented in Chapter 3 show that up to 70% of the maximum possible economic value arises as a result of the cost competitiveness of the project. By contrast, ”conventional wisdom” regarding the Nord Stream case is that only when demand in Europe grew substantially would there be an economic case for Nord Stream investment. This argument abounds in the policy literature and some economic analyses on the Nord Stream pipeline (see literature review in Chapter 3). The implicit assumption of this argument is that Nord Stream is not a cost competitive route compared to existing routes. While this argument was rebutted by the results of Chapter 3, it seems applicable for the South Stream case.

Contrary to the Nord Stream case, South Stream was not found not to be a cost competitive route compared to the Ukrainian route. Thus, in the moderate gas demand expansion scenarios, the economic value of the project is negative. Only when gas demand in Europe grows at more than 2.1% p.a. (which is highly unlikely in reality) could the value of South Stream investment be positive, although marginally (US$ 1.1 bn over 25 years).

Thus, the main difference between the Nord Stream project and the South Stream project is that in the former case the project is cost efficient, and therefore there is no need for high gas demand to support investment in this project, while in the latter case, only high demand could justify the pipeline since it is not expected to be a cost competitive project.

- *Security of Supply*

Despite differences in terms of cost efficiency, both pipeline projects have been promoted on grounds of security of supply. Thus, proponents of both the Nord Stream and South Stream projects argue that these two projects are justifiable as insurance against Ukrainian transit interruptions. This reasoning gained even more credibility after the January 2009 gas crisis between Russia and Ukraine. However, the results presented in Chapters 3 and 4 show that the security value for both projects is rather marginal, and thus, from an economic perspective, security of supply reasoning would not justify the costs of building Nord Stream or South Stream.

The causal logic of the security of supply reasoning is that since Ukraine appears to be an unreliable transit country, Gazprom should bypass it with the Nord Stream and South Stream pipelines. However, most analyses of these two projects miss an important dimension in this causal logic, namely placing the projects in the broader context of

Russo-Ukrainian gas bargaining, which may reveal Gazprom's strategic thinking concerning its bypass pipelines.

- *Strategic bargaining*

The case study results demonstrate that Gazprom's bypass pipelines, Nord Stream and South Stream, have strategic bargaining value. In the Nord Stream case, Ukraine is anticipated to react to the construction of the bypass pipeline by cutting its transit fee because the Nord Stream route is cost efficient compared to the Ukrainian route. By comparison, Ukraine's rational reaction to the South Stream pipeline would be to *not* reduce its transit fee. Given that Ukraine is prone to bargain over gas trading with Russia (demanding higher transit fees or lower import prices), Gazprom's investment in South Stream should be viewed as insurance against opportunistic behaviour by Ukraine and, as such, investment in South Stream has a large economic value.

Since 2006, Gazprom has consistently attempted to reduce the opportunity cost of transiting gas through Ukraine by gradually equalizing the import price for Ukraine with the prices paid by its European customers. This strategy resulted in two transit disruptions in 2006 and 2009, which badly hit both Gazprom's and Ukraine's reputations as reliable gas suppliers; however, after the January 2009 gas crisis, Gazprom was able to completely eliminate any price differential and consequently removed the opportunity cost of transiting gas through Ukraine. Thus, in 2009 the value of Ukraine's export market was the second largest in Gazprom's export portfolio, just behind Gazprom's traditional market – Germany. For Gazprom, any investment in Nord Stream and South Stream must safeguard this value without risking its supplies to Europe; otherwise, Ukraine may bargain and reduce this value substantially.

- *Nord Stream and South Stream in Gazprom's route diversification strategy since the 1990s*

The Nord Stream and South Stream projects are seen as a natural continuation of Gazprom's diversification strategy, which the company has pursued since 1992. However, in contrasting Nord Stream and South Stream with each other and with Gazprom's past efforts to bypass Ukraine, the implications of the different projects for Gazprom are striking.

Gazprom's pipeline investment projects since the fall of the USSR – the Yamal-Europe and Blue Stream pipelines - were primarily aimed at meeting expected gas demand expansion, although security of supply was also referenced. The security of supply rationale focused on “normalizing” Ukraine’s behaviour in the gas trade with Gazprom, which included setting a clear schedule for repayment of Ukraine’s past gas debts, preventing the siphoning off of gas from transit pipelines and re-exporting of Russian gas to Europe, and setting up a Russo-Ukrainian pipeline consortium to jointly manage the transit pipelines. However, in 2004-2008, as gas prices in Europe soared (quadrupling over this period), the bypass strategy developed a completely new meaning to Gazprom – eliminate Ukraine’s transit monopoly and bring Ukraine’s import price in line with prices paid by Gazprom’s European clients. Indeed, in 2004-2008 Ukraine’s transit monopoly posed a huge opportunity cost for Gazprom, which amounted to about US$ 24.7 bn.[35]

Thus, while past efforts at circumventing Ukraine could be described as Gazprom’s efforts to expand its sales in Europe, with the secondary benefit of a marginal net decrease in reliance on transit countries (due to shifting flows from Ukraine to Belarus as the Yamal-Europe pipeline came into operation), Gazprom’s investment in Nord Stream and South Stream should be considered as a strategic move to increase the value of Ukraine as an export market for Gazprom without risking its supplies to Europe.

[35] The opportunity cost was calculated as the difference between the German border price for Russian gas netted back to Ukraine and Ukraine’s actual import price multiplied by gas imports by Ukraine in 2004-2008.

CHAPTER 2

Strategic Eurasian Natural Gas Model for Energy Security and Policy Analysis

2.1. Introduction

Competition, decarbonisation, security of supply and affordability are the main principles of European energy policy (EC, 2006; EC, 2008a; DTI, 2007; BERR, 2008). Natural gas plays an important role because of its relatively low carbon content compared to other fossil fuels. Moreover, as one of the major energy sectors, the European Commission (EC) hopes to make the natural gas market in Europe more competitive and thus contribute to the overall competitiveness of European economies.

In 2009, natural gas consumption in the European Union (EU) member states totalled 503 billion cubic metres per year (bcm/y) (IEA, 2010a), of which indigenous production accounted for 39%.[36] By 2030, natural gas consumption in the EU is projected to grow at an annual growth rate of +0.6% (EC, 2008b) or +0.7% (IEA, 2009). Meanwhile, by 2030 EU indigenous gas production is anticipated to decline substantially (EC, 2008b), and thus consumption has to be increasingly met with external sources.

In 2009 major suppliers to the region - Norway, Russia and Algeria - together exported around 51% of all gas consumed in the EU. Russian gas exports alone cover around one quarter of the EU's natural gas consumption, or 6.2% of the bloc's primary energy supply (BP, 2010a). Over 90% of Russian gas exports are transported through Ukraine and Belarus before entering European markets (see Appendix L for details of Russia's export options). Russia's "difficult" relations with key transit countries on its Western border - Belarus and Ukraine - have resulted in several major gas transit disruptions. These include transit disruptions through Belarus for 3 days in June 2010 and through Ukraine for 4 days in January 2006 along with, most severely, two weeks in

[36] Own calculations based on (IEA, 2010a; BP, 2010a).

January 2009, affecting millions of customers in South-Eastern Europe and the Western Balkans (Pirani et al., 2009; Kovacevic, 2009; Silve and Noël, 2010).

Since the breakdown of the Soviet Union, Gazprom has pursued a strategy of diversifying its export options to Europe, beginning with the construction of the Yamal-Europe pipeline in the 1990s (Victor and Victor, 2006). It has continued more recently with the Nord Stream and South Stream projects – under the Baltic and the Black Sea, respectively. Once operational, these two projects would have a total capacity larger than the current volume of gas being transported through Ukraine to Europe. Therefore, as argued by Gazprom and its large Western European clients, these projects should increase the security of gas supplies to Europe (Gazprom, 2010e; E.ON, 2010; BASF, 2010b; GDF SUEZ, 2010; Gasunie, 2010; Gazprom, 2010h; ENI, 2007; EDF, 2010). Indeed, the importance of these two projects to the security of supply to Europe cannot be overestimated. If materialized, their total export capacities would constitute 23% of the EU's annual consumption, or 39% of the EU's total gas imports. Despite their importance to supply security, rigorous analyses of the economics of these projects are very limited.

Therefore, the research objective is to develop a gas simulation model which can be used to analyse the economics of security of supply pipelines, particularly the Nord Stream and South Stream pipelines. While large-scale gas simulation models have been formulated and used extensively in the analysis of the security of gas supplies to Europe, e.g., Holz (2007), Egging et al. (2008), Holz et al. (2009) and Lise et al. (2008), the model presented in this paper differs from earlier models in its detailed representation of the Former Soviet Union gas sector. The transit activities of Ukraine and Belarus are explicitly modelled, while their transit/transmission pipelines are represented in detail. Russian gas production is distinguished by its dominant producer - Gazprom - and independent gas companies (oil producers and small gas companies in Russia), as well as by its production regions (both current and future regions, such as the Yamal Peninsula and the Shtokman field). The Russian transmission system and export pipelines from Central Asia to Russia are also presented in the model with a sufficient level of detail. Central Asian gas production and sales to Gazprom that are further re-exported to Europe/CIS are also explicitly modelled. Gazprom's exports to Belarus, Ukraine and Moldova, as well their indigenous gas production, are also explicitly represented in the model. This level of detail in the representation of the Former Soviet

Union[37] (FSU) gas "region" in a computational economic model is unique and represents one of the major contributions of this work.

The aim of this chapter is to detail the mathematical formulation of the model and the assumptions and data used, as well as demonstrating the model's capabilities. For this purpose, an analysis of the following questions will be presented:

- How do perfect and imperfect competition models differ in their evaluation of the Nord Stream pipeline project (and why)?
- Assuming that transit countries exert substantial market power against Gazprom, would consumers and Gazprom be better off if Nord Stream is built?

The rest of this chapter is organized as follows. The existing literature is reviewed in the next section. The model is presented in Section 2.3 and its validation is discussed in Section 2.4. Section 2.5 presents the results and analysis. The chapter concludes with a discussion of future developments of the model.[38]

2.2. Literature Review

In the following, the existing literature on natural gas modelling is reviewed and there is a discussion of where this model fits into the existing literature. First, there is a review of the complex, large-scale gas computational models that have been applied to the analysis of gas supply security to Europe. Then, there is an outline of research that has used theoretical (economic) models to analyse natural gas developments in the Former Soviet Union (FSU) countries. Lastly, there is a brief overview of applied game-theoretic literature that focuses on strategic interactions between Russia and its gas transit countries.

Using a strategic European gas simulation model, GASMOD (Holz et al., 2008), Holz (2007) analysed the role of Russian gas in European markets and the effects on prices and consumption of Russia withholding exports. GASMOD is a two-stage successive oligopolies gas market model (Holz et al., 2008). GASMOD explicitly considers imperfect competition in upstream production (first stage) and downstream gas trading (second

[37] In this research, by FSU countries the following are meant: Russia, Ukraine, Belarus, Moldova, Kazakhstan, Uzbekistan, Turkmenistan and Azerbaijan. Although Estonia, Lithuania and Latvia were also members of the USSR, they are referred to as countries of Western Europe in this research.
[38] This chapter is an updated version of the work done in collaboration with Professor Benjamin F. Hobbs who commented and helped drafting part of this chapter.

stage) in European markets. In both stages, market participants can exert market power by playing a Cournot game. The relationships between traders and upstream producers are modelled *à la* Stackelberg, i.e., traders are price-takers with respect to producers' border prices. The geographical coverage of the model is wide – on the demand side it includes all European markets, and on the supply side it includes major exporters to Europe. The underlying market structure implemented in GASMOD (successive oligopolies) is similar to the structure of the static GASTALE model developed by Boots et al. (2004).

A more detailed strategic European gas simulation model was developed by Egging et al. (2008). The model contains a detailed presentation of market players (such as producers and traders, LNG liquefiers and regasifiers, storage and transmission operators, etc.) on the supply side, whereas the demand side is represented by 52 consuming countries, three seasons (low demand, high demand and peak) and three consumption sectors (residential, industrial and power generation). The market structure that their model implements is different from that of GASMOD and the static GASTALE model (Boots et al., 2004). Egging et al. (2008) assumed that only traders, as international market players, can exert market power vis-a-vis consumers by playing the Cournot game against other traders. According to Egging et al. (2008), one of their contributions is the application of their model to the analysis of the security of gas supplies to Europe.[39]

Lise and Hobbs (2008) extend the static version of the GASTALE (Boots et al., 2004; Egging and Gabriel, 2006) model to include the dynamics of investment in infrastructure capacities (such as storage, pipelines and LNG infrastructure). Similarly to the model developed by Egging et al. (2008), the dynamic GASTALE model contains a detailed representation of both the supply and demand sides. The market structure of the dynamic GASTALE model is similar to the market structure assumed in (Egging et al., 2008). Lise and Hobbs (2008) assumed that only producers have market power. The primary purpose of extending the GASTALE model to include dynamic investment is to address the policy question of energy corridors to Europe. The dynamic GASTALE model was particularly used in (Lise et al., 2008) to study the security of gas supplies to Europe.[40]

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[39] For example, one of their analyzed scenarios involves the curtailment of gas supplies to Europe through Ukraine, with another case involving the disruption of gas flows from Algeria to Europe.
[40] Lise et al. (2008) studied the effects of gas flow interruptions from Algeria and Russia to Europe, and from Azerbaijan and Iran/Iraq to Turkey.

Lastly, there is the TIGER model developed at EWI Cologne (Lochner and Dieckhöner, 2010). The TIGER model is a linear optimization model with a very detailed representation of the physical gas infrastructure of Europe. The model results are based on the infrastructure and cost fundamentals of the natural gas market and, therefore, the strategic considerations of market players are not taken into account (Lochner and Lindenberger, 2009). The model is extensively applied to an analysis of the impact of major gas import infrastructure and gas flow interruption scenarios on the operation of the European natural gas network (see, e.g., (Bettzuege et al., 2010; Lochner and Lindenberger, 2009; Lochner and Bothe, 2007; Lochner et al., 2010)). While all previous large-scale models explicitly represent the market power of different players in the European gas market, the TIGER model assumes perfect competition, which makes it less appropriate for studying strategic interactions between market participants in the European gas market.

The reviewed gas models did not have a detailed representation of upstream activities outside EU borders, particularly the gas sectors of Ukraine, Belarus, Russia and Central Asia (e.g., a detailed presentation of pipeline networks, producing regions, the market power of transit countries and commercial gas relations between these countries). Therefore, the contribution of this work to the natural gas modelling literature is to include detailed modelling of the FSU gas sector in a large-scale strategic gas market simulation model.

A detailed presentation of the FSU gas sector in a large-scale gas simulation model is important for the analysis of the security of supply to Europe and the analysis of downstream competition in EU markets. As Smeers (2008) noted, gas producers compete against one another through the transmission system. Further, producers' access to transport infrastructure (both transit and transmission) determines not only their ability to compete against one another but also the degree of market power they might be able to exercise. The market power of producers and transit countries is currently the driving force behind most discussions of the security of gas supplies to Europe (Smeers, 2008). As Smeers (2008, p. 41) argues:

> *It is certain though that very few would mention security of gas supply if resources were owned by one thousands producers and not reside in a few hands. One would not interpret Russia trying to get market prices (possibly excessive, but in any case non discriminatory) from Ukraine or Belarus as a political move if Russia were*

just one small producer among many. It would just be a normal market operation: Ukraine and Belarus have had to pay Western market price or be cut off. This trivial observation makes it clear that the market power of the producers is the driving theme of most of the discussion of security of supply.

Thus, upstream gas activities in the Former Soviet Union (FSU) countries and the market power of transit countries (particularly Ukraine and Belarus) deserve much greater attention in any analysis of the security of gas supplies to Europe (Smeers, 2008).

The analysis of the natural gas sector of FSU countries using economic models (mostly using a non-cooperative game theoretic framework) has gained considerable interest from researchers since the mid-1990s. During the 1990s and early 2000s, a push for market reforms and liberalization of national economies in the FSU countries spurred interest in researching gas relations between these countries in different contexts: (*i*) Russian gas exports to Europe and the country's relations with transit countries (Grais and Zheng, 1996), (*ii*) gas pricing policies in Russia (Tarr and Thomson, 2004), and (*iii*) Russia's gas transportation options to Europe and its relations with transit countries (Chollet et al., 2000; Hirschhausen et al., 2005). Since the mid-2000s, Russia's gas relations with its key transit countries (Belarus and Ukraine) have deteriorated, resulting in several gas transit disruptions to Europe; thus the economic modelling of FSU gas relations has again gained interest among researchers, but primarily in the context of the security of gas supplies to Europe (Bolle and Ruban, 2007; Morbee and Proost, 2008; Sagen and Tsygankova, 2008).

Lastly, another interesting stream of literature on modelling gas relations between FSU countries using applied game-theoretic models (such as cooperative bargaining models) is represented by (Newbery, 1994; Hubert and Ikonnikova, 2003; Hubert and Ikonnikova, 2004; Hubert and Suleymanova, 2008; Hubert and Ikonnikova, 2009). More specifically, this research is concerned with questions of strategic investment in large-scale gas pipelines in the context of bilateral (Newbery, 1994) and multilateral bargaining (Hubert and Ikonnikova, 2003; Hubert and Ikonnikova, 2004; Hubert and Suleymanova, 2008; Hubert and Ikonnikova, 2009) between Russia and its largest transit countries (such as Ukraine and Belarus).

In contrast to the large-scale gas market simulation models discussed above, the latter two research streams (cooperative and non-cooperative game theoretic models) lack any detailed representation of the downstream side of the European gas markets or the strategic interactions between gas exporters to Europe, and have a rather loose presentation of the upstream gas sector of the FSU countries. The consequence of neglecting these important market developments is that conclusions based on their analysis might change substantially once these market developments are accounted for.

Therefore, the primary objective in developing a large-scale gas simulation model here is to "bridge" this gap. By doing this, a contribution is made to the literature on large-scale gas simulation models by creating an explicit representation of the FSU gas "region". By using this Eurasian gas model we will be able to refine and obtain new insights into the strategic nature of gas relations between FSU countries that have been overlooked by previous economic and applied game-theoretic models.

2.3. Model Description

2.3.1. Modelling Framework

In the natural gas modelling literature (Mathiesen et al., 1987; Golombek and Gjelsvik, 1995; Golombek et al., 1998; Boots et al., 2004; Zwart and Mulder, 2006; Egging et al., 2008; Lise and Hobbs, 2008), a framework that is often used to model imperfect competition among market participants (usually, upstream producers and/or downstream suppliers) is the Cournot non-cooperative game. In this game, a Nash equilibrium is a set of actions (e.g., quantity of gas sales) such that no market participant (player) has an incentive to unilaterally deviate from his own actions, given his opponents' actions (Tirole, 1988).

In a gas market model, a player's objective is to maximize his profit given a set of constraints (such as production or transmission capacities constraints). Under certain conditions, such as a concavity of objective functions (for maximization problems) and convexity of feasible regions, the Karush-Kuhn-Tucker (KKT) conditions are both necessary and sufficient conditions for optimality of the maximization problem. Therefore, the essence of modelling the gas market system is to find an equilibrium that *simultaneously* satisfies each market participant's KKT conditions for profit maximization and market clearing conditions (supply equals demand) in the model. Due to the necessity and sufficiency of KKTs for global optimality when the players' problems are convex, this solution is a Nash equilibrium of the market game embodied in the model.

To illustrate the underlying mathematical structure of the model here, consider a simple problem that a gas producer might face:

$$\max_{q \geq 0} \pi = qp(q) - C(q) \tag{2.1}$$

subject to

$$q \leq Q \quad (\lambda) \tag{2.2}$$

where q is a sales variable, $p(q)$ is an affine inverse demand function, $C(q)$ is a production cost function such that $C'(q)>0$, $C''(q)>0$, and Q is the producer's production capacity. Then, the KKT conditions for (2.1) are

$$0 \leq q \perp p + \frac{\partial p}{\partial s} q + \lambda - C'(q) \leq 0 \tag{2.3}$$

$$0 \leq \lambda \perp (q - Q) \leq 0 \tag{2.4}$$

The symbol $\perp$ denotes orthogonality, which in the case of (2.3) is a more compact way of expressing the following complementarity relationship:

$$0 \leq q, \qquad p + \frac{\partial p}{\partial s} q + \lambda - C'(q) \leq 0, \qquad q\left(p + \frac{\partial p}{\partial s} q + \lambda - C'(q)\right) = 0$$

The set of conditions (2.3-2.4) is a set of complementarity conditions, or a complementarity problem. If there are also equality conditions, the problem is known as a mixed complementarity problem (MCP). Gathering these conditions for all optimization problems combined with all market clearing conditions (such as supply equals demand) in the gas market system forms a market equilibrium problem in the form of an MCP (Gabriel and Smeers, 2005). Applications of the MCP to energy market modelling are numerous (see, e.g., above-cited gas models; Smeers (1997) and Gabriel and Smeers (2005) provide an overview of natural gas market modelling using the MCP, and Hobbs and Helman (2004) discuss the application of MCP to electricity market modelling). The existence and uniqueness of the results for a class of gas market models formulated as MCPs has been established by Gabriel et al. (2005a). Large-scale simulation models formulated as MCPs can be efficiently solved with commercial solvers such as PATH.

2.3.2. Structural Assumptions

2.3.2.1. Model Structure

The scope of the model presented here is medium- to long-term. European countries face substantial energy challenges over this period of time, such as declining indigenous production, reliance on a relatively small number of external gas exporters coupled with increasing risks of supply disruptions, and rising carbon prices that may increase demand.

The structure of the model is summarised in Figure 2.1 (for European markets) and Figure 2.2 (for the FSU gas sector). The model represents major gas producers and consumers in Europe and in the Former Soviet Union (FSU), although the model could also be used to represent gas markets elsewhere in the world. Producers and consumers are connected by pipeline networks and the LNG bilateral shipping network. Gas producers sell gas to suppliers,[41] who in turn re-sell to final markets. Gas producers can either export gas through pipelines (e.g., Producer *i1*, Figure 2.1) or as LNG (e.g., Producer *i2* to Country C, Figure 2.1). In order to import LNG, consuming countries need regasification terminals (e.g., Country C, regasifier *r1*).

[41] Hereinafter, the terms "supplier" and "trader" are used interchangeably. A gas supplier/trader is understood as a large utility company which has gas import contracts with upstream producers. A supplier/trader buys gas from producers and then re-sells it to final customers.

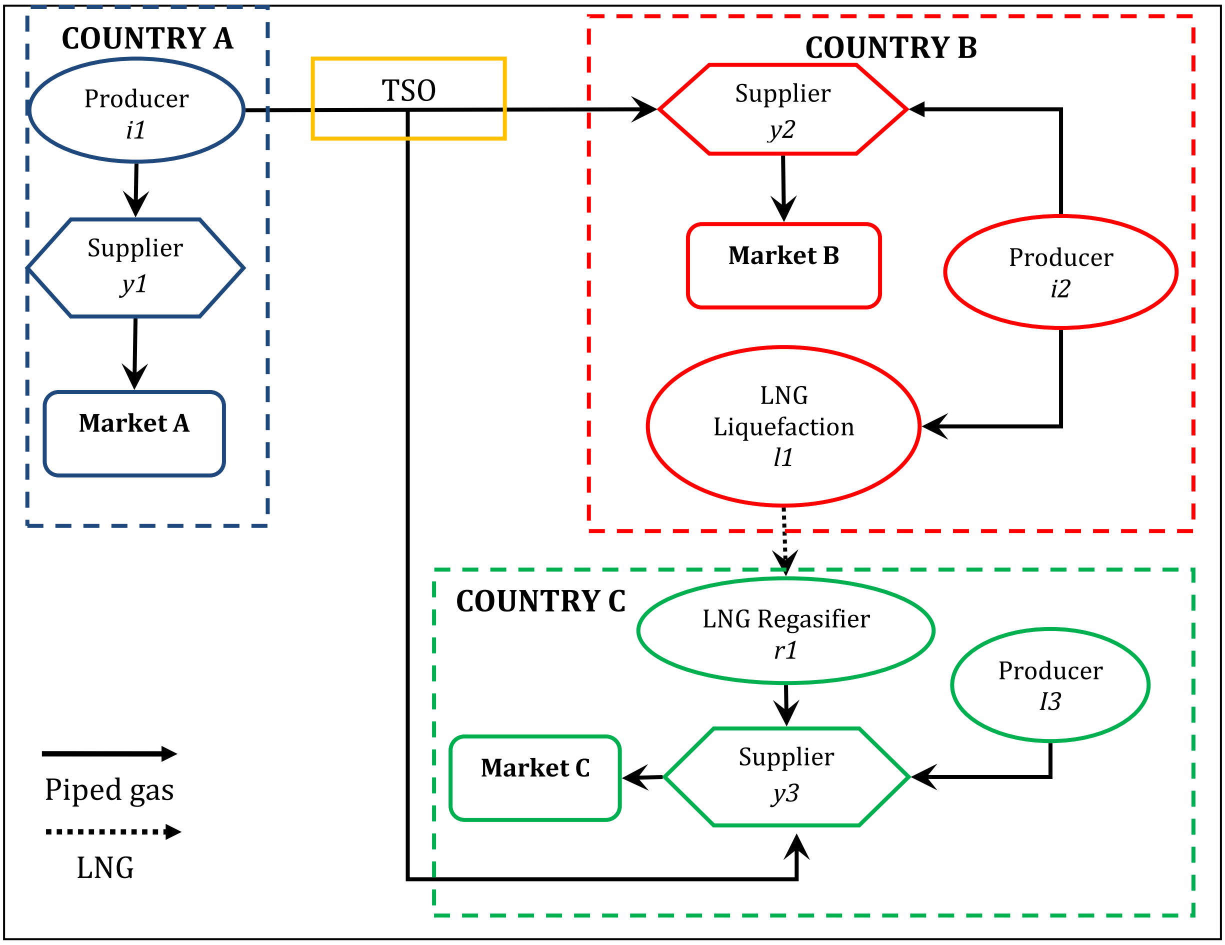

Figure 2.1: Schematic of the Structure of the European Sub-model

The FSU gas sector model is based on the structure in Figure 2.2. For transparency, the activities of vertically integrated companies such as Gazprom and Naftogaz of Ukraine are modelled separately.[42] For example, in Figure 2.2, Gazprom is modelled as having four subsidiaries corresponding to four major activities – production, LNG liquefaction, domestic marketing and export. Modelling each subsidiary of an integrated company as a separate player is similar to modelling the integrated company as one problem, provided that the relationships between subsidiary companies are modelled as competitive (price-taking). The proof of this statement is given in Appendix A. Thus, Gazprom's production subsidiary sells gas to its marketing and export subsidiaries at a competitive (marginal cost) price. The same applies to Naftogaz of Ukraine – Naftogaz's production subsidiary sells gas to its marketing subsidiary at a competitive price.

[42] Egging et al. (2008) modelled the activities of vertically integrated companies similarly.

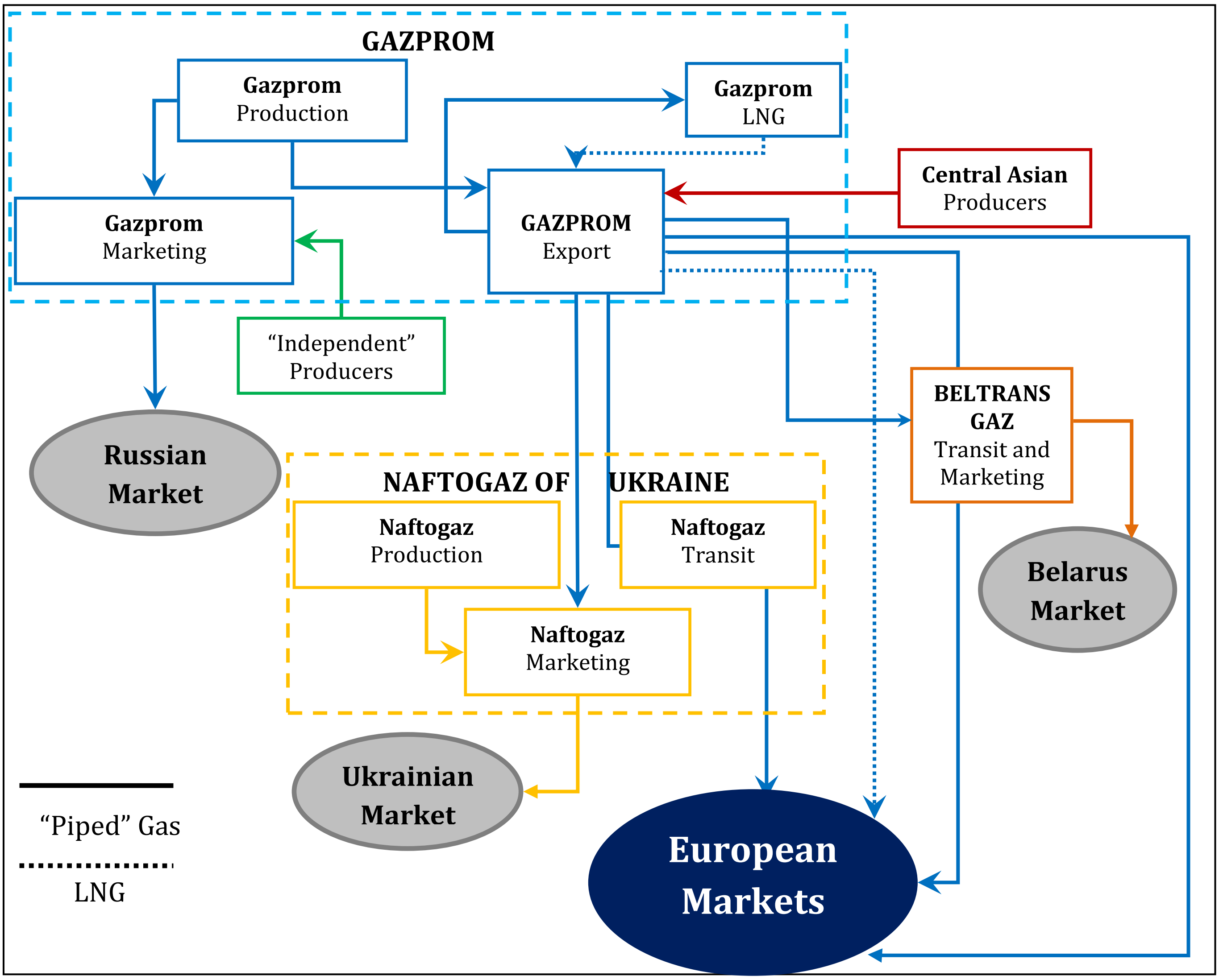

Figure 2.2: Schematic of the Structure of the FSU Gas Sub-model

It is assumed that each FSU gas market is dominated by a state-owned supplier, which is consistent with reality. For example, in Russia the dominant domestic supplier is "Mezhregiongaz" (Gazprom's subsidiary), and in Ukraine it is "Gas of Ukraine", a subsidiary of Naftogaz of Ukraine (for simplicity, a domestic supplier like Gazprom Marketing or Naftogaz Marketing is called a "marketing" company in Figure 2.2.). Since gas companies are completely or majority state-owned, it is assumed that they have a legal obligation to supply the domestic market at regulated prices[43] (Sagen and Tsygankova (2008) make a similar assumption in their model of the Russian gas sector concerning Gazprom's legal obligation to supply domestic consumers at regulated prices). Thus, both domestic prices and gas demand in the FSU countries are exogenous to the model. The growth rate of domestic gas prices is assumed to be 0.8% p.a (the base

[43] For example, Ms. Vlada Rusakova, a member of Gazprom's management committee and Head of Gazprom's strategic planning department, stated that Gazprom is legally responsible for meeting domestic demand at regulated prices (Grivach, 2006).

price is reported in Appendix E: Table E.1) and is consistent with growth rates applied to other markets in the model (see Appendix E: Table E.1). Gas demand is assumed to grow at +0.4% p.a., which is based on the IEA's WEO 2009 forecast ("reference case") (IEA, 2009).

The state-owned suppliers must meet domestic demand by purchasing gas from indigenous production (at competitive prices) or by importing gas from other entities. For example, in this model Gazprom Marketing buys gas from "independent" gas producers and from Gazprom Production to meet Russian domestic demand. Similarly, in Ukraine Naftogaz Marketing purchases gas from Naftogaz production and it has to import gas from Gazprom Export, since domestic demand exceeds indigenous production. Thus, the goal of state-owned suppliers in the FSU sub-model is to minimize the cost of meeting domestic demand because regulated prices and gas demand are exogenous to the model.

Gazprom Export is Gazprom's subsidiary responsible for international marketing and export activities. Gazprom Export holds a monopoly position in exporting Russian gas to European and CIS markets (Gazprom, 2010d). It is assumed that to meet its export obligations Gazprom Export can purchase gas both from Gazprom Production and from Central Asian producers (Figure 2.2). In order to export gas, Gazprom Export has to contract transport services through Ukraine and Belarus, paying transit fees to Naftogaz Transit (through Ukraine) and Beltransgaz (through Belarus) respectively. Gazprom Export can also export gas directly to consuming countries (e.g., through Blue Stream to Turkey and through Nord Stream and South Stream to Europe, if the latter two projects materialize as planned by Gazprom). Gazprom plans to enter the global LNG market with anticipated LNG projects such as Shtokman and on the Yamal Peninsula; therefore, this model includes the possibility of Gazprom exporting gas as LNG.

There are two connections between the FSU sub-model (Figure 2.2) and the European sub-model (Figure 2.1). One is through Gazprom Export's activities, as the blue oval in Figure 2.2 "European Markets" is the market model in Figure 2.1. The other is via the activities of transit countries (Ukraine and Belarus).

2.3.2.2. Behaviour of market players in the model

The model allows the following players to be simulated as having market power:

1. producers (e.g., Producer *i* in Figure 2.1 or Gazprom Export in Figure 2.2)
2. transit countries (e.g., Ukraine and Belarus in Figure 2.2)
3. suppliers (e.g., Supplier *y* in Figure 2.1).

The successive exercise of market power by producers and suppliers

Producers are assumed to exert market power against downstream suppliers by playing a Cournot game with other upstream producers. If there is market power at both the supplier and production levels, a successive structure to the market game is assumed in which producers anticipate (*à la* Stackelberg) how suppliers react. The GASMOD (Holz et al., 2008) and static GASTALE (Boots et al., 2004) models have a similar market structure. Thus, the effective demand for gas producers reflects the exercise of market power by suppliers in their downstream market, and the slope of this effective demand is consistent with Cournot market power among the suppliers and the elasticity of final demand (Boots et al., 2004).

The assumption that producers anticipate how suppliers react and that suppliers treat the border price as given (i.e., suppliers are price-takers with respect to border prices) is not entirely true concerning large suppliers, who may have some market power vis-à-vis gas producers.[44] In contrast to the successive oligopoly relationship between producers and suppliers embodied in this model, the "traditional view" of the European gas markets is that producers and suppliers act simultaneously to extract the whole monopoly profit from the market and then share that profit according to their relative bargaining power (Smeers, 2008). Compared to the successive oligopoly approach, such vertical coordination to exercise market power can result in greater sales and lower prices, and therefore a smaller loss of welfare (Smeers, 2008).

One way to accommodate such vertical coordination in this model's structure is to assume that only producers (or only suppliers) exert market power and that suppliers (producers) receive a fixed mark-up from final gas prices, assuming that the relative bargaining power of suppliers (producers) reflects the mark-up they receive (Smeers, 2008).

[44] As Smeers (2008: p.19) noted:

> *"Global oil and gas companies may have lost a lot of bargaining power to acquire resources in Russia and Kazakhstan and some are kicked out of Venezuela; still they retain bargaining power at the EU border when it comes to buying and marketing natural gas."*

Representing transit market power

In this model, transit market power is represented by the conjectured transit demand curve approach, which assumes that large transit countries (e.g., Ukraine and Belarus) believe that they face a declining effective demand curve for their services with an assumed slope, rather than deriving a slope based on market fundamentals. For example, if Ukraine conjectures that Gazprom's transit quantity will diverge from its equilibrium value (x^*) in proportion to the change in Ukraine's transit fee from its equilibrium tf^*, the resulting conjectured transit demand equation is:

$$(x - x^*) - M(tf - tf^*) = 0, \quad M < 0 \tag{2.5}$$

where $(x\text{-}x^*)$ is a change in demand for transportation services that the transit country conjectures will happen if it changes its transit fee by $(tf\text{-}tf^*)$, and M is a conjectured slope for the transit demand curve.

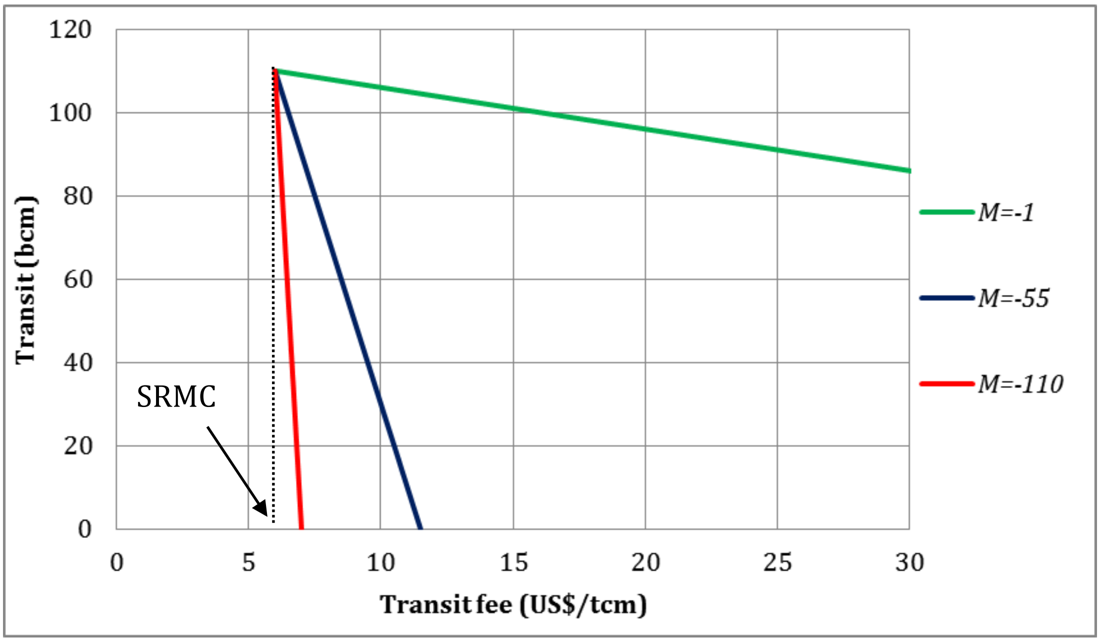

Figure 2.3: Ukraine's Conjectured Transit Demand Curves

In Figure 2.3, as an example, the transit demand curve for Ukraine under different values of conjectured slope M is plotted.[45] It can be seen from this figure that if the slope of the transit demand curve is large enough (e.g., M=-110), then small changes in the transit fee will cause large changes in the transit quantities. This is possible if, for

[45] The transit demand slopes plotted in Figure 2.3 are for expositional purpose only. The values of M={-1;-55;-110} are taken to clarify the meaning of M in the context of Gazprom's bypass pipelines. Sensitivity analysis of M is provided in Appendix I.

example, Gazprom has substantial transport capacities in alternative pipelines that “bypass” Ukraine. *M=-110* was chosen as an example to represent the scenario of Gazprom building both the Nord Stream and South Stream pipelines (with a total capacity of 110 bcm). In this scenario, Ukraine conjectures that a unit increase in the transit fee may cause Gazprom to divert up to 110 bcm from Ukraine to alternative pipelines. This is why the transit demand curve is very steep (the “red” line in Figure 2.3) and close to its short-run marginal cost (SRMC). In this scenario, Ukraine prices its transit service close to the competitive price, which is logical since if Gazprom has capacity that allows it to totally avoid Ukraine, then there is no market power left for Ukraine to exercise. The scenario of *M=-55* corresponds to Gazprom building Nord Stream only (its transport capacity is 55 bcm).

Where the conjectured slope is negligible (e.g., *M=-1*), Ukraine believes that any change in its transit fee has little effect on the quantity Gazprom ships through Ukraine, e.g., because Ukraine believes that Gazprom has no alternative export pipelines. In Figure 2.3, the transit demand curve with the slope *M=-1* (“green” line) is almost flat.

In general, a conjectural variation shows a firm’s belief about the reaction (or variation) of another firm to potential adjustments in the first firm’s actions. In the case being considered here, this belief is captured in the form of an exogenous parameter, *M*, expressing the derivative of the transit quantity with respect to the transit price. It is easy to see that at the limit eq. (2.5) is the definition of the derivative of the transit quantity with respect to the transit fee:

$$\lim_{\Delta\to 0}\frac{\Delta x}{\Delta tf}=\frac{\partial x}{\partial tf}\overset{\text{def}}{=}M<0 \tag{2.6}$$

where $\Delta x = x - x^*$ and $\Delta tf = tf - tf^*$

Despite the appeal of its simplicity, the conjectural variations approach has theoretical limitations (Smeers, 2008). In general, economic theorists view conjectural variations as being the endogenous result of a dynamic game (Dockner, 1992); therefore, interpreting it as a constant parameter in a static model might be misleading (Friedman, 1983). Also, the firm’s conjecture about another firm’s response need not be correct (Friedman, 1983) and is highly dependent on precise market conditions.

Therefore, the conjectured transit demand slope, *M*, is treated parametrically and a sensitivity analysis of this parameter is provided (see Appendix I). Despite these shortcomings, as has been shown above, the conjecture transit demand function has an intuitive and practical interpretation. Furthermore, it allows the model user to conveniently explore oligopolistic behaviour between competitive and monopolistic extremes.

Finally, the application of the conjectural variations approach to representations of market power is quite common in the energy market modelling literature. For example, the conjectured supply function has been applied in natural gas market modelling (Egging and Gabriel, 2006; Zwart and Mulder, 2006; Egging et al., 2008). The conjectured supply function represents traders' conjectures about variations in the supply from other traders in response to deviations in supply from the first trader. The conjectural variations approach is also widely used in the electricity market modelling literature, for example in the form of the conjectured supply function and the conjectured transmission price function (Day et al., 2002; Hobbs and Rijkers, 2004; Hobbs et al., 2004). In (Hobbs and Rijkers, 2004; Hobbs et al., 2004), the conjectured transmission price function represents a generator's belief about how its demand for transmission services affects the cost of transmitting power between two points. In this sense, the conjectured transmission price function, as applied in (Hobbs and Rijkers, 2004; Hobbs et al., 2004), has an inverse relationship to the conjectured transit demand function here because, in the first case, the generator believes that increasing demand for power transmission might drive up prices, whereas in this case the transit operator conjectures that an increase in the transit fee might depress transit flows through its pipelines.

Bilateral market power in the FSU gas sector

Modelling gas relations between buyers and sellers in FSU countries (Russia, Central Asia, Ukraine, Belarus and Moldova) represents a challenge for several reasons. First, the gas sector in the FSU countries is heavily regulated. Consequently, (*i*) natural gas is under-priced compared to its opportunity cost, and (*ii*) the gas "markets" are barely contestable, as the gas sector is dominated by a state-owned incumbent. Therefore, applying the Cournot framework (as it is applied to European markets) might not be appropriate for the FSU countries, where market fundamentals are not yet in place and where there is significant market power on the part of both buyers and sellers.

Alternatively, a cooperative bargaining framework might be suitable for the analysis of bilateral gas monopolies in the FSU. Therefore, the following bilateral gas relations are modelled using the cooperative bargaining framework (see Appendix B for details):

1. Gazprom Export–Naftogaz Marketing
2. Gazprom Export–Beltransgaz
3. Gazprom Export–Central Asian gas producers
4. Gazprom Marketing–Russian "independent" gas producers.

Competitive access to the gas infrastructure

Apart from producers, suppliers and transit countries, all other market participants (such as transmission system operators and operators of liquefaction and regasification terminals) in the model are assumed to possess no market power. Therefore, transmission costs and the costs of LNG services are priced efficiently, i.e., access to pipelines and LNG facilities is granted to those market players who most value the services (i.e., based on marginal willingness to pay). This would result in charges based on (long-run) marginal costs and a congestion premium in case of pipeline or LNG facility saturation (Cremer et al., 2003; Gabriel and Smeers, 2005). Since congestion in natural gas transmission does not yet seem to be a major concern (Gabriel and Smeers, 2005), it is assumed here that users of pipelines and LNG facilities do not pay the congestion premium when pipelines and LNG facilities are saturated.[46] Thus, these congestion fees are used as a mechanism to simulate the efficient allocation of scarce pipeline and LNG capacities (Gabriel et al., 2005a; Gabriel et al., 2005b; Zhuang and Gabriel, 2008). The assumption of the efficient pricing of access to gas pipelines and LNG infrastructure is consistent with other strategic gas models (e.g., (Gabriel et al., 2005a; Egging et al., 2008; Lise and Hobbs, 2008)).

Smeers (2008) argues that efficient pricing of access to gas infrastructure is somewhat optimistic and diverges from the reality of gas market development in Europe (Smeers, 2008). However, recent agreements between private companies and European antitrust authorities (such as the capacity release programme agreed between GDF SUEZ, ENI, E.ON and EC) promise more competitive access to both transmission pipelines and LNG import terminals in Europe (EC, 2009a; EC, 2009b; EC, 2010).

Further, to represent the case when free access to the gas infrastructure and competitive pricing are not the norm in European markets, a scenario is simulated

[46] The profit of the corresponding player is here adjusted ex-post to remove the resultant congestion costs.

where pipeline (cross-border) and LNG import/export capacities are drastically limited, either because of physical saturation or because of restrictive practices found by the European Commission (EC, 2009a; EC, 2009b; EC, 2010) (see Appendix I).[47] The effect of this scenario on gas markets can be evaluated against the benchmark case of efficient access pricing for infrastructure.

2.3.3. Model Notation

2.3.3.1. Sets and Indices

$n \in N$	Set of all the nodes in the model, which includes the production, LNG liquefaction, regasification and transhipment nodes.
$N'(n)$	Set of nodes N' adjacent to node n. Nodes are connected either by gas pipelines or by LNG bilateral shipping links. LNG bilateral shipping links are only formed between LNG liquefaction terminals and regasification terminals.
$r \in R \subset N$	Set of regasification nodes R, a subset of all the nodes.
$l \in L \subset N$	Set of liquefaction nodes L, a subset of all the nodes
$c \in C$	Set of 'non-FSU' consumption countries. $N(c)$ is denoted as a set of gas off-take nodes in country c. This could be either pipeline border points, LNG regasification terminals or indigenous production points.
$i \in I$	Set of all 'non-FSU' gas producing firms. For this model version there is an allocation of one firm to one production node[48]
$N(i)$	Set of nodes where i can produce gas
$y \in Y$	Set of all 'non-FSU' suppliers who buy gas from producers and exporters and re-sell it to final markets
$j \in J$	Set of all gas producers and exporters who sell gas to suppliers, Y. This includes all 'non-FSU' producers, I, and Gazprom Export, G

[47] The "restrictive" pipeline access scenario is inspired by Smeers' (2008: p.34) suggestion.
[48] The exception is Russia, where two firms are assigned - Gazprom and "independent" producers. If required, the allocation of firms to different production sites can be easily altered in the model.

G	Variables and parameters associated with Gazprom Export are denoted with the letter G
$f \in F$	Set of FSU consumption countries. $N(f)$ is denoted as a set of gas off-take nodes in country f.
$u \in U \subset N$	Set of entry nodes of transit pipelines (Ukraine and Belarus)
$u' \in U'(u) \subset N$	Set of nodes u' that are directly connected to node u
$k \in K$	Set of 'FSU' producers, K
$t \in T(f)$	Set of suppliers that serve node f (In the implementation in this paper there is one supplier per consumption node, f, but more general implementations can be made).
$K(G)$	Set of 'FSU' producers who have commercial relations with Gazprom Export (G) (i.e. buying/selling gas)
$K(t)$	Set of 'FSU' producers who have commercial relations with supplier a t (i.e. buying/selling gas)
$T(k)$	Set of suppliers, T, who have commercial (gas buying/selling) relations with a producer, k (i.e. buying/selling gas)
$T(G)$	Set of suppliers, T, who have commercial relations with Gazprom Export (purchasing and selling gas)
$N(k)$	Set of production nodes, N, where producer k can be located
$N(t)$	Set of nodes, N, through which supplier t can import gas

2.3.3.2. Variables

For clarity of presentation, an asterisk (*) is used to denote variables that are exogenous to a particular market player's maximization problem. The variables might be exogenous to one or more players, but such variables are endogenously determined in the model. This is done either through market clearing conditions or through the maximization problems of other players.

Subscripts are used for indexation, and superscripts denote that a particular variable (or parameter) belongs to a particular type of player in the model. For example, s_{jync}^{Y} means the quantity of gas purchased by supplier *y* from upstream firm *j* and re-sold in market *c* through node *n.* Superscript *Y* denotes the sales variable for suppliers operating in European markets. Further, where necessary, buying and selling relationships between players are specified using the following notation: leftwards arrow (←) to denote "*from*" and rightwards arrow (→) to denote *"to"*. For example, $h_{tkn}^{T\leftarrow K}$ means gas purchases by supplier *T* from producer *K*, and $s_{ktn}^{K\rightarrow T}$ means gas sales by producer *K* to supplier *T*.

European sub-model:

Supplier's Decision Variables

s_{jync}^{Y}	Quantity of gas purchased by supplier *y* from upstream firm *j* and re-sold in market *c* through node *n*.	Bcm/y

Producer's Decision Variables

s_{inc}^{I}	Producing firm *i*'s total gas supply to all suppliers in market *c* through node *n*	Bcm/y
$x_{inn'}^{I}$	Producer *i*'s transportation variable from node *n* to the next node *n'*	Bcm/y
$xl_{inn'}^{I}$	Producer *i*'s LNG shipping variable from liquefaction node *n*∈*N(l(i))* to regasification node *n'*∈*N'(r)*	Bcm/y
q_{in}^{I}	Producer *i*'s production at node *n*∈*N(i)*	Bcm/y

TSO's Decision Variables

$d_{nn'}^{TSO}$	TSO decision variable regarding gas flows from node *n* to the next node, *n'*	Bcm/y

LNG Decision Variables

q_{n}^{liq}	LNG liquefaction quantities at node *n*∈*N(l)*	Bcm/y
$q_{n'}^{regas}$	LNG regasification quantities at regasification node *n'*∈	Bcm/y

N'(r)

Price Variables

p_c	Average consumer retail gas price in consumption country *c*	US$/tcm
bp_c	Border price for bulk gas in market *c*	US$/tcm
$tc_{nn'}$	Transmission price from *n* to *n'*, including congestion premium	US$/tcm
$p_{n'}^{regas}$	LNG regasification price at node $n' \in N'(r)$	US$/tcm
p_n^{liq}	LNG Liquefaction price at node $n \in N(l)$	US$/tcm

FSU Sub-model:

Supplier's Decision Variables

s_{tf}^T	Supplier *t* gas sales for final consumption in market *f*	Bcm/y
$h_{tkn}^{T \leftarrow K}$	Supplier *t* gas purchases from producer *k* and gas producing node $n \in N(k)$	Bcm/y
$h_t^{T \leftarrow G}$	Supplier *t* gas purchases from Gazprom Export *(G)*	Bcm/y

Producer's Decision Variables

$s_{ktn}^{K \to T}$	Producer *k* gas sales (produced from node $n \in N(k)$) to supplier *t*	Bcm/y
$s_{kn}^{K \to G}$	Producer *k* gas sales (produced from $n \in N(k)$) to Gazprom Export (*G*)	Bcm/y
q_{kn}^K	Producer *k* gas production from $n \in N(k)$	Bcm/y

Gazprom Export

s_{nc}^G	Gazprom Export's total gas sales to all suppliers in market $c \in C(G)$ through node $n \in N(c)$	Bcm/y

$s_{tnf}^{G \to T}$	Gazprom Export's gas sales to supplier $t \in T(f)$ in consumption country f through node $n \in N(t)$	Bcm/y
$h_{kn}^{G \leftarrow K}$	Gazprom Export's gas purchases from producer k and node $n \in N(k)$	Bcm/y
$x_{nn'}^{G}$	Transport variable from n to n'	Bcm/y
$xl_{nn'}^{G}$	LNG shipping variable from $n \in N(l(G))$ to $n' \in N'(r)$	Bcm/y

Natural Gas Transit

$tf_{uu'}$	Decision variable representing the transit fee through pipeline (u,u')	US$/tcm
$d_{uu'}^{TR}$	Transit operator's decision about how much transit capacity through (u,u') to render to Gazprom Export	Bcm/y

Price Variables

$p_{ktn}^{K \to T}$	Price of gas produced from $n \in N(k)$ by producer k to supplier t	US$/tcm
$bp_{t}^{G \to T}$	Gazprom Export's sales (border) price to supplier t	US$/tcm
$p_{pz}^{K \to G}$	Sales prices of gas produced from $n \in N(k)$ by producer k to Gazprom Export	US$/tcm
$p_{uu'}^{TR}$	Congestion premium through transit pipeline (u,u')	US$/tcm

2.3.3.3. *Exogenous Parameters and Functions*

European sub-model:

Supplier's Parameters/Functions

DC_c	Unit distribution cost in market c	US$/tcm
R_c	Number of suppliers serving market c	
Θ_c^Y	0-1 parameter: $\Theta_c^Y = 0$ if suppliers serving final market c are competitive players, and $\Theta_c^Y = 1$ if those suppliers	

	are instead Cournot players in the final market c	
Producer's Parameters/Functions		
$TPC_i(\cdot)$	Producer i's total production cost	US$
CAP_{in}^{PR}	Producer i's production capacity as available at node n	Bcm/y
Θ_{ic}^{I}	0-1 parameter: Θ_{ic}^{I}=0 if producer i behaves competitively, and Θ_{ic}^{I}=1 if producers are Cournot players in market c	
TSO's Parameters/Functions		
$TC_{nn'}^{TSO}(\cdot)$	Total transmission cost to transport gas from $n \in N$ to $n' \in N'(n)$	US$
$CAP_{nn'}^{TSO}$	Capacity of pipeline *(n,n')*	Bcm/y
$LOSS_{nn'}^{PIPE}$	Loss factor due to fuel consumption by compressors along pipeline *(n,n')*	fraction of gas transport per km
LNG Parameters/Functions		
$SC_{nn'}$	LNG unit shipping cost from $n \in N(l)$ to $n' \in N'(r)$	US$/tcm
$TC^{liq}(\cdot)$	Total cost of gas liquefaction (assumed linear in this model, although more general formulations are possible)	US$
CAP_{n}^{LIQ}	Total liquefaction capacity at node $n \in N(l)$	Bcm/y
$TC^{regas}(\cdot)$	Total cost (linear) of LNG regasification	US$
$CAP_{n'}^{REGAS}$	Total regasification capacity available at node $n' \in N'(r)$	Bcm/y
$LOSS_{nn'}^{LNG}$	Total loss factor during LNG liquefaction, shipping and regasification from n' to n	fraction of gas shipments

FSU Sub-model:

Supplier's Parameters/Functions

DC_f	Unit distribution cost in market f	US$/tcm
$D_f(\cdot)$	Demand function in market f, which depends on the regulated average retail price P_f^{REG}	Bcm/y

Producer's Parameters/Functions

$TCP_k(\cdot)$	Producer k's total production cost	US$
CAP_{kn}^{PR}	Producer k's production capacity available at node $n \in N(k)$	Bcm/y

Gazprom Export's Parameters/Functions

Θ_c^G	0-1 parameter: Θ_c^G=0 if Gazprom Export behaves competitively in market c, Θ_c^G=1 if Gazprom Export is *à la* Cournot in market c	

Natural Gas Transit Parameters/Functions

$TC_{uu'}^{TR}(\cdot)$	Total transit cost (linear) through pipeline *(u,u')*	US$/tcm
$M_{uu'}$	Conjectured transit demand slope through transit pipeline *(u,u')*, $M_{uu'}$<0	Bcm/US$/ tcm
$CAP_{uu'}^{TR}$	Transportation capacity through transit pipeline *(u,u')*	Bcm/y
$\Theta_{uu'}^{TR}$	0-1 parameter: $\Theta_{uu'}^{TR}$=0 if transit through pipeline *(u,u')* is priced competitively, and $\Theta_{uu'}^{TR}$=1 if the transit country is assumed to exercise market power vis-a-vis Gazprom Export over the transit pipeline *(u,u')*	

2.3.4. Profit Maximization Problems

2.3.4.1. European Sub-model

Supplier Model

It is assumed that suppliers are multinational firms who operate in different markets through their independent national subsidiaries. Thus, the model assumes that competition in supply is limited to national boundaries and price discrimination might occur due to the absence of arbitrage in the model. The supplier's objective is to maximize its profit (π_y^Y) from purchasing gas from upstream firm *j* through node *n* at border price bp_{yc}^* and re-selling it to final market *c*:

$$\max_{s_{jync}^Y \geq 0} \pi_y^Y = \sum_{j\in J, n\in N(c), c\in C} s_{jync}^Y \left(p_c - bp_{yc}^* - DC_c\right) \tag{2.7}$$

The border price, bp_{yc}^*, is exogenous to the supplier's problem, however it is determined endogenously in the model (as denoted by the asterisk). Supplier *y* has to pay a distribution cost, $DC_{c,}$ to sell gas to the final customers in *c*. Further, it is assumed that suppliers treat the border price as given, i.e. they are price-takers with respect to border prices. This formulation of the supplier's problem has been used previously, for instance by Boots et al. (2004).

The following are the first-order (Karush-Kuhn-Tucker, KKT) conditions for the downstream profit maximization problem (2.7):

$$0 \leq s_{jync}^Y \perp \left[p_c - bp_{yc}^* - DC_c + \frac{\partial p_c}{\partial s_{jync}^Y} s_{jync}^Y\right] \leq 0, \qquad \forall c \in C \tag{2.8}$$

Then the expression for the border price is derived from (2.8) as follows:

$$bp_{yc}^* \geq p_c - DC_c + \frac{\partial p_c}{\partial s_{jync}^Y} s_{jync}^Y, \qquad \forall c \in C \tag{2.9}$$

In this model version, for each country, *c*, one aggregate demand function is assumed, i.e. gas consumption is not differentiated by sector (e.g., industrial, household, power sectors, etc.); more detailed formulations of the demand side are, of course, possible (e.g., (Egging et al., 2008; Lise and Hobbs, 2008)). Following Boots et al. (2004), a linear demand function for natural gas is assumed as follows:

$$p_c = B_c + A_c \sum_{j\in J, y\in Y, n\in N(c)} s_{jync}^{Y}, \qquad \forall c \in C \tag{2.10}$$

where $B_n>0$, $A_n<0$ are parameters to be calibrated at assumed elasticity and price-quantity pairs for the base year (2009) (see Appendix E, Table E.1 for reference prices and consumption assumed for all markets in the model).

Similarly to Boots et al., (2004), it is assumed that suppliers in market c are identical[49] and cannot be discriminated between, so $bp_{yc}=bp_c$; furthermore, the sales variable of upstream firm j to market c is $s_{jnc}^{J} = \sum_y s_{jync}^{Y}$. If supplies to market c are strictly positive, then by taking into account the assumed symmetry of suppliers in market c we can use expression (2.10) to express the border price for market c as follows:

$$bp_c = \hat{B}_c + \hat{A}_c \sum_{j\in J, n\in N(c)} s_{jnc}, \qquad \forall c \in C \tag{2.11}$$

where:

$$\hat{B}_c = B_c - DC_c, \qquad \forall c \in C \tag{2.12}$$

$$\hat{A}_c = A_c\left[\Theta_c^{Y}\left(\frac{R_n+1}{R_n}\right) + (1-\Theta_c^{Y})\right], \qquad \forall c \in C \tag{2.13}$$

The latter expression accounts for whether the supplier market is assumed to be competitive or Cournot ($\Theta_c^{Y}=0$ if suppliers serving market c are competitive players, and $\Theta_c^{Y}=1$ if suppliers are Cournot players).

Producer Model

The producer's objective is to maximize its profit (π_i^{I}) by choosing how much gas to sell to market c (s_{inc}^{I}) through node n. It also has to choose the production quantity (q_{in}^{I}) at node n, paying total production costs (TPC_i). Following Golombek and Gjelsvik

[49] As Smeers (2008) argues, this assumption does not correspond to the reality of European downstream gas markets.

(1995), Egging et al. (2008) and Lise and Hobbs (2008), the total production cost is assumed to be an increasing function of the production rate q_{in}^{I} (for details see Appendix E, Table E.6). The production cost function (TPC_i) is assumed to be separable over time, so inter-temporal production constraints and costs (arising from, e.g., depletion effects) are not considered.[50] More general functions could be considered (e.g., (Zwart and Mulder, 2006; Gabriel et al., 2003)). Apart from production costs, transport expenses from nodes n to n' are also incurred, either through pipelines ($x_{inn'}^{I}$) and paying transmission costs ($tc_{nn'}^{*}$), or through LNG vessels ($xl_{inn'}^{I}$), paying liquefaction (p_n^{liq*}), shipping ($SC_{nn'}$) and regasification costs ($p_{n'}^{regas*}$). The resultant producer's maximization problem is as follows:

$$\max_{s_{inc}^{I},q_{in}^{I},x_{inn'}^{I},xl_{inn'}^{I}\geq 0} \pi_i^I$$

$$= \sum_{n\in N(c),c\in C(i)} s_{inc}^{I} bp_c - \sum_{n\in N(i)} TPC_i(q_{in}^{I}) - \sum_{n\in N}\sum_{n'\in N'(n)} x_{inn'}^{I} tc_{nn'}^{*} \tag{2.14}$$

$$-\sum_{n\in N}\sum_{n'\in N'(n)} xl_{inn'}^{I}\left(p_n^{liq*} + SC_{nn'} + p_{n'}^{regas*}\right)$$

subject to

$$s_{inc} + \sum_{n'\in N'(n)} \left[x_{inn'}^{I} + xl_{inn'}^{I} - \left(1 - loss_{n'n}^{pipe}\right)x_{in'n}^{I} - \left(1 - loss_{n'n}^{lng}\right)xl_{in'n}^{I}\right] \leq q_{in}^{I}, \tag{2.15}$$

$$(\beta_{in}^{I} \geq 0), \qquad \forall n \in N(i), c \in C(i)$$

$$q_{in}^{I} \leq CAP_{in}^{PR}, \qquad (\gamma_{in}^{I} \geq 0), \qquad \forall n \in N(i) \tag{2.16}$$

As indicated by eq. (2.15) (preservation of mass balance at node n), the gas pipeline network is modelled as a transhipment problem with a constant proportion of losses.[51] Detailed technical phenomena, such as line pack or nonlinear pipeline shipment costs as a function of total flow, are not considered; more sophisticated representations are possible (e.g.,(O'Neill et al., 2004; De Wolf and Smeers, 1996; Midthun et al., 2009)).

The KKT conditions for producers and the following player optimization problems can be found in Appendix C. These conditions are derived in similar ways as described

[50] It should be noted that the producer model presented here is only an approximation to the complicated engineering problems of petroleum extraction in the real world.

[51] Flow conservation at a particular node is expressed as inequality rather than equality, as this allows the model to be solved more efficiently. The solution of the model with flow conservation expressed as equalities is the same as in the case of inequalities.

above for the supplier model, i.e. by taking the first-order conditions with respect to each decision variable and the constraints.

Efficient TSO Model (Non-FSU)

It is assumed that the transmission cost through the pipeline *(n,n')* is priced efficiently, i.e. it is assumed that TSOs behave competitively and grant access to the pipeline infrastructure to those market players who value transmission services the most. This would result in a transmission charge based on marginal costs and a congestion premium in case pipeline *(n,n')* is saturated (Cremer et al., 2003; Gabriel and Smeers, 2005). Thus, the TSO objective is to

$$\max_{d_{nn'}^{TSO} \geq 0} \pi^{TSO} = \sum_{n \in N \backslash U,\ n' \in N'(n)} \left[d_{nn'}^{TSO} tc_{nn'}^{*} - TC_{nn'}^{TSO}(d_{nn'}^{TSO}) \right] \tag{2.17}$$

subject to

$$d_{nn'}^{TSO} \leq CAP_{nn'}^{TSO}, \qquad (\gamma_{nn'}^{TSO} \geq 0), \qquad \forall n \in N \backslash U, n' \in N'(n) \tag{2.18}$$

LNG Model

In order to export LNG, upstream firm *j* liquefies natural gas and then ships it to consuming markets, where the LNG will be regasified for final consumption. As with TSOs (other than Ukraine and Belarus) who manage transmission pipelines, it is assumed that liquefiers and regasifiers behave competitively and price LNG services efficiently (this is consistent with previous gas models where the LNG value chain has been explicitly modelled; see, e.g., (Egging et al., 2008)).

Further, it is assumed that the producer retains ownership of the gas and contracts transport services, as opposed to a situation where the transporter buys the gas from the producer at the point of liquefaction. Since it is assumed that LNG services (liquefaction and regasification) are priced competitively, this assumption does not change the results (see Appendix A for the proof of this statement).

Liquefaction

The objective of liquefiers is to maximize the value of liquefaction services (2.19) given their constraints on liquefaction capacity (2.20):[52]

$$\max_{q_n^{liq}} \pi^{LIQ} = q_n^{liq} p_n^{liq*} - TC^{liq}(q_n^{liq}) \tag{2.19}$$

subject to

$$q_n^{liq} \leq CAP_n^{LIQ}, \qquad \left(\gamma_n^{LIQ} \geq 0\right), \qquad \forall n \in N(l) \tag{2.20}$$

Regasification

LNG needs to be regasified in order to supply final customers. The regasifier maximizes the profit gained from the provision of regasification services (2.21) subject to capacity constraints (2.22):

$$\max_{q_{n'}^{regas}} \pi^{REGAS} = q_{n'}^{regas} p_{n'}^{regas*} - TC^{regas}(q_{n'}^{regas}) \tag{2.21}$$

subject to

$$q_{n'}^{regas} \leq CAP_{n'}^{REGAS}, \qquad (\gamma_{n'}^{REGAS} \geq 0), \qquad \forall n' \in N'(r) \tag{2.22}$$

2.3.4.2. FSU sub-model

Supplies to the domestic market

In the following, the modelling of gas supplies for consumption in Russia, Ukraine, Belarus and Moldova is discussed. Each of these markets (*f*) is served by the state-owned gas supplier, *t*. The supplier's main goal is to meet domestic demand, D_f, at the regulated price, P_f^{Reg}. The supplier t can do so by purchasing gas from indigenous production ($h_{tkn}^{T\leftarrow K}$) or by importing gas from Gazprom Export ($h_t^{T\leftarrow G}$), paying them the wellhead price ($p_{ktn}^{K\rightarrow T*}$) and border price ($bp_f^{G\rightarrow T*}$), respectively. Thus, the objective of the supplier is to maximize its profit (π_t^T):[53]

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[52] After solving the model, where appropriate the profit of the liquefaction operator is added to the overall profit of the producer who in reality owns the liquefaction facility. Since the liquefaction facility is priced competitively, this does not alter the results. Proof of this statement is in Appendix A.
[53] Note that since P_f^{REG} is exogenously fixed, (2.23) is equivalent to the cost minimization problem.

$$\max_{s_{tf}^{T},h_{tkn}^{T\leftarrow K},h_{t}^{T\leftarrow G}\geq 0}\pi_{t}^{T}=s_{tf}^{T}\left(P_{f}^{Reg}-DC_{f}\right)-\sum_{k\in K(t)}\sum_{n\in N(k)}h_{tkn}^{T\leftarrow K}p_{ktn}^{K\to T*}-h_{t}^{T\leftarrow G}bp_{f}^{G\to T*} \tag{2.23}$$

subject to

$$s_{tf}^{T}-D_{f}\left(P_{f}^{REG}\right)=0,\qquad \left(\alpha_{f}^{T}-free\right),\qquad \forall t\in T(f),f\in F \tag{2.24}$$

$$s_{tf}^{T}\leq\sum_{k\in K(t)}\sum_{n\in N(k)}h_{tkn}^{T\leftarrow K}+h_{t}^{T\leftarrow G},\qquad \left(\beta_{f}^{T}\geq 0\right),\qquad \forall t\in T(f),f\in F \tag{2.25}$$

Gas Production

The objective of a gas production company is to maximize its profit, π_k^K, (2.26) by deciding how much to produce (q_{kn}^K) from each region ($n \in N(k)$) and how much to sell to each supplier t and Gazprom Export (G). Producers sell gas at the wellhead prices (p_{ktn}^{K*} and $p_{kn}^{K\to G*}$); their sales should not exceed quantity produced (2.27) and their production should not exceed production capacity (2.28). The resultant maximization problem is as follows:

$$\max_{s_{ktn}^{K\to T},s_{kn}^{K\to G},q_{kn}^{K}\geq 0}\pi_{k}^{K}=\sum_{t\in T(k),n\in N(k)}s_{ktn}^{K\to T}p_{ktn}^{K\to T*}+\sum_{n\in N(k)}s_{kn}^{K\to G}p_{kn}^{K\to G*}-\sum_{n\in N(k)}TCP_{k}(q_{kn}^{K}) \tag{2.26}$$

subject to

$$\sum_{t\in T(k)}s_{ktn}^{K\to T}+\sum_{n\in N(k)}s_{kn}^{K\to G}\leq q_{kn}^{K},\qquad \left(\beta_{kn}^{K}\geq 0\right),\qquad \forall k\in K,n\in N(k) \tag{2.27}$$

$$q_{kn}^{K}\leq CAP_{kn}^{PR},\qquad \left(\gamma_{kn}^{K}\geq 0\right),\qquad \forall k\in K,n\in N(k) \tag{2.28}$$

Gazprom Export

The objective of Gazprom Export is to maximize its profit (π^G) from gas sales to the export market, *c,* through node n (s_{nc}^G) at the border price (bp_c), and from exporting to FSU markets f through node n ($s_{tnf}^{G\to T}$) at the border price $bp_f^{G\to T*}$. In order to export gas it has to purchase gas ($h_{kn}^{G\leftarrow K}$) at prices ($p_{kn}^{K\to G*}$) set by gas producers. Also, it has to transport gas to final markets ($x_{nn'}^G$), paying a transmission price ($tc_{nn'}^*$ including transit fees through Ukraine and Belarus). The resultant profit maximization problem for Gazprom Export is:

$$\max_{s_{nc}^{G}, s_{tnf}^{G}, h_{kn}^{G\leftarrow K}, x_{nn'}^{G}, xl_{nn'}^{G} \geq 0} \pi^{G}$$
$$= \sum_{n\in N(c)} \sum_{c\in C(G)} s_{nc}^{G} bp_c + \sum_{t\in T(G)} \sum_{n\in N(t), f\in F} s_{tnf}^{G\to T} bp_f^{G\to T*}$$
$$- \sum_{k\in K(G)} \sum_{n\in N(k} h_{kn}^{G\leftarrow K} p_{kn}^{K\to G*} - \left(\sum_{n\in N} \sum_{n'\in N'(n)} x_{nn'}^{G} tc_{nn'}^{*} \right. \tag{2.29}$$
$$\left. + \sum_{n\in N} \sum_{n'\in N'(n)} xl_{nn'}^{G} (p_n^{liq*} + SC_{nn'}^{G} + p_{n'}^{regas*}) \right)$$

subject to

$$s_{nc}^{G} + \sum_{t\in T(G)} s_{tnf}^{G\to T} + \sum_{n'\in N'(n)} \left[x_{nn'}^{G} + xl_{nn'}^{G} - \left(1 - loss_{n'n}^{pipe}\right) x_{n'n}^{G} - \left(1 - loss_{n'n}^{lng}\right) xl_{n'n}^{G} \right]$$
$$\leq \sum_{k\in K(G)} h_{kn}^{G\leftarrow K}, \qquad (\beta_n^G \geq 0), \qquad \forall n : n \in \left(N(G) \cup N(k)\right), c \in C(G) \tag{2.30}$$

Gazprom Export maximizes its profit (2.29) subject to flow conservation constraints (2.30).

Transit pricing through Ukraine and Belarus

The transit country maximizes its profit from rendering transit services to Gazprom Export as follows:

$$\max_{tf_{uu'} d_{uu'}^{TR} \geq 0} \pi^{TR} = \sum_{u,u'} [tf_{uu'} x_{uu'}^{G} + (d_{uu'}^{TR} p_{uu'}^{TR*} - TC_{uu'}^{TR}(d_{uu'}^{TR}))] \tag{2.31}$$

subject to

$$d_{uu'}^{TR} \leq CAP_{uu'}^{TR}, \qquad (\gamma_{uu'}^{TR} \geq 0), \qquad \forall u \in U, u' \in U'(u) \tag{2.32}$$

The first term ($tf_{uu'} x_{uu'}^{G}$) in the brackets is the revenue gained due to the exercise of market power, while the second term is the profit under efficient transit pricing (similarly to the efficient TSO model (2.17-2.18)), where $p_{uu'}^{TR*}$ is the congestion premium determined by market clearing conditions (2.41).

2.3.4.3. Market-Clearing Conditions

In this section all the market clearing conditions that are needed to equate demand with supply are gathered. The following market clearing constraints (2.33) require that the average final price matches the inverse demand function at the equilibrium point:

$$p_c^* - \left(B_c + A_c \sum_{j \in J, y \in Y, n \in N(c)} s_{jync}^Y \right) = 0, \qquad \forall c \in C \tag{2.33}$$

and the following market clearing conditions (2.34) define the effective border price (as derived in Section 2.3.4.1.: "Supplier Model") :

$$bp_c^* - \left(\hat{B}_c + \hat{A}_c \sum_{j \in J, n \in N(c)} s_{jnc} \right) = 0, \qquad \forall c \in C \tag{2.34}$$

Market clearing conditions (2.35) equate demand for transmission services through pipelines *(n,n')* with TSO's supplying of such services:

$$d_{nn'}^{TSO} - \sum_{i \in I} x_{inn'}^I - x_{nn'}^G = 0, \qquad (tc_{nn'}^* - \ free), \qquad \forall n \in N \backslash U, n' \in N'(n) \tag{2.35}$$

The market clearing conditions necessary to equate supply and demand for liquefaction services are as follows:

$$q_n^{liq} - \sum_{n' \in N'(r)} \left[\sum_{i \in I(l)} xl_{inn'}^I + xl_{nn'}^G \right] = 0, \qquad \left(p_n^{liq*} - free\right), \qquad \forall n, \in N(l) \tag{2.36}$$

and the market clearing constraints below ensure that demand for regasification service equals supplies:

$$q_{n'}^{regas} - \sum_{n \in N(l)} \left[\sum_{i \in I(r)} xl_{inn'}^{I} + xl_{nn'}^{G} \right] = 0 \qquad (p_{n'}^{regas*} - free), \qquad \forall n' \in N'(r) \quad (2.37)$$

The wellhead prices that producer k receives are obtained from the market-clearing conditions that balance supply and demand for gas:

$$s_{ktn}^{K\to T} - h_{tkn}^{T\leftarrow K} = 0, \qquad (p_{ktn}^{K\to T*} - free), \qquad \forall k \in K(t), t \in T(k), n \in N(k) \quad (2.38)$$

$$s_{kn}^{K\to G} - h_{kn}^{G\leftarrow K} = 0, \qquad (p_{kn}^{K\to G*} - free), \qquad \forall k \in K(G), n \in N(k) \quad (2.39)$$

The market clearing conditions that ensure that the total purchases ($h_t^{T\leftarrow G}$) by supplier t from Gazprom Export are equal to the total sales by Gazprom Export ($\sum_n s_{tnf}^{G\to T}$) to that supplier through the border points (*n*∈*N(t)*) are as follows:

$$\sum_n s_{tnf}^{G\to T} - h_t^{T\leftarrow G} = 0, \qquad (bp_t^{G\to T*} - free), \qquad \forall t \in T(G), f \in F \quad (2.40)$$

The congestion premium ($p_{uu'}^{*}$) through transit pipelines *(u,u')* is defined through the market-clearing conditions that ensure that the transit quantity demanded by Gazprom Export ($x_{uu'}^{G}$) through pipelines *(u,u')* equals the transit capacity supply ($d_{uu'}^{TR}$):

$$d_{uu'}^{TR} - x_{uu'}^{G} = 0 \qquad (p_{uu'}^{TR*} - free), \qquad \forall u \in U, u' \in U'(u) \quad (2.41)$$

Gathering all the KKT conditions and market clearing constraints presented above forms the MCP, which is coded in GAMS and solved with PATH solver. Since the objective functions of the maximization problems of market participants are concave and the associated constraints are convex, the solution to the MCP is a simultaneously global optimum to all the individual maximization problems in the model. Thus, the solution to the MCP is also a Nash equilibrium of the market game implemented in this model.

The model contains 25 gas markets from Western, Central and Eastern Europe and from the FSU and 27 producing regions (see Appendix E: Tables E.1 and E.2). The scale of the model is large in terms of the number of equations (1223 in total). The model is solved quite efficiently using the PATH solver and it takes about 2.5 minutes in total to solve the model with a time horizon of 22 years (2009-2030) on a computer with 1.8GHz clock speed with 2GB of RAM.

2.4. Model Validation and Results from Sensitivity Analysis

A validation of the model has been performed as follows. First, the model's results were verified to confirm that all the constraints, such as production, pipeline and LNG capacities, as well as energy balances at each node, are satisfied by the solutions. Secondly, the numerical results produced by the model have been compared with real market data for the years 2008 and 2009 (see Appendix I, Tables I.1a, I.1b and I.2).

Comparison of the model with historical data shows that in general the model's results are in line with actual market outcomes for the years 2008 and 2009. In particular, model validation with 2008-2009 data shows that among three assumptions on market structure, namely (*i*) double marginalization (producers and traders exert market power in sequence), (*ii*) upstream oligopoly (only producers exert market power), and (*iii*) perfect competition, the upstream oligopoly market assumption produces results that are closer to the observed market data (price and consumption) than the results under the other two market assumptions. The double marginalization assumption produces much higher final prices and lower quantities than the other solutions. This is generally in line with the theory of double marginalization (Spengler, 1950). Furthermore, these prices are much higher (and quantities much lower) than in reality, consistent with Smeers' (2008) observation that double marginalisation is an inappropriate characterization for European gas markets. On the other hand, the perfect competition assumption inflates final gas consumption quite substantially compared to real market data. Consequently, the average final prices in European markets are much lower than the observed real prices. Therefore, motivated by these results, the upstream oligopoly market structure was selected for the Base case scenario.

It should be noted that there is one common feature in the three market power scenarios - diversity of the gas sources for particular markets plays a crucial role in determining prices and consumption. Less diverse countries in terms of supply sources always suffer higher prices and lower consumption compared to the prices and consumption of those countries that have more diversified supply sources. In contrast, countries with a diverse supply portfolio enjoy lower prices and higher consumption than would be the case otherwise. In general, this observation is line with economic intuition regarding market power and competition. Therefore, the model behaves in a predictable way which is in line with fundamental economic intuition and theory.

Sensitivity analyses (see Appendix I, Tables I.3 and I.4) show that the model's results are fairly robust in terms of major structural assumptions. Particularly, the Base Case solution was tested against ten alternative scenarios of structural assumptions (such as the elasticity of demand parameter, gas demand growth, production, pipeline, LNG import and export capacities) (see Appendix I, Box I.1). The sensitivity results are reported in terms of a robustness index that describes the responsiveness of the model output to a change in input parameters in a manner analogous to the elasticity concept (see Appendix I, eq. [I.1]). As a result, among these alternative assumptions the most critical input parameters appear to be (in order of importance): (*i*) the production capacities of the two largest producers in the model – Russia and Norway, and (*ii*) the elasticity of demand.

Moreover, the direction of changes in input parameters matters. Thus, a <u>decrease</u> in the production capacities of Russia and Norway is very critical to the model's results (prices, consumption, profits and welfare), whereas an <u>increase</u> in production capacities of these two countries has little effect on the model's outputs. Similarly, a decrease in the elasticity of the demand parameter is more critical to the model's results than an increase. In general, a one percentage point (p.p.) decrease in the production forecast of Russia and Norway relative to the Base Case forecast changes the final prices by more than 0.5 p.p. for most of the countries in this model (with a few countries seeing changes in prices of more than 1 p.p.), whereas a 1 p.p. decrease in the elasticity parameter produces an average increase in final prices of 0.37 p.p.

It should be noted that, contrary to our expectation, variations in pipeline capacities (cross-border) have only a marginal impact on the model's results. For example, a 1 p.p. decrease in cross-border pipeline capacities relative to the Base Case assumption increases final prices by an average of 0.04 p.p. and decreases model-wide consumption by 0.03 p.p. compared to the Base Case solution (see Appendix I, Tables I.3 and I.4). Similar sensitivity results were obtained regarding the LNG import/export capacities. Therefore, although the assumption of efficient pricing of access to and congestion in infrastructure capacities in this model diverges from the European market reality, these results indicate that these assumptions might not drastically bias the model results.

In general, changes in other inputs (e.g., demand forecast) have very little effect on the model's results – a 1 p.p. change in all other input parameters only changes the model results by 0-0.2 p.p.

Finally, sensitivity scenarios (see Appendix I, Box I.2) were run to check the robustness of the model's results against different assumptions about the conjectured transit demand slope, *M*. The results show that different assumptions about the transit conjecture parameter only substantially affect the profits of transit countries (see Appendix I, Table I.5). However, in general, different conjectured transit demand slopes only slightly modify the model results (such as final prices and consumption) - within a range of 1% from the Base Case results.

2.5. Results

2.5.1. Base Case Results

Figure 2.4 reports natural gas consumption by sources obtained from the Base Case solution (the reported gas consumption includes all countries as reported in Appendix E: Table E.1 except for the FSU countries).

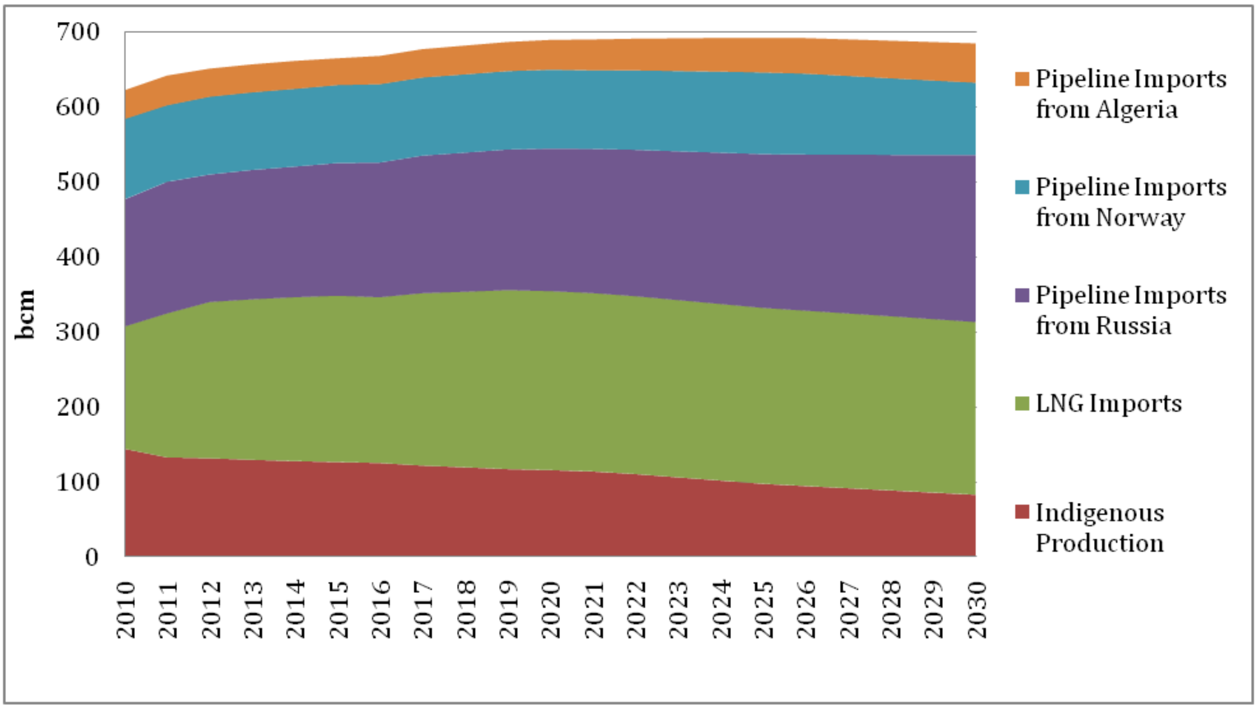

Figure 2.4: Breakdown of Gas Consumption by Sources for European Countries

In this scenario, total gas consumption in Europe will increase from 622 bcm in 2010 to 685 bcm by 2030 (+0.5% CAGR). The increase in gas consumption in Europe will be increasingly met with external gas supplies. Gas imports through pipelines from Russia, Norway and Algeria will total 371 bcm in 2030 (+0.6% CAGR from 2010). LNG will import a total of 230 bcm in 2030 or 34% of total consumption (in 2010 LNG imports constitute 26% of total European gas consumption). Indigenous gas production in Europe will decline steadily through to 2030 (-2.8% CAGR) and total 83 bcm.

It should be noted that total gas consumption in Europe peaks in 2025 (Figure 2.4) at the level of 692 bcm and declines to 685 bcm in 2030. This is because the model does not include investment decisions concerning production and transport infrastructure; therefore gas supplies at the end of the modelling period (2025-2030) are rather limited and constrain the growth in natural gas consumption.

The development in final gas prices obtained from the Base Case solution differs slightly between regions (Figure 2.5). Natural gas prices may differ substantially among countries due to both the geography of production and consumption (such as transport costs involved in delivering gas from producers to consumers) and market structures (such as competition between gas producers).

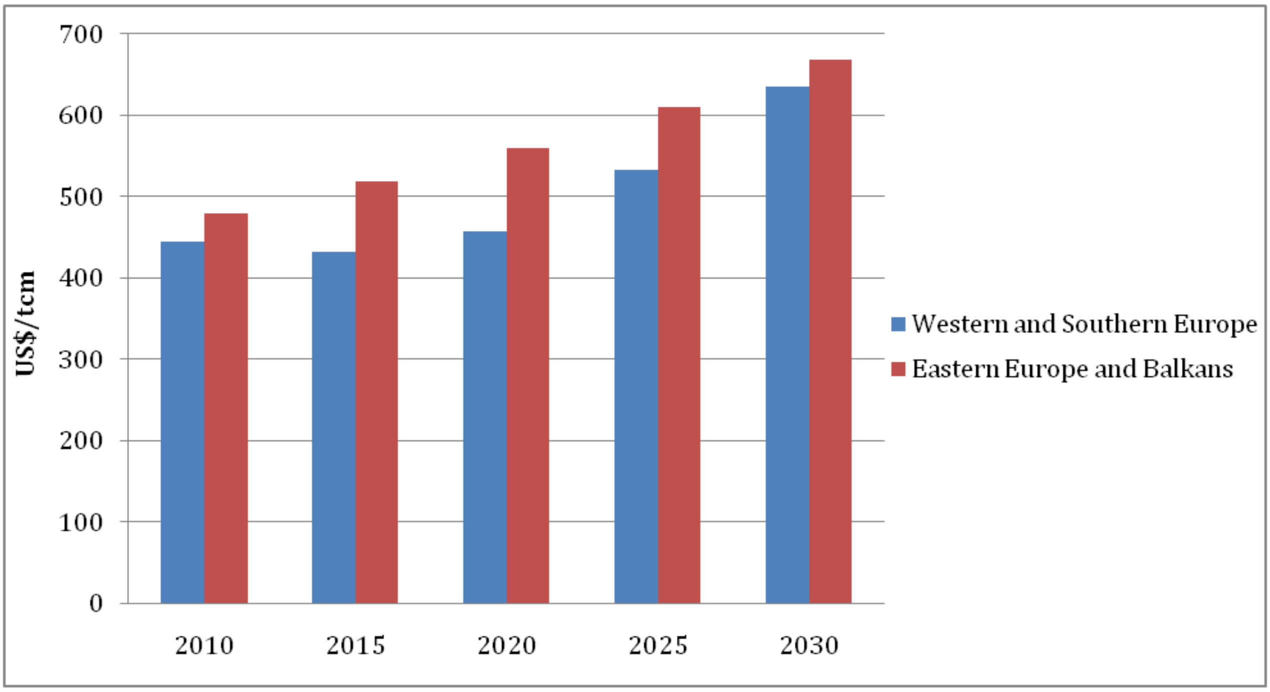

Figure 2.5: Dynamics of Average Final Prices

Further, gas prices among countries of the EU might differ by more than the (marginal) costs of transportation between these countries due to the absence of arbitrage in the model. Therefore, due to the lack of upstream gas competition, the final (quantity-weighted) average price for Eastern Europe and Balkans is 16% higher, on average, than the gas price for Western and Southern Europe. Moreover, Western and Southern European gas prices see a slight decrease between 2010 and 2015 due to increased LNG regasification and the new pipeline capacities to be commissioned during this period. In general, the (quantity-weighted) average prices of the two regions increases at a CAGR of around 1.7% through to 2030.

Figure 2.6 shows the Base Case result for Russian natural gas exports to Europe through different transit routes (for details of current Russian gas export routes see Appendix L: Table L.1). In the Base Case (Figure 2.6) it is assumed that Russia's bypass pipelines, Nord Stream and South Stream, come online gradually (Nord Stream and South Stream are assumed to be fully operational in 2012 and 2017 respectively). It can be seen from Figure 2.6 that once these two projects are built Russian gas transits through Ukraine will be diverted to these two projects. Total transit through Ukraine in 2017 (after South Stream's operation) reduces to 22 bcm, versus 128 bcm in 2011. Therefore, once the bypass projects are built Ukraine's role as a transit country becomes marginal and Gazprom only uses Ukraine's transit system to transport some gas to Moldova, Poland, Slovakia and Romania, i.e. to those markets where it is assumed that gas cannot be reached with bypass pipelines. On the other hand, it can be seen from Figure 2.6 that there is no impact from bypass pipelines on transit flows through the Belarusian section of the Yamal-Europe pipeline.

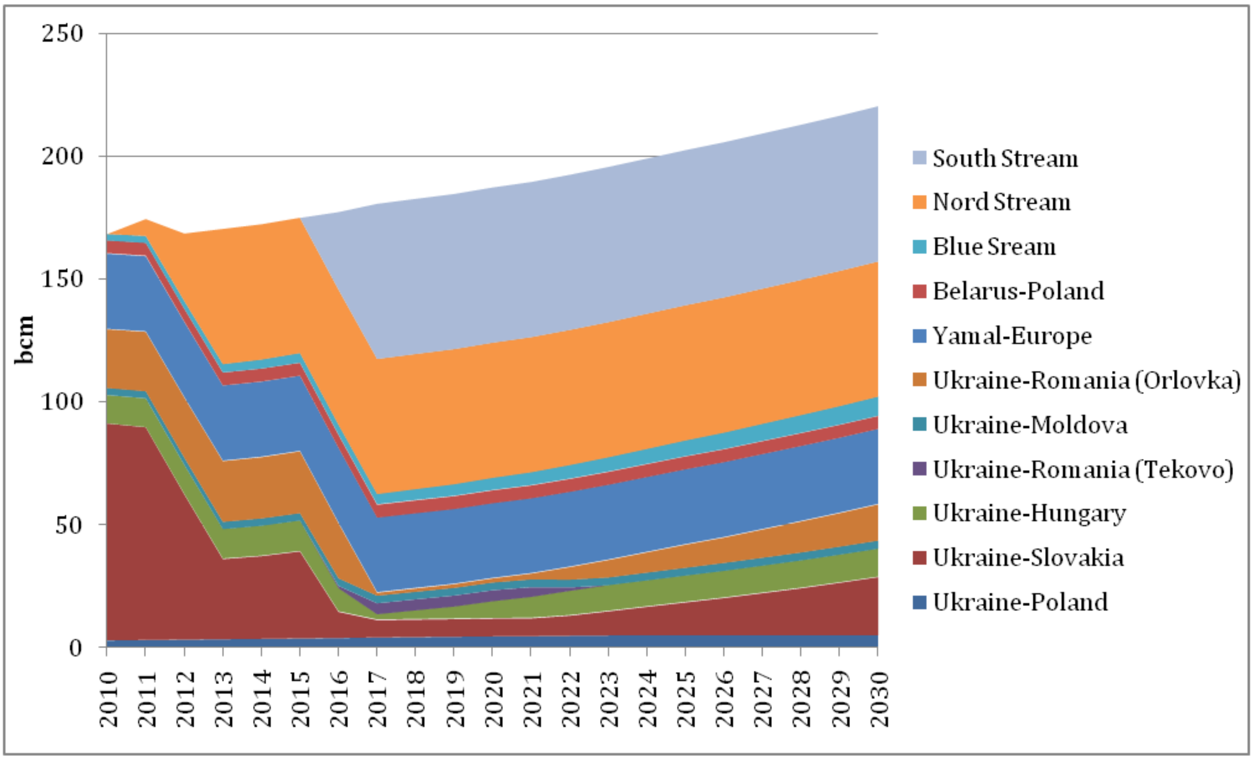

Figure 2.6: Russian Gas Exports by Pipelines

2.5.2. Investment in Nord Stream, Market Power and Social Welfare

The aim of this section is to show the model's capability by analysing the effects of different market structures on changes in social welfare resulting from Nord Stream investment. Specifically, answers to the following questions are sought:

(i) How do perfect and imperfect competition models differ in their evaluation of the Nord Stream gas pipeline project (and why)?

(ii) If transit countries (Ukraine and Belarus) exert substantial market power against Gazprom, would consumers and producers (particularly Gazprom) be better off if Nord Stream is built?

For this analysis, Base Case data are assumed (as outlined in Appendix E). However, it is assumed that South Stream is not built. This assumption is required to focus solely on Nord Stream evaluation (note that in the Base Case scenario both the Nord Stream and South Stream pipelines are built).[54] Table 2.1 reports the market power scenarios analysed here.

Table 2.1: Market Power Scenarios

	Successive market power	Double marginalization	Upstream oligopoly	Perfect Competition
Cournot Producers	√	√	√	
Cournot Traders	√	√		
Transit market power	√			

When transit countries are assumed not to exert market power (double marginalization. upstream oligopoly and perfect competition cases), their transit fees are exogenously fixed at 2010 levels (for details of the transit fees through Ukraine and Belarus see Appendix E: Tables E.11 and E.12). However, in the successive market power scenario it is assumed that, apart from producers and traders, transit countries also behave imperfectly. In this scenario, transit market power is represented with the conjectured transit demand function. The application of this function requires the specification of the slope M_{uu}, of the conjectured transit demand curve. This slope can be interpreted as the transit country's belief about Gazprom's ability (measured as a fraction of existing transit capacities) to divert gas from transit pipelines if the transit fee is raised by some amount (e.g., by US$ 1/tcm):

[54] Investment in South Stream and its interactions with Nord Stream will be analysed in a forthcoming paper.

$$M_{uu'} = -F \times CAP_{uu'}^{TR} \tag{2.42}$$

where $CAP_{uu'}^{TR}$ is the capacity of the transit pipeline *(u,u')* and F is a percentage number (details of transit pipeline capacities are documented in Appendix E, Table E.3). For the purpose of this analysis, an arbitrary small F (1%) was chosen, which results in a rather small conjectured slope.[55] This small conjectured transit slope was chosen to simulate the hypothetical case of transit countries believing they have substantial market power vis-a-vis Gazprom.[56] A sensitivity analysis with alternative assumptions about the conjectured transit demand slope is presented in Appendix I.

For the analysis of Nord Stream investment, data on the costs of the pipeline project and corresponding transport costs are required. The methodology and data used for costing the Nord Stream system are discussed in Appendices G and H. The results of the estimation of transport costs through the Nord Stream system are in Appendix E: Table E.9.

The basic criterion used to evaluate the Nord Stream investment is the change in market efficiency or social welfare, ΔSW, defined as:

$$\Delta SW = SW^{NS} - SW^{No\ NS} \tag{2.43}$$

$$\begin{aligned} SW = {} & Gazprom\ Profit + Transit\ Profit + Producer\ Profit + Trader\ Profit \\ & + Consumer\ Surplus \end{aligned} \tag{2.44}$$

where SW^{NS} is the social welfare when Nord Stream is built; $SW^{No\ NS}$ is the social welfare if the Nord Stream system is not built; *Gazprom Profit* is its total profit from exporting gas overseas (for a list of the gas markets in the model see Appendix E: Table E.1); *Transit Profit* is the sum of the profits of the transit countries (Ukraine and Belarus) from transporting Russian gas to Europe; *Producer Profit* is the sum of the profits of all the producers in the model, excluding Gazprom's profit (for a list of all the producers in the model see Appendix E: Table E.2); *Trader Profit* is the sum of the profits of all the

[55] For example, the existing transit capacity through Ukraine to Western Europe (i.e., Ukraine-Slovak border) is 92.6 bcm/y; thus, the result of applying F=1% is a conjectured slope of M=-0.926. This conjectured slope expresses Ukraine's belief (not necessarily correct) that an increase in transit fees might force Gazprom to divert gas from Ukraine by up to 0.926 bcm/y (if this proves more efficient for Gazprom).

[56] This case was more realistic during the 1990s and early 2000s, when Gazprom had no alternative export routes other than using Ukrainian and Belarusian pipelines to export gas to Europe.

traders from supplying gas to a particular market and *Consumer Surplus* is calculated for all the markets in the model. Thus, the analysis of the impact of Nord Stream investment on society includes all the markets and players in the model.

Table 2.2 summarizes the annualized changes in profits and welfare (*ΔSW*) resulting from investment in Nord Stream relative to the scenario of "no" Nord Stream investment. The annualized changes were calculated at a 10% discount rate over the next 25 years. It should be noted that the discount rate of 10% is often used to evaluate private investment projects; however, this value might be quite high for the analysis of investment projects from a social perspective (i.e., the discount rate applied for a social cost-benefit analysis might be substantially lower than 10%).[57] Thus, a sensitivity analysis of the effects of Nord Stream investment on social welfare with respect to different discount rates is also provided in Appendix D: Table D.1.

As can be seen, different assumptions about market structures affect the evaluation of Nord Stream quite substantially.

Table 2.2: Annualized Net Gains (Losses) Resulting from Investment in Nord Stream (US$ bn/year)

	Successive market power	**Double Marginalization**	**Upstream Oligopoly**	**Perfect Competition**
Gazprom Profit	1.99	1.26	2.67	-4.97
Profit of Transit Countries	-0.87	-0.47	-0.68	0.00
Profit of other producers	-6.13	-5.06	-8.80	-41.59
Trader Profit	2.56	2.29	0.00	0.00
Consumer Surplus	4.22	3.44	10.67	59.84
Social Welfare	1.77	1.47	3.86	13.28

Impact on Gazprom and transit countries

Among the market power scenarios analysed, the annualized value of the Nord Stream system to Gazprom is highest (US$ 2.67 bn/y) when only producers behave strategically (the upstream oligopoly scenario), while traders and transit countries are assumed to be competitive. Thus, Gazprom (and other producers) enjoys higher profit from selling gas directly to final customers (traders are competitive) than under the Double Marginalization case. Higher margins on gas sales due to supplies at final prices lead to a larger positive impact on Gazprom's profit from Nord Stream investment.

[57] For example, in its guide to making a cost benefit analysis, the European Commission (EC, 2008c) suggests a benchmark value of 3.5%-5.5% for a social discount rate applied to the appraisal of investment projects.

On the other hand, if traders behave strategically (the double marginalization scenario) then the impact of Nord Stream on Gazprom's annualized profits is positive but rather modest: US$ 1.26 bn/y, or about 47% of Gazprom's annualized profits in the upstream oligopoly case. Strategic behaviour by traders lowers gas sales for final consumption, and thus modifies both final and border prices and, consequently, the margin they earn. Therefore, when traders behave strategically the border prices that Gazprom and other producers receive are smaller than the final prices (see Table 2.3); thus, the lower margins on gas sales mean that the expanded sales that Nord Stream makes possible have less of an impact on Gazprom's profitability.

Finally, in the case of perfect competition, investment in Nord Stream negatively impacts Gazprom's profits (US$ -4.97 bn/y) because of non-strategic behaviour by producers who see border prices as fixed and sell gas until the marginal cost equals the border price. Thus, by having invested in Nord Stream, Gazprom exports more gas than it would have otherwise and so border prices decrease (because of inverse demand functions) and so does its profitability. In a sense, under perfect competition, not investing in Nord Stream would have the inadvertent effect of an oligopolistic-like restriction of supply, which would increase Gazprom's profits relative to the Nord Stream case.

Table 2.3: Average Annual Consumption and Prices in Europe: 2010-2030 [Export and Consumption in bcm; Final and border prices in US$/tcm]

		Successive market power	**Double Marginalization**	**Upstream Oligopoly**	**Perfect Competition**
Russian gas export to Europe	A	127	127	190	252
	B	117	119	177	206
Consumption in Europe	A	545	546	673	761
	B	541	543	662	715
Russia market share in Europe	A	23%	23%	28%	33%
	B	22%	22%	27%	29%
Average border prices[a]	A	395	394	487	350
	B	404	402	506	429
Average final prices[a]	A	713	712	499	362
	B	720	718	518	441

Note: [a] quantity-weighted average; NS – Nord Stream; A – Nord Stream is built; B – Nord Stream is not built

If transit countries exert market power (the successive market power scenario), then investment in Nord Stream increases Gazprom's annualized profit by US$ 1.99 bn/y, which is 25% lower than in the case of an upstream oligopoly and about 60%

higher than in the case of double marginalization. Once Nord Stream is built, the transit fees through Ukraine and Belarus will drop (Figure 2.7). This decrease in transit fees is due to lower transit flows through their pipelines (gas flows are diverted to the Nord Stream system). Since transit market power is modelled using a conjectured transit demand function (with an assumed negative slope), lower transit flows reduce transit fees.

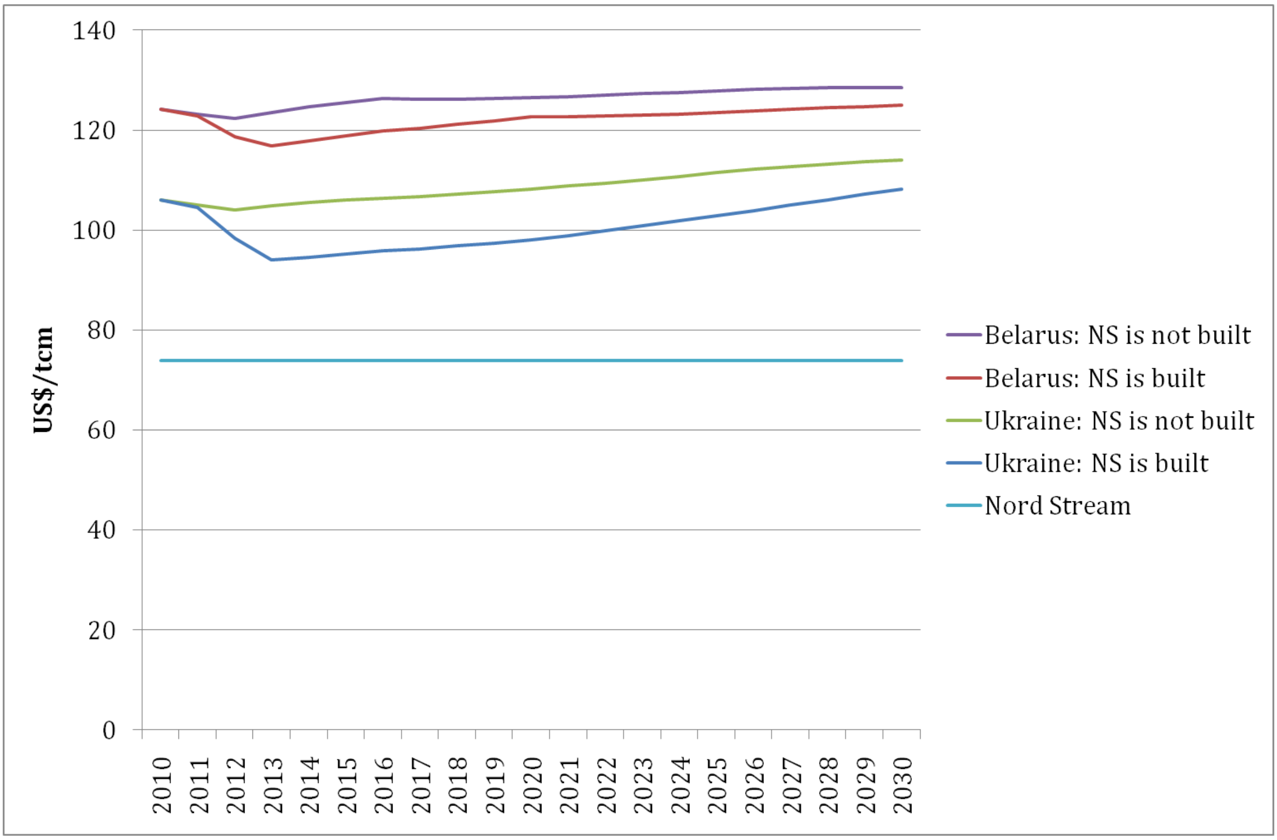

Figure 2.7: Transit fees through Ukraine and Belarus under the Market Power Scenario[58]

Note: the Belarusian route in this figure is the Northern Light pipeline system, not the Yamal-Europe pipeline which is owned by Gazprom; NS- Nord Stream

In general, it has been found that Russian gas will become more competitive with the building of Nord Stream due to lower transportation costs (see Figures 2.7 and 2.8) and the expected change in the geography of gas production in Russia.[59] The expected transition from the traditional fields towards the Yamal peninsula and possibly the

[58] The reported costs are for transporting gas from Gazprom's current production region (Urengoi) to the German-Czech border (Olbernhau). The reported transit fees through Ukraine and Belarus are averages (quantity-weighted).

[59] Traditional super-giant gas fields (such as Urengoi, Medvezhie, Zapolyarnoe) in Russia are in steep decline and there is an urgent need for Gazprom to develop new a generation of super-giant fields on the Yamal peninsula and the Shtokman field to fulfil its domestic and export obligations; see, for example, (Stern, 2005; Victor, 2008; Noël, 2009; Stern, 2009b) for an informed discussion of future gas production in Russia.

Shtokman field makes the Nord Stream project more competitive (by exploiting shorter routes) than the Ukrainian route and the Belarusian Northern Light pipeline system (Figure 2.8). Indeed, the model shows that over the next 20 years, on average, only about 25% of gas exports through Nord Stream would come from existing fields (fields in operation in Nadym-Pur-Taz (NPT) region), while 50% would come from the Yamal Peninsula and about 25% from the Shtokman field in the Barents Sea (after 2020) (Figure 2.9) (see Appendix E, Table E.2 for the assumptions about production capacities in Russia).

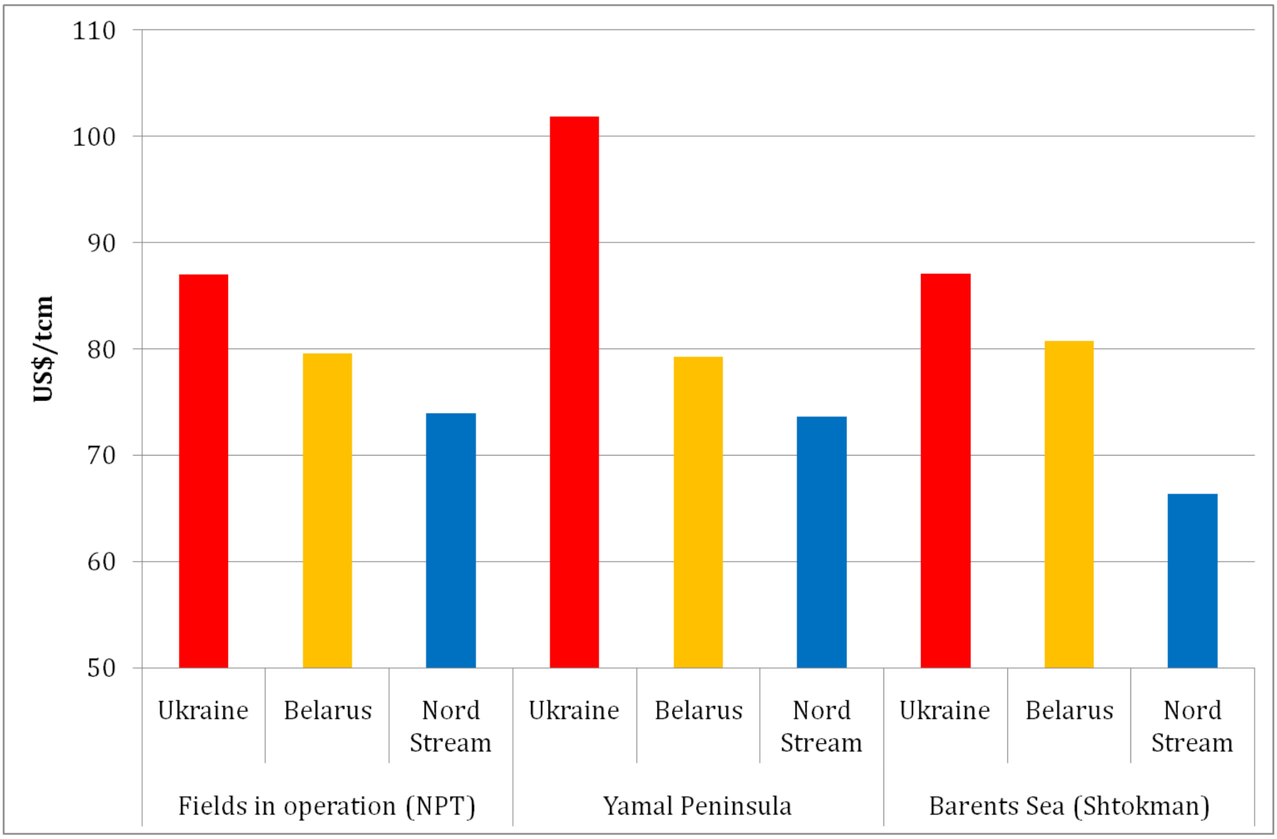

Figure 2.8: Transportation Costs from Russia to Germany
Note: the Belarusian route in this figure is the Northern Light pipeline system, not the Yamal-Europe pipeline which is owned by Gazprom. The final delivery point for the Ukrainian and Belarusian Northern Light routes is the German-Czech Border (Olbernhau). The final delivery point for the Nord Stream route is Greifswald, Germany (the end point of the offshore Nord Stream).

Thus, investment in Nord Stream is attractive and allows Gazprom to gain greater market shares in European markets (see Table 2.3). The expansion of Russian gas in Europe is due to both increased consumption and gaining a greater market share at the expense of other producers. As Nord Stream becomes operational, (quantity-weighted) average final prices in Europe will decrease slightly compared to the case of there being "no" Nord Stream (see Table 2.3); as the result, total consumption in Europe will also increase.

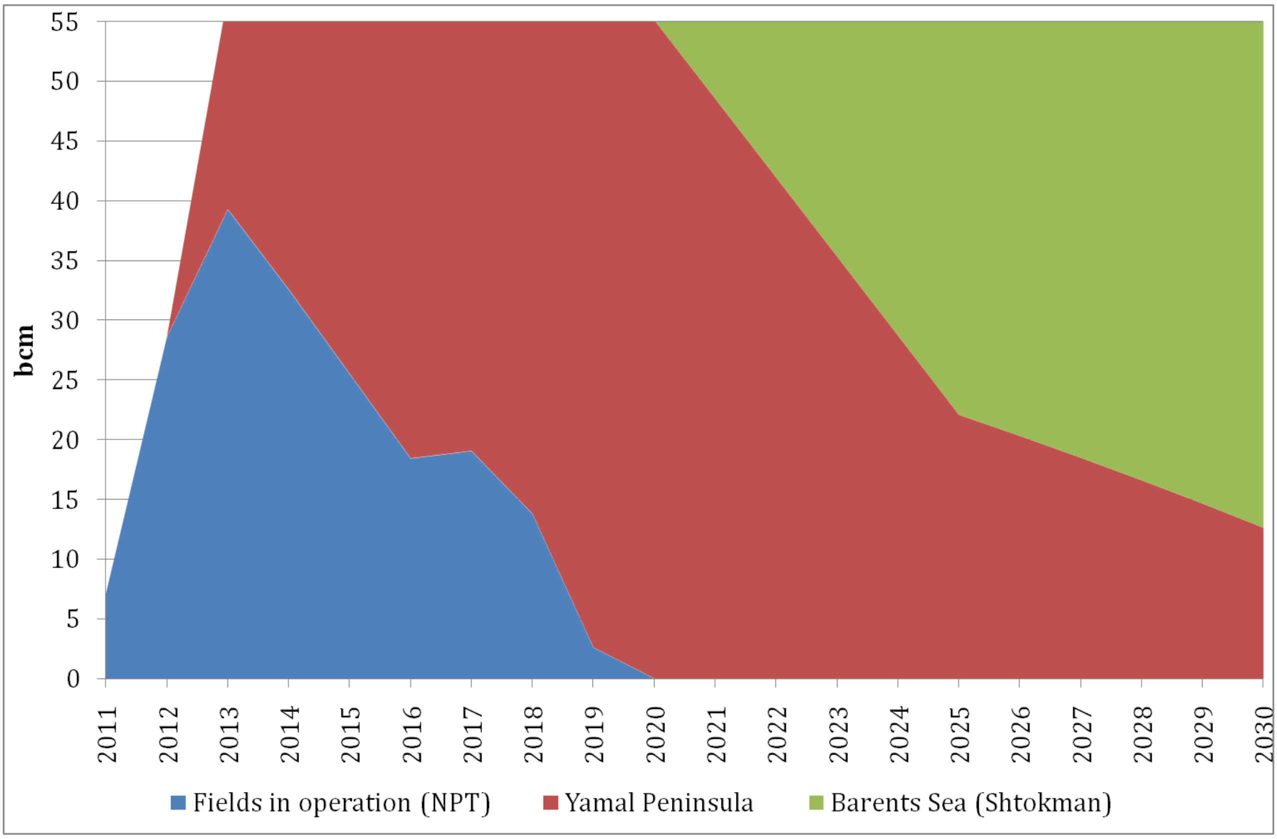

Figure 2.9: Gas Exports through the Nord Stream Pipeline

As one would expect, Nord Stream has a negative impact on the profits of transit countries in all market power scenarios. As discussed above, compared to the Ukrainian route and the Northern Light pipeline system, the Nord Stream pipeline is a cheaper option for carrying Russian gas to Western European markets (Figure 2.8). This is the major economic reason why Gazprom diverts gas away from the Ukrainian transit system and from the Belarusian Northern Light system, and consequently reduces their profits. However, in the perfect competition scenario there is no impact from Nord Stream on transit flows (and consequently profits) through Ukraine and Belarus because, in this scenario, demand in Europe is substantially higher due to marginal cost pricing by producers and traders. Thus, the Nord Stream project provides additional net export capacity to Europe.

Impact on other market participants

In general, it is found that Nord Stream has a negative impact on the profitability of all other producers supplying gas to European markets. With a cheaper transport option

(Nord Stream), Russian gas gains a greater market share than if there was "no" Nord Stream (see Table 2.3), and consequently the market share and profit of all other producers fall.

By definition, traders' total economic profits are zero when they behave competitively (perfect competition and upstream oligopoly scenarios). Traders' profits are strictly positive only when they can modify final and border prices (and consequently their profits) by strategically "withholding" sales to consumers (successive market power and double marginalization scenarios). In this scenario, Nord Stream investment positively affects the profitability of all traders (Table 2.2).

In general, the results show that consumers benefit from investment in Nord Stream in all market power scenarios. Further, the higher the competition among producers and traders, the higher is the benefit of Nord Stream to European consumers. In a perfectly competitive gas world, the benefit of Nord Stream to consumers is almost six times higher than in a scenario where producers behave imperfectly (upstream oligopoly). In the case of double marginalization, the benefits of Nord Stream to consumers are quite limited (the benefits are US$ 3.4 bn/year) compared to the other market power scenarios.

Nord Stream's potential impact on overall market efficiency

Figure 2.10 summarizes the findings discussed above. It shows the cumulative effect of Nord Stream investment on social welfare under different market power scenarios. The numbers above bars (Figure 2.10) are annualized changes (increments) in social welfare valued at a 10% discount rate over 25 years (US$ bn/y). For example, under the Double Marginalization case, the impact of Nord Stream investment on social welfare is US$ 1.5 bn/y. Further, if transit countries exerted market power vis-à-vis Gazprom (the Successive Market Power scenario), then the construction of Nord Stream would add US$ 1.8 bn per year (i.e., US$ 1.5 bn plus US$ 0.3 bn) to social welfare. Therefore, the sum of all the numbers in Figure 2.10 gives the maximum possible impact of Nord Stream on social welfare, i.e. US$ +13.3 bn/y (under the Perfect Competition scenario). Most of these gains are driven by the benefits of Nord Stream investment to consumers (see Table 2.2).

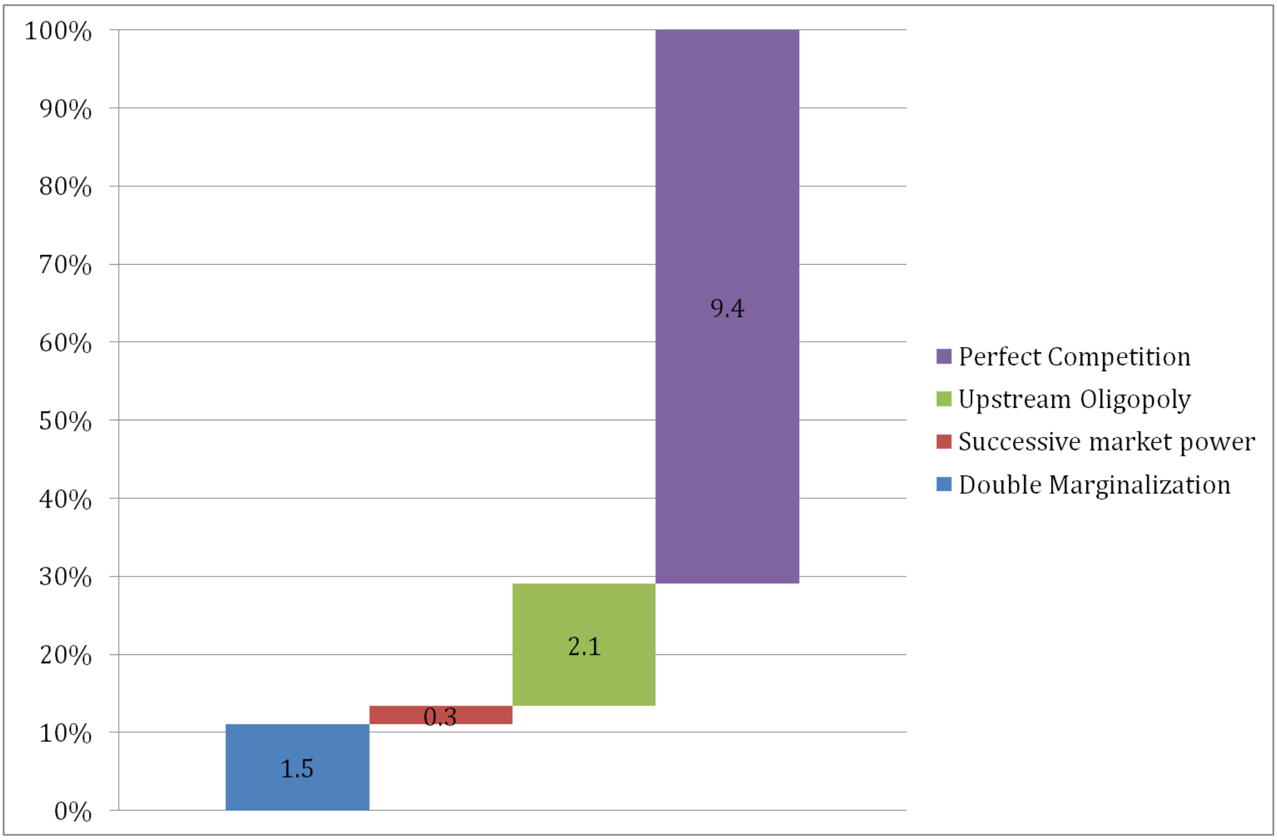

Figure 2.10: The Incremental Impact of Nord Stream Investment on Social Welfare

Figure 2.10 also shows (the vertical axis) the net benefits of Nord Stream investment relative to the benchmark case – the perfect competition scenario in which the net benefit of Nord Stream to society is highest: US$ +13.3 bn/y. Accordingly, the net benefit of Nord Stream to society under the double marginalization case is about 11% of the net benefit under the perfect competition case (US$ 1.5/13.3 bn). Further, the market power of transit countries adds another 2% on top of the 11%, and therefore under the Successive Market Power scenario the net benefit of Nord Stream to society is 13% of the maximum possible value. If traders were competitive (the Upstream Oligopoly scenario), then the net benefit of Nord Stream would increase by another US$ 2.1 bn/y on top of the US$ 1.8 bn/y under the Successive Market Power case. Thus, if only producers behave imperfectly the net benefit of Nord Stream to society is about 30% of the benchmark value.

In general, investment in Nord Stream has a positive impact on social welfare in all analysed market power scenarios. The higher the competition between market participants, the larger is the benefit of Nord Stream investment to society. However, in the perfect competition scenario the impact of Nord Stream investment on Gazprom's profit is negative (US$ -4.97 bn/y) (Figure 2.11). As discussed above, this is due to marginal cost pricing. Gazprom's additional sales through Nord Stream would depress prices, and consequently its profit, substantially compared to the Perfect Competition case without Nord Stream investment. It was found that only in cases of imperfect competition is the economic value of Nord Stream investment to Gazprom positive (Figure 2.11). Strategic behaviour motivates Gazprom not to oversupply the market when Nord Stream is built, and therefore it retains part of the net benefit which, under marginal cost pricing (Perfect Competition), would go entirely to consumers.

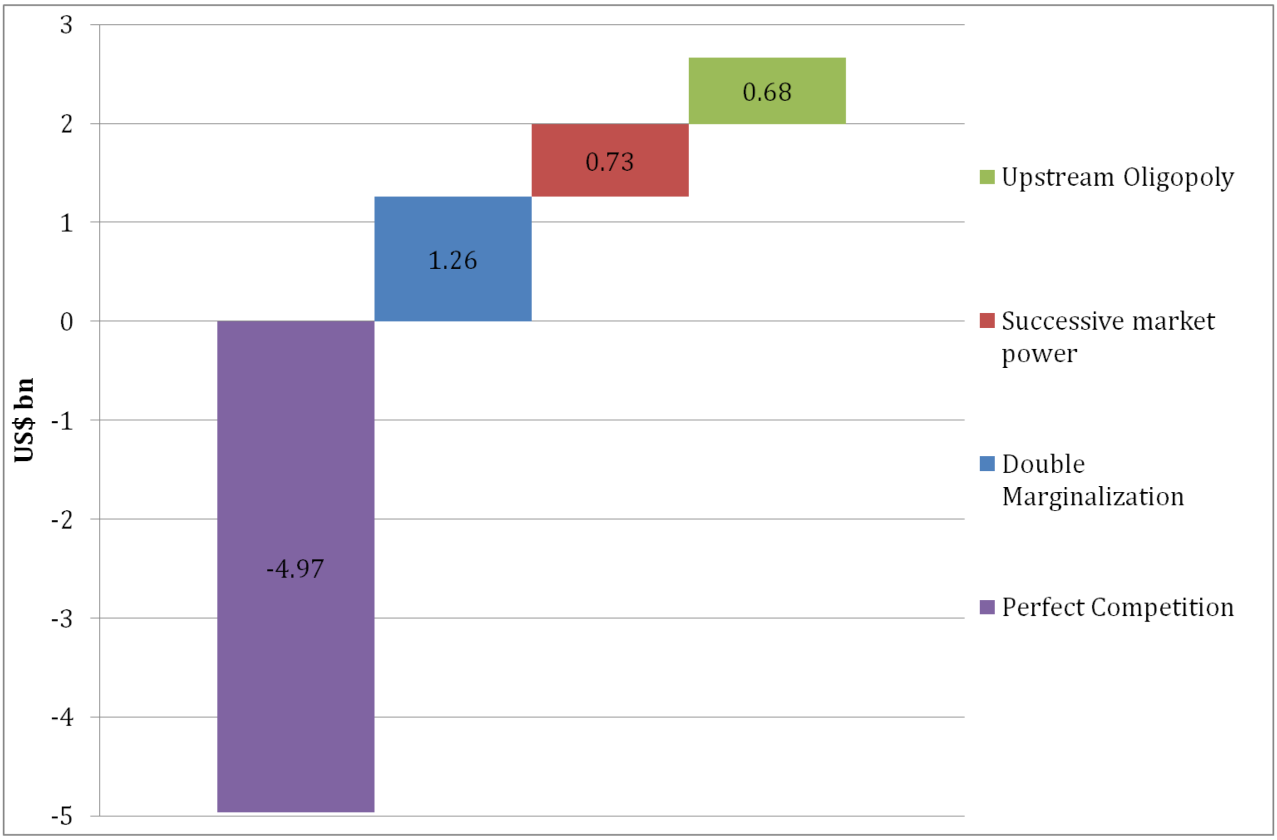

Figure 2.11: The impact of Nord Stream Investment on Gazprom's Profit

It is also interesting to note that when there is transit country market power Nord Stream investment is far more important for Gazprom than it is for society as a whole. When transit countries exert market power, investment in Nord Stream adds as much as 58% of the potential additional profits to Gazprom (US$ bn 0.73/1.26, Figure 2.11) under the Double Marginalization case, whereas it only adds some 20% to society (US$ bn 0.3/1.5, Figure 2.10).

2.6. Conclusions

In this paper the mathematical formulation of the equilibrium gas simulation model was presented. This model is different from previous gas models in its detailed presentation of the FSU gas sector. The inclusion of details of the FSU gas sector in the large-scale gas simulation model was mainly motivated by the analysis of policy questions related to the anticipated structural changes in gas exports from the FSU region to the European markets (such as route diversification by Russia), and the possible impact of these changes on European gas markets and participants.

The model was demonstrated by analysing a Base Case scenario of European gas market development (2010-2030) in which only producers may exert market power while all other market participants are assumed to be price-takers. In the Base Case scenario it was also assumed that Russia's bypass projects, Nord Stream and South Stream, would be built according to Gazprom's plan. Findings from the Base Case scenario suggest, among other things, that in light of the decline in indigenous gas production in Europe, the role of Russian gas is still important but quite limited (between 2010 and 2030 the market share of Russian gas increases modestly from 26% to 32%), and that Europe's growing import requirements are increasingly met with LNG imports (the market share of LNG expands from 26% in 2010 to 34% in 2030). This result is in line with the findings of Holz et al. (2009). We also found that once the Nord Stream and South Stream pipelines become operational, the role of transit countries, especially Ukraine, in transporting Russian gas to Europe becomes rather marginal. However, gas flows through the Yamal-Europe pipeline (Belarus) are not affected by these two pipelines.

The model's capability was also shown by carrying out an analysis of investment in Nord Stream and its implications for profits for individual market parties, as well as for overall market efficiency. It was found that investment in Nord Stream is unattractive to its investors only when all market participants are price-takers (which does not conform with current market realities), whereas under market power scenarios Nord Stream appears to be an economically attractive project to its investors (Gazprom and European energy companies). As was shown in the results section, the economics of Nord Stream are mainly driven by: (*i*) lower total transport costs from different production regions in Russia to final consuming markets in Europe compared to the Ukrainian route and the Northern Light system (Belarus), (*ii*) the changing geography of gas production in Russia which also modifies Gazprom's transport cost structure in favour of the Nord Stream route, and (*iii*) the possible exercising of market power by transit countries (Ukraine and Belarus).

Without a detailed representation of the FSU gas "region" in this model it would not be possible to see that Nord Stream can be an economically profitable project on its own (at least in our oligopoly simulations), without strategic bargaining considerations (Hubert and Ikonnikova, 2003; Hubert and Ikonnikova, 2004; Hubert and Suleymanova, 2008). Moreover, the simulations of transit market power using a conjectured transit demand approach show that if transit countries exerted market power then Gazprom would earn twice as much from its Nord Stream investment as it would if transit countries had no market power. This result is in line with the strategic gaming rationale behind the Nord Stream project found by Hubert and Ikonnikova (2003), Hubert and Ikonnikova (2004) and Hubert and Suleymanova (2008). Using the large-scale gas simulation model, we were able to analyse the Nord Stream project in terms of market efficiency and social welfare. Here, it was found that Nord Stream improves market efficiency in all market power scenarios, and that the higher the degree of competition between market participants, the more European consumers gain.

The validation of the model with historical data shows that in general the model's results are in line with actual market outcomes for the years 2008 and 2009, and that the behaviour of the model is consistent with economic intuition. Moreover, the sensitivity analysis shows that the model's results are fairly robust in terms of major structural assumptions.

This model can be used for the analysis of other policy questions concerning the regional gas trade in Europe and CIS (including Central Asia). In Chapter 3 and 4 this model was used to analyse the economic value of Gazprom's investment in the Nord Stream and South Stream pipeline projects under different assumptions about market development, transit pricing policy and transit disruption scenarios.

Further model enhancements are desirable. First, inter-seasonal gas storage should be included in the model (e.g., as in (Egging et al., 2008; Lise and Hobbs, 2008)). The inclusion of inter-seasonal gas storage in the model might refine the results concerning Nord Stream investment. One of the advantages of using the Ukrainian route compared to Gazprom's existing and new routes is cheap access to large underground storage areas in Ukraine. Therefore, once gas storage areas are accounted for, one might find that total transport and storage costs along the Ukrainian route are lower than those costs along Gazprom's existing or new export routes - such as Nord Stream. Also, having gas storage areas in the model would enable a more detailed analysis of transit disruption scenarios. Further, we intend to include the possibility of arbitrage in the downstream market in Europe (e.g. as in (Zwart and Mulder, 2006)). This will refine our results and allow an analysis of different transport market competition scenarios in Europe.

Secondly, geographical coverage of the model could be expanded from regional to global (e.g., as in (Egging et al., 2009a)), as well as representing the demand sector in greater detail (e.g., gas demand divided by sectors and regions instead of representing each country with one demand function). Regional gas markets have become more interconnected recently through increased gas trading in its liquefied form. Therefore, having a global gas model would, of course, refine the results presented above. Moreover, this will allow us to address important questions concerning the globalization of the natural gas trade and energy security on both regional (particularly Europe, CIS and Asia) and global scales. Additionally, the model could be elaborated so that it can endogenously expand capacity (such as pipeline and LNG terminal capacity) (e.g., (Lise and Hobbs, 2008; Egging et al., 2009a)). This would allow analysis of questions concerning optimal investment in gas infrastructure. Moreover, this would allow analysis of the cost efficiency of Nord Stream investment both in terms of alternative capacities and routes. Further, probabilistic elements could also be included in the model (e.g., (Zhuang and Gabriel, 2008; Gabriel et al., 2009)). For example, this would allow inclusion of uncertainty in demand growth. Exogenous probabilities of gas flow disruptions through transit countries could also be specified and then, given that risk, the model can then determine the optimal reaction of market players in terms of investment in capacity expansion (such as storage, "bypass" pipelines and LNG terminals), sales and production.

CHAPTER 3

The Economics of the Nord Stream Pipeline System

3.1 Introduction

In 2009, Russia's natural gas exports to markets in the European Union and the Commonwealth of Independent States (CIS) generated around 4.5% of Russia's GDP, or half of Gazprom's total revenue.[60] Tax receipts from gas exports amount to 30% of Russia's defence budget.[61] On the other hand, one quarter of the EU's natural gas consumption, or 6.2% of the bloc's total primary energy supply, is covered by Russian gas (BP, 2010a). Two countries, Italy and Germany, account for about half of all contracted Russian exports to the EU, with France being the third biggest importer. The 12 newer member states of Central and Eastern Europe together represent about a third of all EU imports of Russian gas.

The EU-Russia gas trade is highly dependent on Ukraine, as three-quarters of gas exports to Europe transit through Ukrainian pipelines (see Appendix L for description of Gazprom's current gas export routes). Russia-EU gas trade relations have been complicated by frictions between Russia and the key transit countries on its Western border - Belarus and Ukraine. There have been several major gas transit disruptions, including through Belarus briefly in 2004 and for 3 days in June 2010, and through Ukraine for 4 days in January 2006 and three weeks in January 2009, including two weeks of total disruption affecting millions of customers in South-Eastern Europe and the Western Balkans (Pirani et al., 2009; Kovacevic, 2009; Silve and Noël, 2010).

Since the breakdown of the Soviet Union, Gazprom has pursued a strategy of diversifying its export options to Europe, beginning with the construction of the Yamal-Europe pipeline in the 1990s. It has continued more recently with the Nord Stream and

[60] This includes revenues from all commercial activities (gas, oil, electricity, transportation and others) of Gazprom and its affiliates.
[61] Authors' own calculations based on (Gazprom, 2010b; Russian Federal State Statistics Service, 2010a).

South Stream projects – under the Baltic and Black Sea, respectively – promoted by Gazprom and its large Western European clients. Once operational, these two projects would have a capacity larger than the current volume of gas being transported through Ukraine to Europe.

We focus on an economic analysis of the Nord Stream pipeline system (for details on the project see Appendix M).[62] Our aim is to assess the economic benefits of the project to its owners and particularly to Gazprom. We will do so in two steps: first, using detailed analysis of the Nord Stream project (see Appendix H for the derivation of Nord Stream costs) we derive its total costs and compare the levelised unit transportation cost (see Appendix G for details of the calculation of the levelized transport cost) through Nord Stream and the existing routes; then we estimate the profits of Gazprom with and without Nord Stream under various scenarios of gas demand in Europe, using a computational game-theoretic model of the Eurasian gas trade. Details of the mathematical formulation of the gas model are provided in Chapter 2.

The rest of this chapter is organized as follows. In the next section, we discuss the existing economic literature on North Stream. Then, in Section 3.3, we briefly discuss the methodology of the derivation of the economic value of the Nord Stream project. Section 3.4 briefly summarizes the gas market model used for this analysis, and Section 3.5 outlines the key market development scenarios used in the analysis. Our results are presented in Sections 3.6-3.9. We summarise our findings and conclude in Section 3.10.[63]

3.2. Literature Review

Nord Stream has been politically controversial but there has not been any attempt – at least none that is publicly available – to examine the economics of the project in an in-depth manner and assess whether it is going to be profitable to its owners.

The applied game-theoretic literature has found some economic rationales for building a project such as Nord Stream (Hubert and Ikonnikova, 2003; Hubert and Suleymanova, 2008) and the Yamal-Europe pipeline (Hirschhausen et al., 2005). The

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[62] By the Nord Stream pipeline system, or NSPS, we mean all pipelines (including the Gryazovets-Vyborg pipeline in Russia, the Nord Stream offshore pipeline underneath the Baltic Sea, Opal, the Nel pipelines in Germany and the Gazelle pipeline in the Czech Republic) that are part of the new export route to Europe.

[63] This chapter is a substantially updated version of (Chyong et al., 2010). Dr. Pierre Noël and Dr. David Reiner commented on the paper and helped drafting it.

economic and strategic insights from this literature are valuable, although the authors may have underestimated the value of Nord Stream and the cost of using the existing transport routes. Hubert and Ikonnikova (2003) and Hubert and Suleymanova (2008) neglect the Russian uptream gas sector and, particularly, the changing geography of Russian gas production. In general, Nord Stream is a shorter route by which to transport gas from Russia's existing fields (Nadym-Pur-Taz region) and from the Yamal peninsula to Western Europe than using the Ukrainian corridor and Russia's existing transmission grid. Furthermore, although investments in the Ukrainian route and the Yamal-Europe pipeline are treated as sunk costs, there are still transit fees to be paid. It is unclear whether these fees are included by the authors when examining the cost of using the Ukrainian and Belarusian routes.

Using a strategic simulation model of European gas supply, Holz et al. (2009) find that Russian gas exports to Europe up to 2025 will not exceed export capacity through the existing routes (i.e. 180 bcm/y through Ukraine and Belarus).[64] Thus, according to Holz et al. (2009: p.145), "*...the much debated Nordstream pipeline from St. Petersburg through the Baltic Sea into Germany lacks an economic justification*". Using a gas market simulation model of the European region, Egging et al. (2008), among other scenarios, analysed the short-term gas supply (2011) situation in the European market. The authors assumed that by 2011 the first line of the Nord Stream pipeline would be built and they asserted that: "*...the current (2004) export capacity of pipelines from Russia to Europe already is of the order of 150 bcm, and that in 2011, Russia would still not be exporting at its full capacity. The Nordstream pipeline project must rather be understood as a strategic option in the transit game with Ukraine and Belarus.*" (Egging et al., 2008: p. 2404). However, by suggesting that Nord Stream is economically justifiable only if Gazprom needs additional export capacity, the authors imply that shipping gas through Nord Stream would necessarily be more expensive than using the existing options. Yet they provide no analytical basis to support this assumption. Explicitly or implicitly, the idea that Gazprom would need additional net transport capacity to justify Nord Stream economically stands behind most claims that Nord Stream is either a purely geopolitical project (among others see, for example, (Christie, 2009a; Christie, 2009b)) or a strategic project aimed at reducing the bargaining power of transit countries (Hubert and Ikonnikova, 2003; Egging et al., 2008; Hubert and Suleymanova, 2008).

[64] We should note that the export capacity of the Ukrainian route through Slovakia to Western Europe is 92.6 bcm/y (Naftogaz of Ukraine, 2010). One has to consider this net export capacity when analyzing Nord Stream, not the total transit capacity though Ukraine, which is approximately 150 bcm/y.

We have not encountered any in-depth, publically available analysis of the economics of Nord Stream in the literature which would allow for a rigorous comparison of the costs of building and using the new pipeline versus the existing transit corridors, and assess the benefits of Nord Stream to its owners.

3.3. Methodology

The analysis presented in this chapter is built upon two basic steps. First, the costs of building and using the Nord Stream system are derived. Secondly, using the strategic, game-theoretic Eurasian gas trade model outlined in Chapter 2, the economic value of Nord Stream system to Gazprom is derived under different market development scenarios. The following sections outline how the economic value of Nord Stream investment is derived. For details of the derivation of the costs of the Nord Stream project, uncertainty analysis of these costs and related assumptions, see Appendices G and H.

3.3.1. Economic Value of Nord Stream

In deriving the economic value of the Nord Stream pipeline under different scenarios and assumptions, the logic of cost-benefit analysis is followed. The value of Nord Stream investment is derived by comparing Gazprom's anticipated total profit between 2011 and 2035 when the Nord Stream project is built with Gazprom's profit if it is not built.[65] This is shown in the following equation:

$$PV^{NS} = \sum_{t=2011}^{2035} \frac{(Profit_t^{+NS} - Profit_t^{-NS})}{(1 + Discount\ Rate)^{(t-2011)}} \tag{3.1}$$

where PV^{NS} is the present value of Gazprom's investment in the Nord Stream system, $Profit_t^{+NS}$ is Gazprom's annual profit when the Nord Stream system has been built, and

[65] Nord Stream's economic lifetime is assumed to be 25 years. Since it is assumed that Nord Stream is built by 2011, the time frame of the analysis goes up to 2035 to cover the lifetime of the project.

$Profit_t^{-NS}$ is Gazprom's annual profit if the pipeline has not been built; the discount rate applied to this calculation is the Nord Stream project discount rate discussed in Appendix H. Gazprom's profit under different scenarios and assumptions is derived from the gas market simulation model presented in Chapter 2.

3.3.2. Economic Value of Nord Stream given the Risk of Transit Disruptions

The expected present value of the Nord Stream system given risks of transit disruptions through Ukraine is computed as follows:

$$E[PV_d^{NS}] = PV^{NS} + P_{td}\left[\sum_{t=2011}^{2035} \frac{(Profit_{td}^{+NS} - Profit_{td}^{-NS})}{(1 + Discount\ Rate)^{(t-2011)}} - PV^{NS}\right] \quad (3.2)$$

where $E[PV_d^{NS}]$ is the expected NPV of Nord Stream investment under transit disruption scenario *d*, $Profit_{td}^{+NS}$ is Gazprom's profit under transit disruption scenario *d* when Nord Stream is built, $Profit_{td}^{-NS}$ is Gazprom's profit under transit disruption scenario *d* if the Nord Stream system is not built; P_{td} is the probability of transit disruption *d* through Ukraine in year *t* and is assumed to be a random variable with uniform distribution in [0;1].

Gas transit disruptions through Ukrainian pipelines are implemented as follows: (*i*) the gas market simulation model is run under different demand scenarios, (*ii*) optimal levels of Russian gas transit through each pipeline of the Ukrainian transit system are recorded, and (*iii*) the model is then re-run but with limits on Ukrainian transit quantities according to the assumed transit disruption scenario *d* (see Section 3.5, Table 3.2).

One should note that the expected value of Nord Stream investment given risks of transit interruptions differs according to when exactly interruptions might occur in the time frame of our analysis (2011-2035), due to the discounting effect. For example, Gazprom's transit disruption value in the near future is different to the value of an interruption occurring in 20 years time. Therefore, deriving the expected NPV of Nord Stream under assumed disruption scenarios (see Table 3.2) is not straightforward, since it is impossible to predict when disruptions through Ukraine might occur between 2011 and 2035 because such predictions depend on a range of known and unknown factors. Thus, for this analysis, it is assumed that a disruption through Ukraine might occur in any year between 2011 and 2035 with equal probability.

It should be noted that the economic value of Nord Stream to Gazprom under transit interruptions is associated with Gazprom's savings in terms of financial losses that might arise from transit interruptions through the Ukrainian route when Nord Stream is built compared to the scenario when the pipeline is not built. That is, by building Nord Stream Gazprom might reduce its financial losses due to the loss of market share when transit through Ukraine is interrupted. Thus, the economic value of Nord Stream under the risks of transit disruptions analysed in this research does not take into account the economic value of Gazprom's gas itself since it is assumed that Gazprom would not lose any cubic metres of natural gas (i.e. the gas molecules are still in Gazprom's fields) when transit through Ukraine is completely shut. In this sense, there might be little or even no economic loss to Gazprom when transit through Ukraine is disrupted because any gas not sold at that moment can be sold later (admittedly at lower than the present value).

3.4. Model summary

Computational gas market models have been used extensively in recent research on structural issues in European and global gas market developments (see, e.g., (Boots et al., 2004; Zwart and Mulder, 2006; Holz et al., 2008; Egging et al., 2009b; Lise and Hobbs, 2009; Zwart, 2009)).[66] Security of gas supply to Europe (both long-term resource and infrastructure availability and short-term gas disruption events) has also been analysed using gas market models (see e.g., (Holz, 2007; Egging et al., 2008; Lise et al., 2008)).

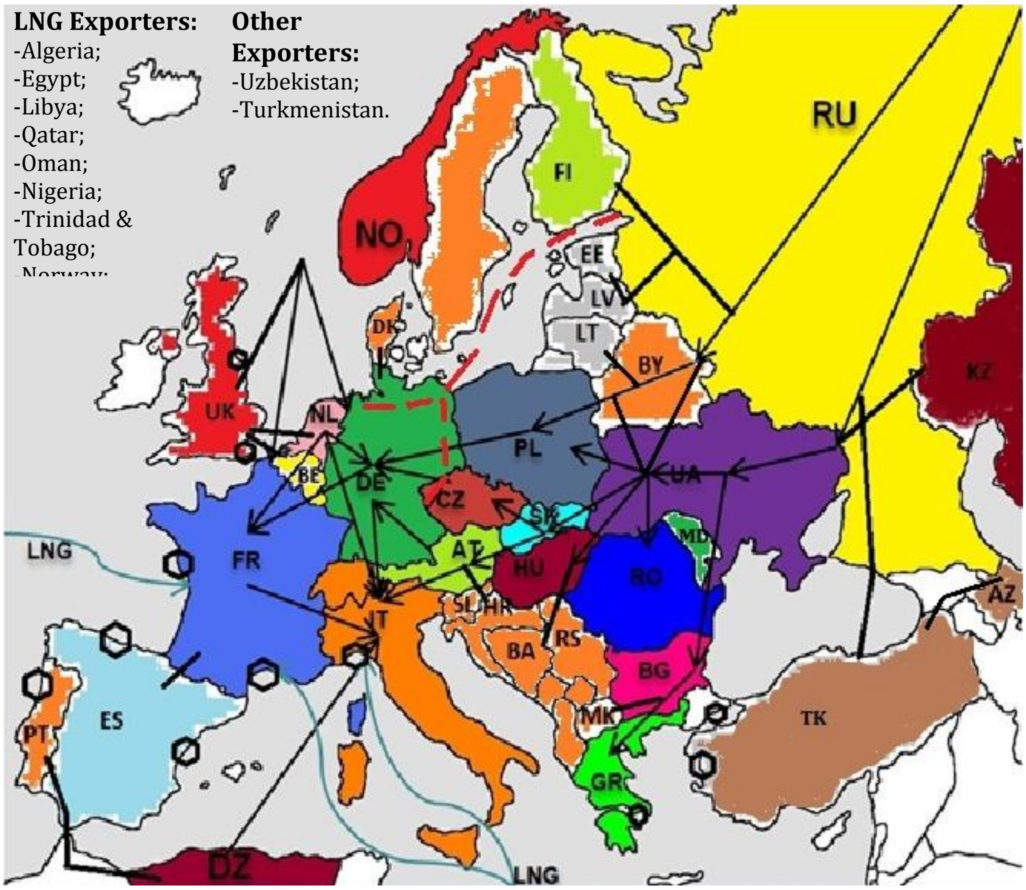
We use the strategic gas simulation model presented in Chapter 2 to quantify the economic value of the Nord Stream pipeline project in a systematic way. The model represents 25 gas markets from Western, Central and Eastern Europe and from the FSU and 27 producing regions (see Appendix E: Tables E.1 and E.2 for lists of the markets and production regions in the model).

[66] For an exhaustive and insightful review of gas simulation models applied to the analysis of European gas markets see, e.g., (Smeers, 2008).

The market structure assumed in the model is as follows. Market participants include producers, transit countries, suppliers, consumers, transmission system operators (TSO) and LNG liquefaction and regasification operators. The objective of market participants in the model is to maximize their profit from their core activities.

Producers and consumers are connected by pipelines and by bilateral LNG shipping networks. Therefore, producers have to contract with pipelines and LNG operators to transport gas to consuming countries. It is assumed that producers can exercise market power by playing a Cournot game against other producers. Further, we assume that transmission costs through pipelines are priced efficiently, i.e. it is assumed that TSOs behave competitively and grant access to the pipeline infrastructure to those users who value transmission services the most.[67] This would result in transmission charges based on the long-run marginal costs and a congestion premium in case pipeline capacity constraints are binding. The behavioural assumption for LNG liquefaction and regasification is similar to that assumed for TSOs, i.e. LNG liquefaction and regasification services are priced efficiently by an independent operator of LNG facilities. Although producers can exercise market power by manipulating sales to suppliers, it is assumed that producers are price-takers with respect to the costs of transmission and LNG liquefaction and regasification services. These assumptions about transmission and LNG services are consistent with other strategic gas models (Boots et al., 2004; Egging et al., 2008; Lise and Hobbs, 2008).

[67] As Smeers (2008) argues, the assumption of efficient pricing of transmission costs is somewhat optimistic and diverges from the reality of natural gas transmission activities in European markets. However, recent agreements between private companies and European antitrust authorities (such as the capacity release programme agreed between GDF SUEZ, ENI, E.ON and EC) promise much more competitive access to both transmission pipelines and LNG import terminals (EC, 2009a; EC, 2009b; EC, 2010).



- Regasification Terminals

Figure 3.1: Geographical Coverage of the Gas Market Model[68]

In each consuming country there are a certain number of gas suppliers who buy gas from producers and re-sell it to final customers, paying distribution costs. Following Boots et al. (2004), the operation of suppliers is modelled implicitly via the effective demand curves facing producers in each country.[69] For this analysis, we assume that suppliers are competitive.

Natural gas prices may differ substantially among countries. Countries that are closer to gas sources enjoy lower prices than countries that are further from gas sources because of the considerable transportation costs involved, including possible congestion fees on transmission pipelines and transit countries' mark-ups due to the exercise of market power. Apart from differences in transport costs, gas prices can also differ

[68] The pipeline links on the map do not represent real pipeline networks. They only represent major (not all) gas flows and market interconnections assumed in the gas model (for details of the model formulation see Chapter 2, and for details of data and assumptions see Appendix C).

[69] In the derivation of the effective demand curve, suppliers operating in each country are assumed to be identical. As Smeers (2008) argues, this assumption does not correspond to the reality of European downstream markets.

significantly due to the different degrees of competition among producers supplying a particular national market. For example, well-diversified markets in Western Europe have lower prices (on average) than the prices enjoyed by some countries of Central and Eastern Europe (some Central and Eastern European countries have only one source of gas supplies).[70]

3.5. Market Development Scenarios and Assumptions

The economics of the Nord Stream project depend greatly on future developments in gas demand and prices in Europe, as well as on gas infrastructure developments (such as LNG import terminals). In this section, we present three scenarios of European gas demand. All other market assumptions, such as gas infrastructure capacities and costs (production, transport, etc.), used for this analysis are extensively documented in Appendix E.

A decade of forecasts by the International Energy Agency (IEA) and the US DOE's Energy Information Administration (EIA) illustrates the downward trend in energy experts' view of future growth in European gas demand (Figure 3.2). Our base case scenario is based on the IEA's 2009 forecast (IEA, 2009), while for our high demand case we average the projected growth rates from the IEA's *World Energy Outlook* (WEO), published between 2000 and 2007. For our low demand case, we assume that European gas consumption will decline 0.1% annually, similar to the WEO 2009's "450 Scenario" (see Table 3.1). The gas price scenarios used in the model are based on IEA's (2009) price outlooks. Since it is assumed that the economic lifetime of the Nord Stream system is 25 years, and that the pipeline will be in operation in 2011, the period of the analysis is 2011-2035; thus it is assumed that after the 2030 gas demand, prices and all other parameters are constant.

[70] For a detailed discussion of gas markets in Central and Eastern Europe see, e.g., (Noël, 2008; Noël, 2009).

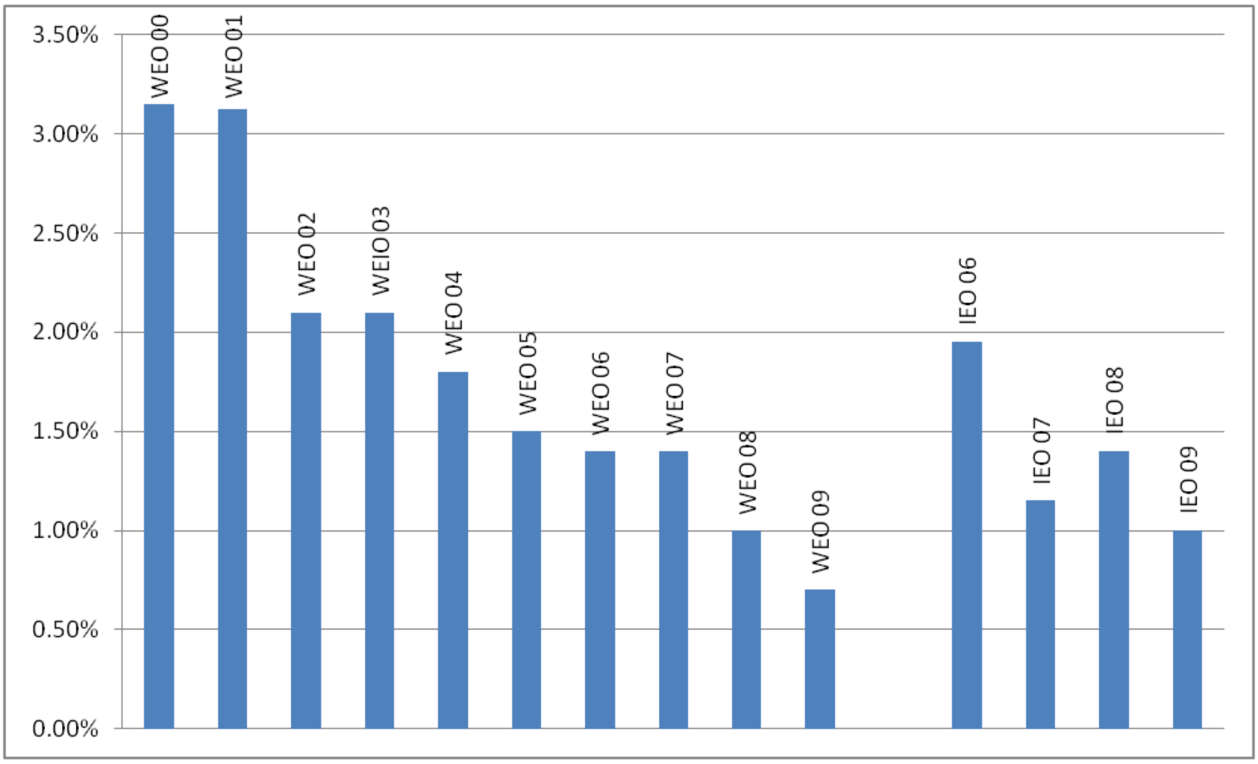


Figure 3.2: Evolution of Gas Demand Outlooks[71]

Table 3.1: Assumed growth rate of gas consumption and price: 2010-2030

	High Demand Case	Base Case	Low Demand Case
Compound Annual Growth Rate of Gas Demand			
Western and Southern Europe	+2.07%	+0.7%	-0.1%
Central and Eastern Europe	+2.07%	+0.8%	-0.1%
Balkan Countries	+2.07%	+0.8%	-0.1%
Compound Annual Growth Rate of Gas Prices			
All consuming countries in the model	+1.4%	+1.4%	+0.3%

In order to derive the expected economic value of Nord Stream investment given risks of transit disruptions through Ukraine, the following disruption scenarios are assumed:

Table 3.2: Transit Disruption Scenarios through Ukraine

Disruption Scenarios	Duration of Disruptions	Frequency of Disruptions	Total days of disruptions
Moderate Disruption Case	3 weeks	5 disruptions in 2011-2035	105 days
Severe Disruption Case	6 weeks	10 disruptions in 2011-2035	420 days

[71] This figure is adapted from Noël (2009).

The disruption scenarios are for analytical purposes only and do not constitute forecasts of transit disruptions through Ukraine. To simplify the analysis, it is assumed that the probabilities of disruptions in any period are independent (e.g. gas transit disruption in 2009 through Ukraine has no effect on the probability of future disruptions through Ukraine). Also, no distinction is made about when exactly the disruption would occur during a particular year (winter or summer), which would require explicit modelling of storage in the gas simulation model. Therefore, the results should be treated as annual average values.

For this analysis, we assume that only producers can exercise market power and that downstream suppliers are competitive. This assumption is motivated by the results of our model validation, discussed in Chapter 2: Section 2.4 and Appendix I, which show that model results under an upstream oligopoly fit better with the real data than the double marginalization or perfect competition market scenarios. Although formally only producers may exercise market power, the implicit assumption that we adopt is that producers and suppliers act simultaneously to extract the whole monopoly profit from the market and then share that profit relative to their bargaining power. Compared to the successive oligopoly approach, in which upstream producers and downstream suppliers are assumed to exercise their market power in sequence, such vertical coordination to exercise market power can result in greater sales and lower prices, and therefore a smaller loss of welfare (Smeers, 2008). This assumption is consistent with the traditional view of the structure of European gas markets (Smeers, 2008).

Based on this assumption, the resultant profit of producers should be treated as the profit of an integrated company producing and selling gas <u>directly</u> to final customers (i.e., the whole monopoly rent from a wellhead to a burner tip). Thus, Gazprom's profit, which it receives by selling gas at final prices, should be re-adjusted after simulation runs, since in reality Gazprom sells gas to suppliers at border prices.

In 2002-2009, the average border price accounted for about 53% of the average final prices in Germany (see Table 3.3).[72] This assumed share is quite consistent with the

[72] German border and final prices were chosen for several reasons: (i) there is very limited (publicly available) information about border prices in Europe markets, (ii) Germany is one of the largest gas markets in Europe and is also the largest market for Russian gas, and (iii) Germany is the final destination of the Nord Stream pipeline and is intended to be the largest off-taker from Nord Stream. Thus, German border and final prices can both be reasonably used to evaluate the economic value of Nord Stream investment.

model results under the double marginalization scenario (see Chapter 2: Table 2.2).[73] Thus, for the calculation of Gazprom's profit its border prices are assumed to be 53% of simulated gas prices for final consumption. The derivation of the economic value of the Nord Stream system to Gazprom is based on this assumed share (i.e. 53% of the final prices obtained from the model simulations). Analysis of the economic value of the Nord Stream project based on different market structure assumptions is provided in Chapter 2: Section 2.5.2.

Table 3.3: Real Border and Final prices (US$/tcm)

	Average gas price at German Border[a] [1]	**Average final price in Germany**[b] [2]	**Border price as % of final price** [3]
2002	121	246	49%
2003	153	285	54%
2004	163	329	50%
2005	223	426	52%
2006	305	545	56%
2007	310	644	48%
2008	446	734	61%
2009	349	649	54%
Average			***53%***

Source: [a]*(Gas Strategies, 2010);* [b]*(Eurostat, 2010)*
Note: [3]=[1]/[2]x100%

3.6. The Costs of Building and Using the Nord Stream Pipeline System

We compare the different export routes available to Gazprom (Nord Stream, the Ukrainian route and the Belarusian one) on the basis of levelised transportation costs between Gazprom's production field and a particular final gas market.

The levelised transportation cost through Nord Stream is obtained by dividing the total investment cost of the Nord Stream pipeline system by the volumes transported over 25 years. We calculate the total investment cost using the methodology and data described in Appendices G and H. Figure 3.3 shows the minimum, the average and the maximum values for each component of the pipeline system. These figures include the construction cost, the cost of compressors and the cost of debt financing.

[73] Indeed, the simulated average border price in Europe under the double marginalization case was about 55% of the average price for final consumption in Europe (see Chapter 2: Table 2.2 column "double marginalization").

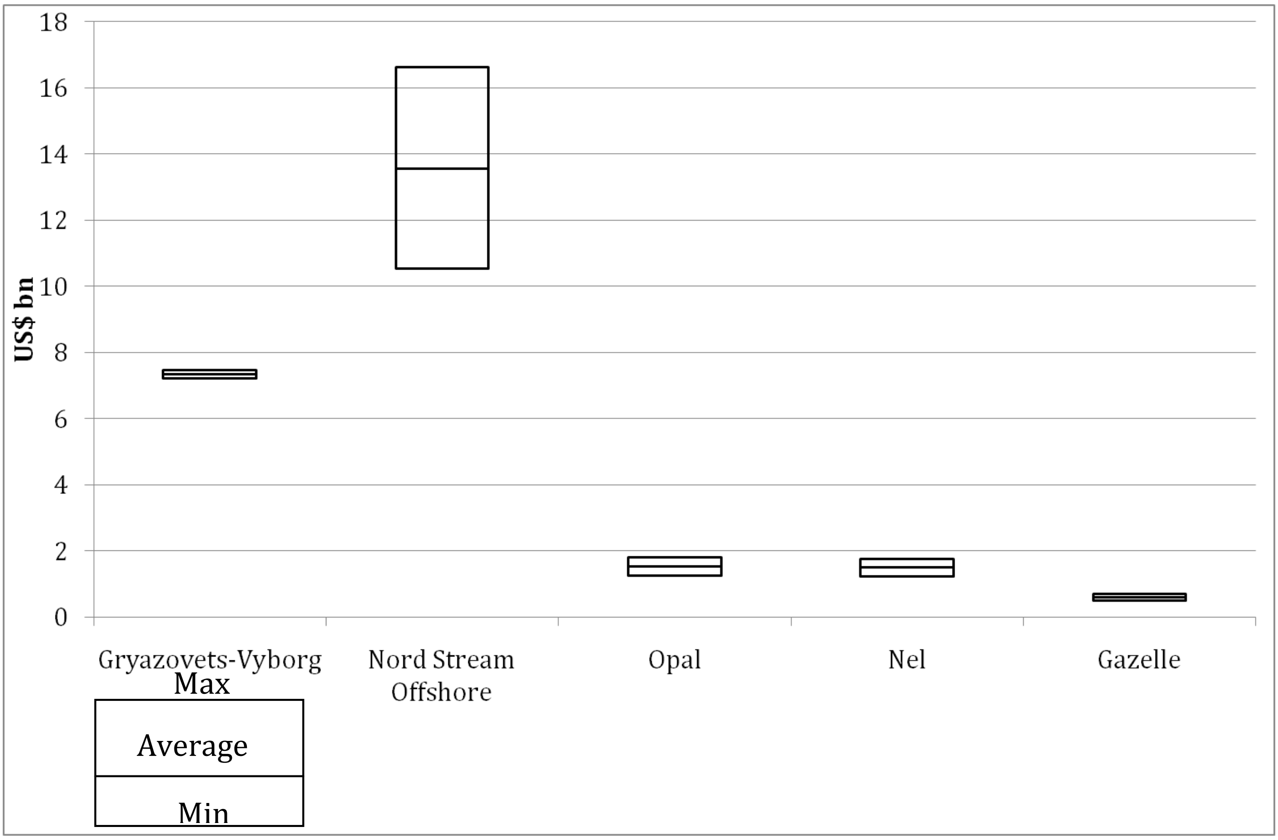


Figure 3.3: Investment Costs of the Nord Stream System

The total investment costs of the Nord Stream system vary between US$ 20.7 bn and US$ 28.3 bn. As might be expected, the single largest component of the Nord Stream system is the offshore pipeline underneath the Baltic Sea, which accounts for about 55% of the total capital cost of the system.

Table 3.4 shows the levelised transportation cost for each section of the pipeline system, assuming they are fully utilised during their economic life-time (results under alternative assumptions are also shown later). The levelized costs presented in Table 3.4 show how much each pipeline should charge in order to pay back its investment costs and annual O&M costs.

Table 3.4: Levelized Transportation Costs through the Nord Stream system (US$/tcm)

	Gryazovets-Vyborg	Nord Stream Offshore	Opal	Nel	Gazelle
Average	20.6	21.1	4.9	11.1	2.5
Max	26.1	30.2	6.2	13.7	3.1
Min	15.5	13.8	3.7	8.6	2.0

To compare the Nord Stream system with the Ukrainian and Belarusian routes, we assume that all transit fees (through Belarus, Poland, Ukraine[74], Slovakia and the Czech Republic) will remain at the level of 2009-2010. The cost of fuel gas as a component of the transit fee has been omitted from this analysis.[75]

As shown in Figure 3.4, building and using the Nord Stream system is a cheaper way for Gazprom to transport gas to Western Europe (Germany) from its major production sites than using the Ukrainian route. This is primarily due to the geography of upstream production in Russia and the designing of the transmission system during the Soviet era. When Soviet planners developed the giant Urengoi fields in North-western Siberia for exports to Europe, sending their gas directly to Germany, avoiding Ukraine, would have been a shorter route; however, the straight route was not materialized and instead it went south through Ukraine. Among other considerations, two factors were in the minds of Soviet planners at that time that granted Ukraine a monopoly in gas transit: (*i*) to ensure adequate off-take quantities along the export route to Germany (in the markets of Central and South Europe), and (*ii*) the direct route to Germany would have to cross Poland and Eastern Germany before terminating in Western Germany – the former was politically risky for Soviet politicians, while the latter was politically unacceptable for West German politicians (Victor and Victor, 2006).

Moreover, the expected gradual shift in Russia's gas production to the north (Yamal Peninsula and Barents Sea), as the Nadym-Pur-Taz (NPT) region declines, has important implications for the relative costs of the transportation options. It positively affects the competitiveness of both the Nord Stream and Belarusian routes (the Yamal-I pipeline) and disfavours the Ukrainian route. This is because the distance from the Yamal Peninsula to the Russia-Ukraine border is longer than the distance from the Yamal Peninsula to the Nord Stream entry point (Vyborg) or to the Russia- Belarus border (Smolensk). However, it seems that the economics of the Nord Stream route greatly depend on Gazprom's ability to use the pipeline at 100% over its economic life time; for otherwise it might be relatively more expensive to use Nord Stream than the Ukrainian route. For example, if the Nord Stream system is utilized at 75%, then using the Ukrainian route is cheaper.

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[74] We examine alternative transit pricing strategies for Ukraine in Section 3.9.

[75] Most transit/transmission operators in Europe (e.g. BOG in Austria, NET4GAS in Czech Republic, and Eustream in Slovakia) ask shippers to provide fuel gas in kind. In any case, the cost of fuel gas is rather small (e.g., 0.2% of the total transported quantity per 100 km of distance).

Further, the economics of the Nord Stream system depend also on the transit pricing policy through Ukraine. As was noted above, the total transit cost through the Ukrainian route (Figure 3.4: “red” bars) is based on its current transit fee (for details see Appendix E: Section 7.3.1). However, if the transit fee through Ukraine is higher than its long-run marginal cost (LRMC) then a credible threat to construct Nord Stream would induce Ukraine to reduce its current transit fee, possibly to its LRMC (assuming Ukraine is rational in its pricing decisions).[76] However, even if Ukraine charged for transit based on LRMC this should not affect the economics of Nord Stream substantially because it would still be cheaper for Gazprom to use the Nord Stream route than the Ukrainian route (compare Table E.11 with Table E.13 in Appendix E to see differences between Ukraine’s current transit fee and its LRMC). Further, it can be argued that in order for Ukraine to stay competitive in light of the construction of the Nord Stream it could even reduce its transit fee to the level of the short-run marginal cost (SRMC); however, transit pricing under the short-run marginal cost would not reflect the huge up-front capital cost of Ukraine’s transit system, and thus it is neither economically nor politically feasible for Ukraine to do so.[77]

[76] It should be noted that whether it is optimal for Ukraine to reduce its transit fee to the LRMC level largely depends on capacities of the Ukrainian route and the Nord Stream route, as well as on relative costs of the two systems.

[77] Moreover, some experts argue that the cost of maintaining and rehabilitating the Russian gas pipeline system (i.e. the cost of keeping the system running) is approaching the industry’s LRMC due to its great age (see, e.g., World Bank (2009: p.247)). Since the Russian and Ukrainian systems are essentially the same age this argument also seems plausible for the Ukrainian system.

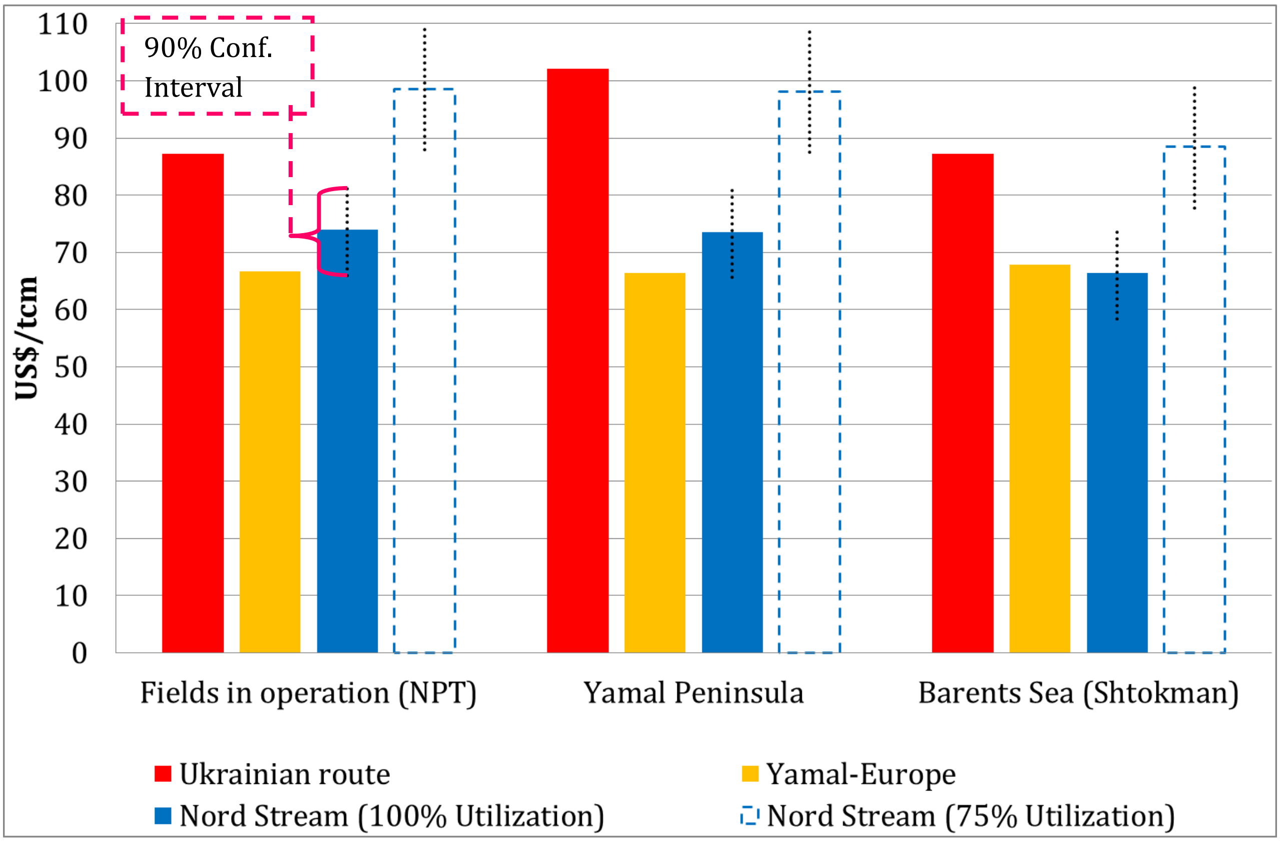

Figure 3.4: Transportation Costs from Gazprom's Production Fields to Germany

Since Gazprom owns the Belarusian section of the Yamal-Europe pipeline, it pays only 0.49 US$/tcm/100km to Beltransgaz, operator of the Yamal-Europe pipeline in Belarus (Ryabkova, 2010). This fee includes only the operational and O&M costs of the pipeline. Therefore, an unbiased comparison between these two routes should include the capacity costs of the Yamal-Europe pipeline as well. Using the same procedure as for the levelised costs, we have calculated the annualised capacity cost through the Yamal-Europe pipeline in Belarus, assuming that it has been fully utilized since it began operation (in 2001). Various sources have reported the capital cost for the Belarusian part to be around US$ 1.6 bln, excluding any finance costs (Interfax, 2000a). This is similar to the capital cost of the Yamal-Europe I pipeline section in Poland, which has almost the same length and number of compressor stations (Europol Gaz s.a., 2010b). We use this figure to obtain an estimate of the annualized unit capacity cost for the Belarus section. The result is remarkably similar to those set by the Polish energy regulator for the Yamal-Europe pipeline in Poland (€1.108/tcm/100km in 2009) (A'LEMAR, 2009).

The results of these calculations show that the Belarusian route appears to be less costly than the Nord Stream route for transporting gas from existing fields and the

Yamal peninsula (see Figure 3.4). However, transporting gas from the Shtokman field is cheaper through Nord Stream than through the Yamal-Europe pipeline, although only marginally. It should be noted that we assume transit fees through Belarus and Poland to be at the 2009 level. However, there is, of course, no assurance that the transit fees through Poland and Belarus will not change before 2030. The Belarus route (Yamal-Europe I pipeline) suffers from the same set of issues Gazprom has faced for many years in dealing with Ukraine, namely the bargaining power of the transit countries. Since the construction and operation of the Yamal-Europe I pipeline, Gazprom has faced quite substantial difficulties in negotiations with both Belarus (e.g. leasing land for additional compressors to raise the pipeline to full capacity) and Poland (negotiation and re-negotiation of financing terms for construction through Poland and bargaining over transit price terms) in constructing and operating the Yamal-Europe pipeline (Victor and Victor, 2006).

3.7. The Economic Value of the Nord Stream System

Using the gas simulation model outlined in Chapter 2 and eq. (3.1), the economic value of Nord Stream investment to Gazprom is estimated. Figure 3.5 shows the economic value of the Nord Stream system under our three demand scenarios. The black boxes with solid lines represent the minimum, average and maximum values of the Nord Stream system, assuming average investment costs (the variability is due to the variance in the discount rate only). The dotted lines show the impact on the project's maximum and minimum NPV of capital expenditures reaching their maximum and minimum values.

In all analysed scenarios, the Nord Stream system has a positive net present value. Assuming that transit fees and other transportation costs through existing routes remain unchanged over time, higher gas demand in Europe increases the economic value of the new pipeline system over its life-time. The average NPV of the Nord Stream system is US$ 2.3 bn in the low demand case, US$ 7.8 bn in the base case and US$ 27.4 bn in the high demand case.

In the best case, when gas demand in Europe is relatively high (CAGR of +2.07%) and the (total) investment costs in the Nord Stream system are low, the economic value of the pipeline could be as high as US$ 36 bn over the lifetime of the system. However, even in the worst case (i.e. a combination of the highest total investment costs and lowest gas demand scenario) the economic value of the Nord Stream system would still be positive, at around US$ 0.3 bn over the lifetime of the pipeline.

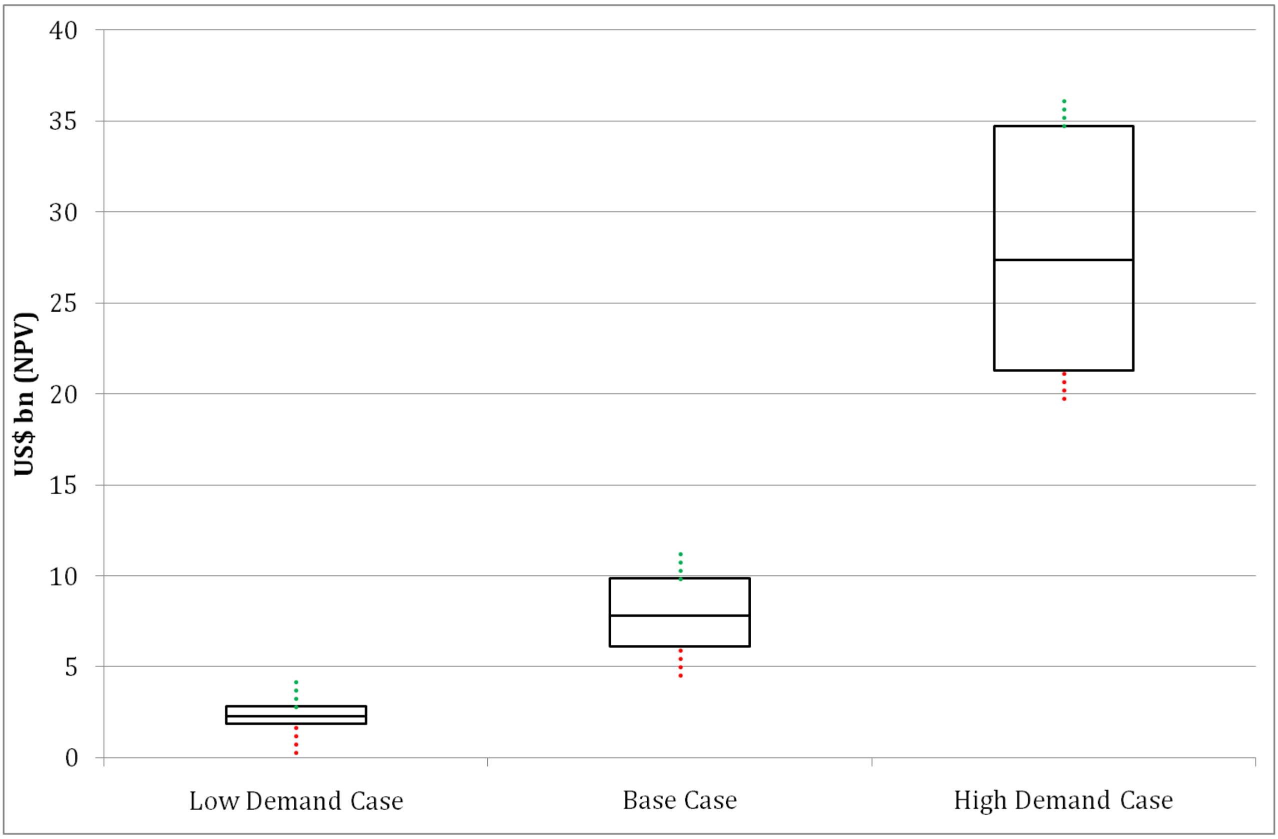

Figure 3.5: Economic Value of the Nord Stream System under Different Market Demand Scenarios

3.8. The Impact of Transit Disruption Risks

Nord Stream's sponsors argue that the project will improve the security of gas supplies to Europe (Nord Stream AG, 2010d; E.ON, 2010; BASF, 2010b; GDF SUEZ, 2010; Gasunie, 2010). This argument has gained traction after the sustained disruption of the Ukrainian transit corridor in January 2009.

To quantify the contribution of the Nord Stream pipeline system to the security of the Russian-European gas trade, we evaluate the impact of the unreliability of transit through Ukraine on the economic value of the Nord Stream pipeline system to Gazprom using eq. (3.3) and disruptions scenarios as outlined in Table 3.2. Figure 3.6 presents the results under different scenarios of demand growth in Europe.

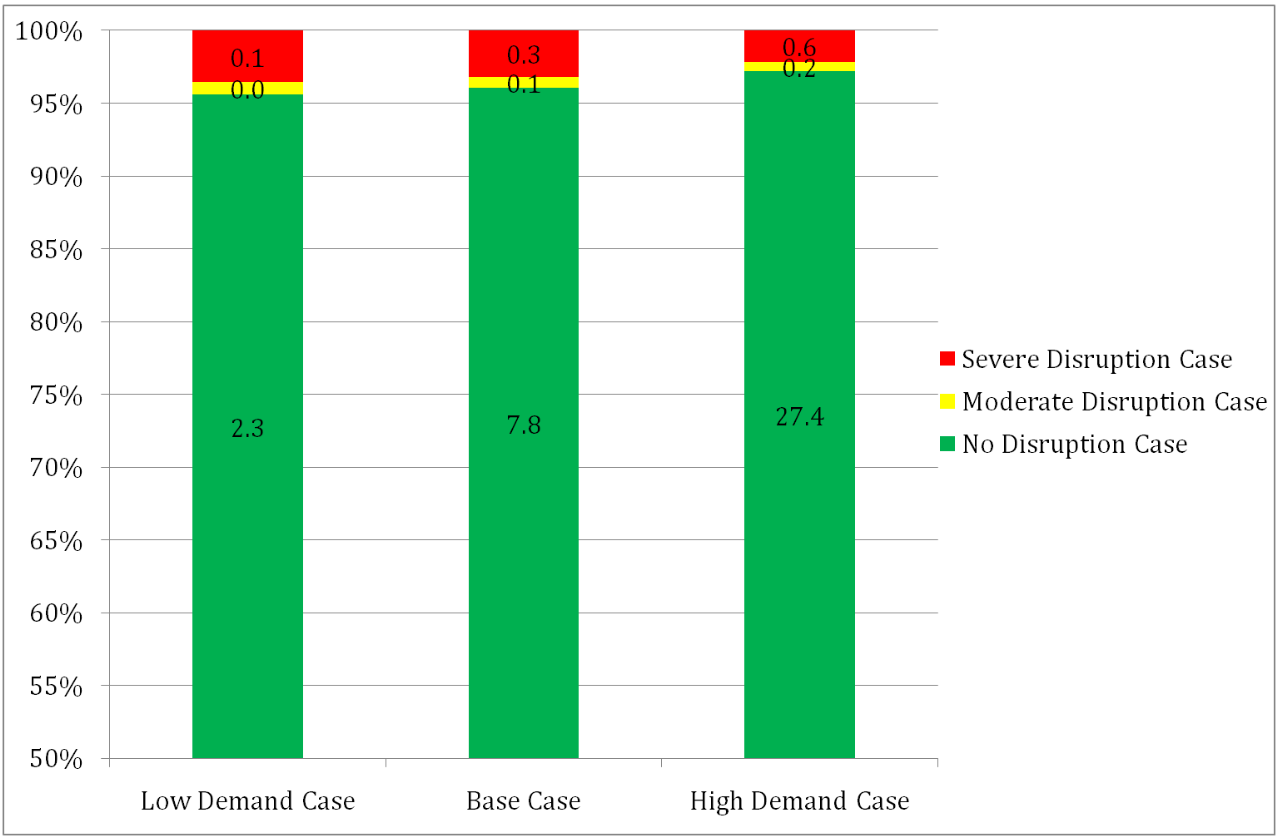

Figure 3.6: Expected Economic Value of the Nord Stream System under Transit Disruption Scenarios[78]

Under the Base Case demand scenario and without any disruption, the average NPV of the system is US$ 7.8 bn. In the moderate disruption case, the expected additional NPV of the system, reflecting its security value, is US$ 0.1 bn, or about 1% of the maximum achievable NPV of the system (i.e., US$ 8.2=7.8+0.1+0.3). Under the severe transit disruption scenario, the security value of the Nord Stream system would be US$ 0.4 bn (i.e., 0.1+0.3) over 25 years, or 4% of the maximum possible value.

Under all analysed demand scenarios, at least 95% of the NPV of the pipeline system comes from the economic fundamentals of the project – lower transportation costs compared to the existing export routes; the security value of the project never represents more than 4% of the expected total maximum value (see Figure 3.6: Low Demand Case).

It should be noted that the economic value of Nord Stream to European consumers as a security of supply measure might be substantially higher than Gazprom's security

[78] The values inside the bars are the average values of the NPV in US$ bn (equivalent to the middle lines of the solid boxes in Figure 3.5).

value as found in this analysis (Figure 3.6).[79] This is due to the fact that the economic costs of unserved energy (natural gas) to a particular country are substantially higher than the financial losses to Gazprom of not being able to export gas at market prices to that country when transit through Ukraine is interrupted.[80]

3.9. The impact of Ukraine's Transit Pricing Decisions

We have so far assumed that the Ukrainian transit fee over time is determined according to the long-term transit contract signed after the January 2009 gas crisis.[81] However, one would think that Ukraine would respond to the emergence of a new competing option by adapting its transit fee. If the quantity of gas transported through Ukraine decreases (e.g. because of diversion of gas flows to the Nord Stream system), then Ukraine's rational reaction would be to slash its transit fee so that it would be more profitable for Gazprom to export gas through the Ukrainian route than through the bypass pipeline. Conversely, increased demand for transportation through Ukraine would allow it to charge a higher fee.

In this section we quantify the impact of Ukraine's transit pricing decisions on the economic value of the Nord Stream system.[82] We compare, under our three demand scenarios, the value of Nord Stream when the Ukrainian transit fee is fixed to its value when the transit fee is a function of Gazprom's demand for transit services through Ukraine (that is, a function of the gas transported through Ukraine) (for details see the model formulation in Chapter 2: Section 2.3.4.2: "Transit pricing through Ukraine and Belarus").

Figure 3.7 shows the value of the Nord Stream system when the Ukrainian transit fee is fixed, i.e. based on the long-term transit contract (black boxes) and when the fee

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[79] A full social cost-benefit analysis of Nord Stream as a security measure against transit interruptions is not the subject of this research and deserves a separate analysis.

[80] For example, the estimated economic costs of 'unserved gas' in the UK is in the range of £5/therm to £30/therm (DTI, 2006). Using an exchange rate of 1.6 USD/GBP, this range is equivalent to about US$ 2900
to 17410/tcm.

[81] The full text (in Russian) of the contract was published on the website of the Ukrainian newspaper "Ukrainska Pravda" shortly after its signing (Ukrainska Pravda, 2009).

[82] For our future research we will include another scenario – Gazprom's acquisition of Naftogaz of Ukraine. Indeed, Ukrainian government officials have explicitly acknowledged that they cannot "stop" the construction of Nord Stream, as it has already started, and therefore the Ukrainian government has suggested that Gazprom and European gas companies invest in refurbishing Ukrainian transit pipelines and co-manage the transit system instead of constructing the second "bypass" pipeline – South Stream (Korrespondent.net, 2010b).

responds to the construction of the 'bypass' pipeline (red boxes). A responsive Ukrainian fee has a positive impact on the NPV of the Nord Stream pipeline system, all the greater when gas consumption growth in Europe is stronger. Under the Base Case demand scenario, Ukraine's rational pricing behaviour increases the average value of Nord Stream by 33%. In the low demand case, the impact of Ukraine's transit pricing policy increases the value of the Nord Stream system by 47%. Under the high demand scenario, Ukraine responds to the high demand for using its transit pipelines by increasing the transit fee very substantially (Figure 3.8), limiting the additional net value of the Nord Stream system to 7%.[83]

However, moving away from the current transit pricing arrangement to rational economic pricing only benefits Ukraine if gas demand in Europe grows at a compound annual rate of over 2% between 2011 and 2035 (which is highly unlikely) (see Figure 3.8). In the low demand and base case scenarios lower transit fees do not encourage Gazprom to use the Ukrainian pipelines more because of the negative implications for European gas prices. Therefore, in cases of low or moderate demand growth in Europe, Ukraine gains little from pricing rationally and might be tempted by short-term, opportunistic behaviour.

[83] Due to increased demand in Europe, the Nord Stream and Yamal-Europe routes are saturated and, therefore, Gazprom has to use the Ukrainian route.

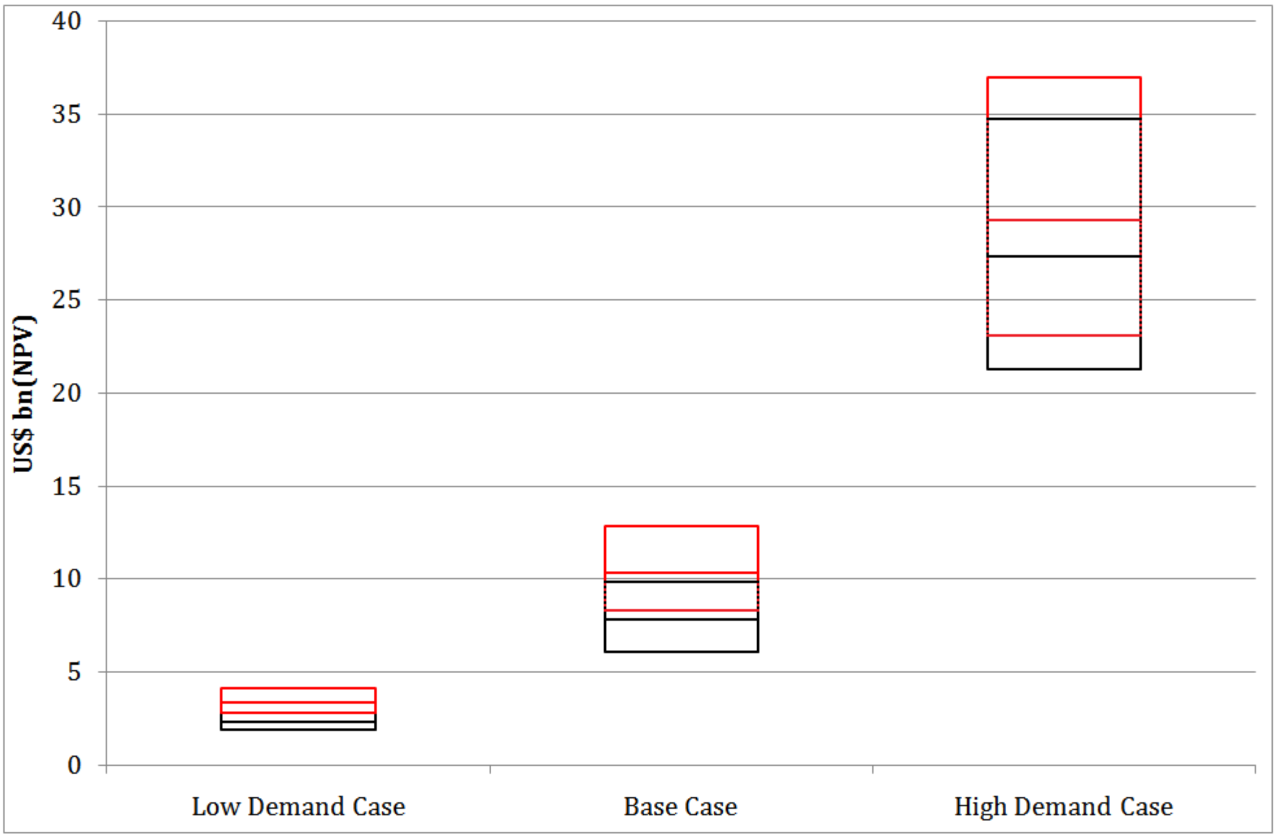

Figure 3.7: Impact of Ukraine's Transit Fee on the Value of the Nord Stream System

It should be noted that the dynamics of Ukraine's transit fee reported in Figure 3.8 are only for the transit fee from the Russia-Ukrainian border to the Ukrainian-Slovak border. Transit fees through Ukraine to other directions, such as Turkey and other Balkan countries, are not reduced because the Nord Stream pipeline only transports gas to Western European markets. Therefore, the expected additional gain from investing in Nord Stream to Gazprom is limited to transit cost savings associated with a reduction in transit fees through Ukraine's western transit pipelines only (not the Trans-Balkan route through which gas is transported to Bulgaria and further to Turkey).

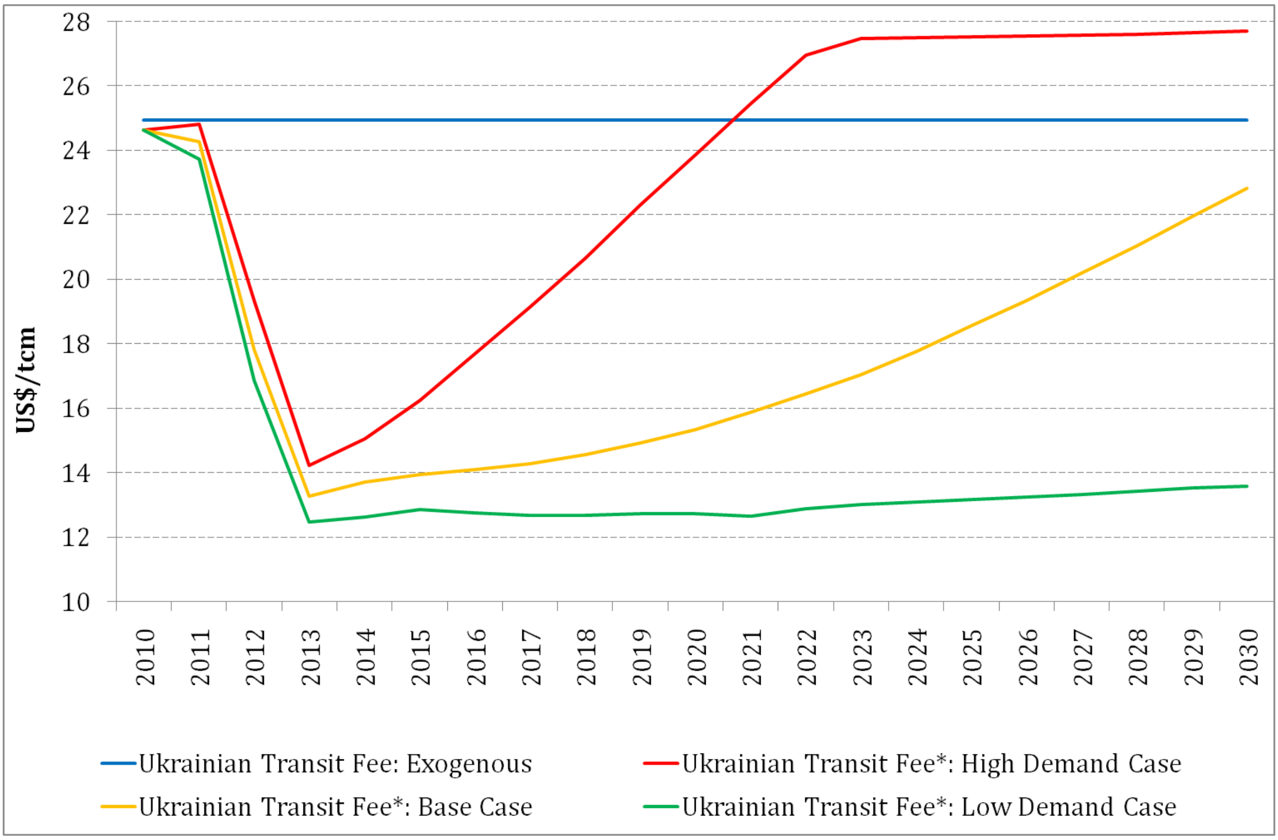

Figure 3.8: Ukraine's Transit Fees under Different Assumptions and Scenarios
Note: * Endogenous

3.10. Summary and conclusions

Three factors contribute to the positive economic value of the Nord Stream pipeline system: the lower transportation cost compared to existing options (the economic fundamentals of the project), the impact of Nord Stream in terms of lowering Ukraine's transit fee, and the insurance against transit disruption risks through Ukraine.

Our results show (Figure 3.9) that the economic fundamentals guarantee that the pipeline's owners will get 66% of the maximum achievable net present value under the low demand scenario. In the base and high demand cases, the economic fundamentals of the project contribute about 73%-91% to the maximum achievable project value. If Ukraine reduces its transit fee because of the building of Nord Stream, this is worth 24%-31% of the maximum achievable value of the project in the low and base case demand scenarios and about 7% for the high demand case. The contribution of the insurance against transit disruption to the value of Nord Stream (under the severe disruption case) is relatively modest at about 3% in all three demand scenarios.

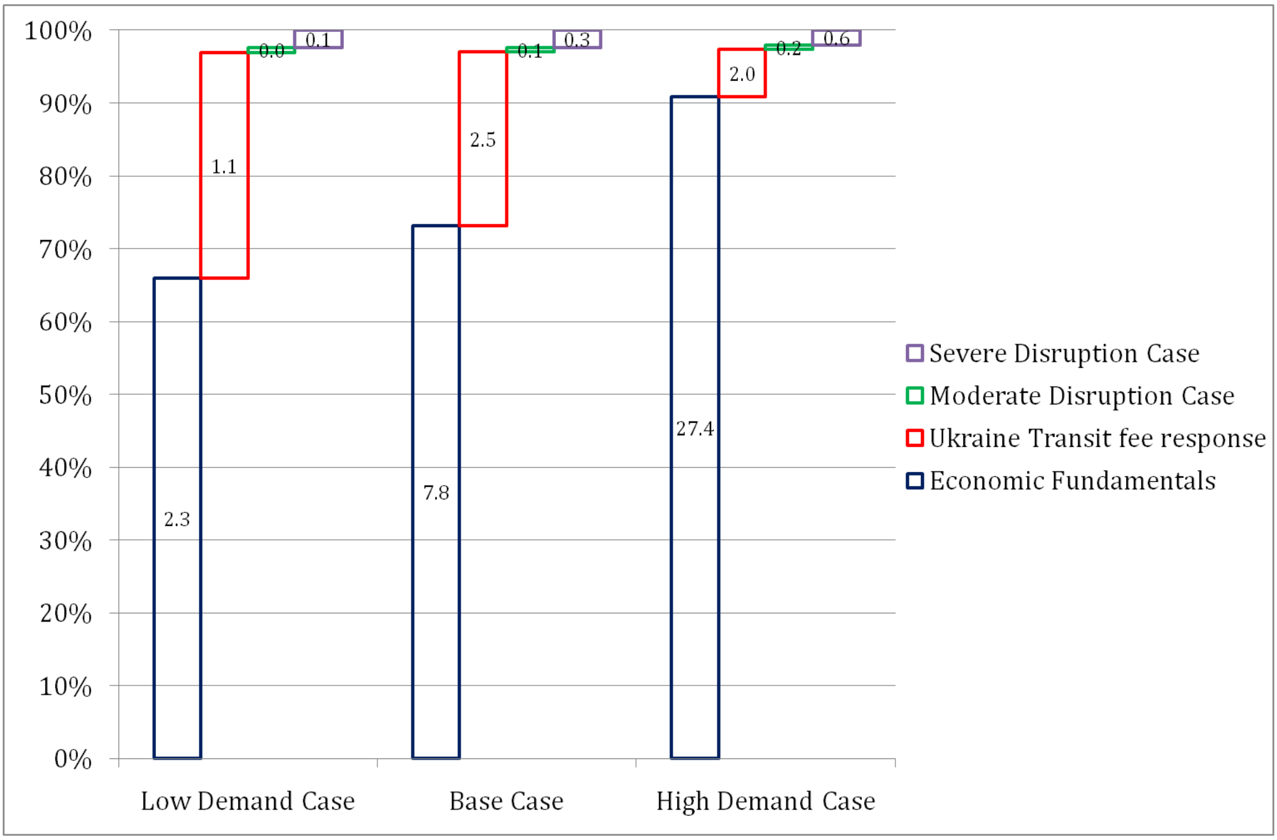

Figure 3.9: Maximum Value of the Nord Stream System[84]

As mentioned at the beginning of this article, the policy literature about Nord Stream generally presents the project as geopolitical, and concludes that it is more a part of Russia's foreign policy than it is of Gazprom's business strategy (see, e.g., (Christie, 2009b)).[85] We find Nord Stream to be profitable even under a scenario of declining gas demand in Europe. Our results tend to give credence to claims by an executive of E.On Ruhrgas, the second largest shareholder in Nord Stream, that *"we expect to get our money back in the long run"* (cited in Gilbert, 2010, p.40) (Gilbert, 2010). However, our analysis does not uphold the idea, widespread among German politicians and commentators that Nord Stream is primarily about additional net European imports from Russia. Our results show that the economic case for Nord Stream primarily rests on

[84] Figures in each bar are in US$ bn (present worth). The reported potential values of the Nord Stream system are those to Gazprom.

[85] Specifically, Christie (2009b, p.20) noted: *"... my recent work on the topic concludes that Russia's motivation for the project is geopolitical, i.e. to accept a partial loss of commercial profits in exchange for stronger political leverage over Central and Eastern Europe."* By partial loss Christie suggested that Nord Stream might still have positive NPV but there are alternative pipelines (such as upgrading Ukrainian transit pipelines or the Yamal-Europe II pipeline crossing Belarus and Poland) with, perhaps, a higher NPV; that is, Nord Stream is sub-optimal from a general economic viewpoint (Christie, 2009b). This insight is partly based on research by Hubert and Suleymanova (2008) (cited in Chistie 2009b). However, Hubert and Suleymanova (2008) found that Nord Stream is sub-optimal due to investment commitment problems among transit countries.

overcoming the dominant position of Ukraine as a provider of transit services. In our base case scenario for EU gas demand, more than 71% of the gas flowing through Nord Stream over the lifetime of the project is diverted away from the existing transit corridors, mainly Ukraine. Finally, Nord Stream's positive net present value does not mean that the project has no serious political implications for Europe (Middleton, 2009), but discussing them is beyond the scope of this paper.

CHAPTER 4

The Economics of the South Stream pipeline in the context of Russo-Ukrainian gas bargaining

4.1 Introduction

In 2009, natural gas consumption in the European Union (EU) totalled 503 billion cubic metres per year (bcm/y) (IEA, 2010a), of which indigenous production accounted for 34%.[86] By 2030, natural gas consumption in EU27 is projected to grow at an annual growth rate of +0.6% (EC, 2008b) or +0.7% (IEA, 2009). Meanwhile, EU indigenous production is anticipated to decline substantially (EC, 2008b), and thus consumption will have to be increasingly met with external sources.

In 2009, Russian gas exports amounted to roughly one quarter of EU natural gas consumption (BP, 2010a). Around 70% of Russian gas to Europe is transported through Ukraine before entering European markets (for details of Gazprom's existing export capacities to Europe see Appendix L). Russia's "difficult" gas relations with Ukraine since the fall of the USSR have resulted in several major gas transit disruptions. Incidents include transit disruptions though Ukraine for 4 days in January 2006 and the more severe disruption through Ukraine of two weeks in January 2009, affecting millions of customers in South-Eastern Europe and the Western Balkans (Pirani et al., 2009; Kovacevic, 2009; Silve and Noël, 2010).

Since the 1990s, Gazprom has started the construction of export pipelines aimed at bypassing Ukraine. It began with the Yamal-Europe I pipeline through Belarus and Poland in the 1990s. Recently, Gazprom and its large West-European clients initiated construction of the second bypass pipeline - Nord Stream, under the Baltic Sea. Moreover, within few years, Gazprom plans to build another pipeline – South Stream,

[86] Author's own calculations based on (IEA, 2010a; BP, 2010a).

under the Black Sea. The combined export capacity of the two latest bypass projects would exceed current Russian gas exports through Ukraine. Assuming that the Nord Stream pipeline is already under construction, the objective of this analysis is to examine the economic rationale of Gazprom's investment in the South Stream pipeline.

The major contributions of this analysis to the debate on Russia's bypass pipelines and its strategic gas policy towards Ukraine are as follows: (i) to our best knowledge, this paper presents the first detailed economic analysis of the South Stream pipeline; and (ii) Russo-Ukrainian gas negotiations in the context of South Stream have not been analysed before. The question that we seek to answer with this analysis is as follows:

- What is the economic value of the South Stream project to Gazprom under:
  1. different scenarios of gas demand in Europe,
  2. different scenarios of transit interruptions through Ukraine, and
  3. different scenarios of transit fees through Ukraine?

The rest of the Chapter is organized as follows. We review existing literature concerning the South Stream project in Section 4.2. In Section 4.3 we outline the research framework. Before presenting the results, we summarize the gas simulation model in Section 4.4 and outline major assumptions and scenarios of the analysis in Section 4.5. Then, in Section 4.6, we present the major findings. In Section 4.7 we conclude the analysis.

4.2. Literature Review

This section briefly summarizes the existing literature and debate surrounding the South Stream project. It begins with a brief summary of the current policy literature concerning Gazprom's investment in the South Stream project; particularly, its competition with the EU-backed Southern Gas Corridor. Then, the security of supply reasoning used to justify costly investment in South Stream, which saturates both expert analysis and media commentary, is discussed. Finally, limited efforts in the energy economics literature to systematically analyse South Stream investment are outlined.

Since its inception, the South Stream project has become politically controversial. This is especially true in the context of the EU's Southern Gas Corridor.[87] The new gas

[87] The Southern Corridor is a mix of pipeline projects that are supported by the EU: Nabucco, ITGI and White Stream.

transport corridor is intended to bring gas to Europe from the Caspian region and the Middle East, bypassing Russia. The majority of analyses in the public domain focus on South Stream as a pipeline project that intends to foreclose potential competition coming from the Southern Gas Corridor (among others, see e.g., (Finon, 2009; Lajtai et al., 2009; Hoedt and Beckman, 2010; Paszyc, 2010)).[88] Thus, the on-going debate concerning competition between the South Stream project and the Nabucco pipeline (the core project of the EU's Southern Gas Corridor) has led to the emergence of two camps – the supporters of South Stream and its opponents (Kazmin, 2009). In general, the supporters of South Stream argue that the project will 'feed' energy-hungry European markets and, more importantly, will improve the security of Russian gas supplies to Europe. On the other hand, the opponents question the economic feasibility of the South Stream project and its cost efficiency compared to the Nabucco pipeline. Further, they argue that the project will increase Europe's dependence on Russian gas, which contradicts its official policy goal of limiting its dependence on any one external supplier.

In the context of Russo-Ukrainian gas relations, South Stream is mainly viewed as a Ukrainian transit avoidance pipeline that would improve security of Russian gas supplies to Europe (see e.g.,(Stern, 2009a):p.12 and (Pirani et al., 2009):p.39). Some experts argue that costly investment in South Stream could be justified if the transit risk premium through Ukraine is taken into account (see, e.g. (Finon, 2009:p.12)). Also, a few analyses briefly mention South Stream's strategic role in advancing Russia's political goals in Ukraine (see, e.g., (Michaletos, 2008; Nicola, 2010)). The reasoning is that, if South Stream is built, then most gas flows through Ukraine would be diverted to South Stream, putting substantial economic and, therefore, political pressure on Ukraine.

In general, the mainstream view on the South Stream project is based on the implicit assumption that the South Stream project is very costly and that using the Ukrainian transit system remains the cheapest option for Gazprom to export gas to Europe. Thus, so goes the view, South Stream investment may have: (*i*) political value to the Russian government, e.g., in advancing its influence over its 'near abroad' area and/or as a means of consolidating domestic support for Russia's current leadership[89], (*ii*) strategic economic value to Gazprom (foreclosing competition from the Europe's

[88] The web portal (Euractiv.com, 2011) contains concise and structured information about Europe's Southern Gas Corridor and its competing projects, including major political and expert views on this matter.
[89] See (Baev and Øverland, 2010) for a detailed discussion concerning the view of South Stream as a mega-project in consolidating domestic public support for Russia's 'tsarist' leadership.

southern corridor), and (*iii*) security of supply value to Gazprom and European consumers (South Stream as Gazprom's insurance against possible transit interruptions through Ukraine).

Despite the mainstream view in the policy literature on the South Stream project, there are very limited systematic analyses of South Stream investment in the energy economics literature that would examine some of the above-mentioned policy conclusions.

Dieckhöner (2010) has used the TIGER natural gas infrastructure model to evaluate the importance of the Nabucco and South Stream projects to the security of gas supplies to Europe in terms of the risks of transit interruptions through Ukraine.[90] The author has found that, while both the Nabucco and South Stream projects increase security of supply to South-Eastern Europe, the latter project seems to be a better 'security' option than the former project when transit through Ukraine is disrupted (Dieckhöner, 2010). Nevertheless, Dieckhöner (2010) has not attempted to analyze whether it is economically justifiable for Gazprom to invest in South Stream in light of transit interruptions through Ukraine.

Whereas Dieckhöner (2010) has focused on security of supply issues, Smeenk (2010) has attempted to quantify the economic value of South Stream investment, focusing on the project as Gazprom's pre-emptive strategy. Smeenk (2010) has used a real-option game approach in his analysis. Specifically, South Stream investment was anlayzed using a two-stage game involving only Gazprom, assumed to be a dominant player, and a potential competitor/entrant. Smeenk (2010) has found that the net present value, NPV, of South Stream investment is positive due to economies of scale and strategic pre-emption. Smeenk has made a number of simplifications at both theoretical and empirical levels, which, if adressed in greater detail, may change the author's results and conclusions.

Firstly, although Gazprom supplies a quarter of the EU's annual gas consumption, this does not necessarily mean Gazprom will enjoy a first-mover advantage in South Stream investment, which requires substantial investment resources and political support from the EU.[91] Secondly, the assumed market structure (duopoly) is rather simplistic. Thirdly, the assumption that an entrant cannot make a strategic investment is

[90] See (Lochner and Dieckhöner, 2010) for a description of the model and its applications.
[91] Gazprom intends to obtain political support for its South Stream project from the European Union in general and EU member countries in particular in order to achieve the same status as other pipelines that form part of EU-backed Southern Gas Corridor (Gazprom, 2010h).

rather ad-hoc, and sensitivity analysis on who moves first and what each player can do (i.e., invest strategically or commercially) is desirable.

At the empirical level, Smeenk (2010) has used an industry average CAPEX per unit of pipeline diameter and length in deriving capital costs for South Stream and a competing project. The CAPEX for pipelines varies greatly from one project to another due to project-specific factors such as route, financial strategy (such as debt/equity financing ratio) and business model ('merchant' pipeline or a pipeline project that is part of a vertically integrated company). Moreover, Smeenk has focused the analysis entirely on potential net growth in gas import demand, thus, avoiding the issue of Gazprom's existing markets and utilization of existing routes (Ukraine, Belarus and Blue Stream). Furthermore, an assumption is made according to which gas flows through Ukrainian pipelines will gradually fall in line with a decrease in Gazprom's supply commitments under its existing long-term contracts; i.e., it is assumed that the servicing of new contracts will be shifted to South Stream. Thus, it was implicitly assumed that, either because of security of supply reasoning or due to cost efficiency, Gazprom will definitely use South Stream instead of the Ukrainian route. However, Smeenk (2010) has provided no analytical basis to support this assumption.

Despite the shortcomings in Smeenk's quantitative analysis, the author has provided a comprehensive qualitative framework (partly based on the framework advanced by (Victor et al., 2006)) to analyze Gazprom's infrastructure investments, and the aim of his stylistic quantitative model is to supplement his qualitative results.

To summarize, policy literature is rather ambiguous regarding the South Stream project, and limited efforts have been invested in quantifying and testing some of the policy conclusions. Therefore, the aim of this analysis is to focus on South Stream investment in the context of Russo-Ukrainian gas relations and risks of transit interruptions through Ukraine. In order to be rigorous and systematic, the analysis presented here focuses only on the cost efficiency of South Stream compared to the utilization of existing pipelines through Ukraine, taking risks of transit interruptions into account. This analysis does not attempt to reveal any strategic pre-emption value of South Stream investment and cost efficiency in pursuing this strategy.[92] The Southern Gas Corridor and competition for the energy resources (and thus competition between pipeline projects) of Central Asia and the Middle East is a complex issue with many

[92] The question of whether pre-empting a competing project (e.g., Nabucco) through the Ukrainian route would be more efficient than through the South Stream system desires a separate analysis, which is adressed in a forthcoming paper.

stakeholders/players involved, and this analysis is by no means able to cover the whole complexity but only contribute to an understanding of the role and the relevance of Ukraine, as a major transit country of Russian gas, in motivating Gazprom to invest in the South Stream pipeline system.

4.3. Methodology

The analysis presented in this chapter is based on two interconnected steps. Firstly, the cost of building and using the South Stream system is derived. Secondly, using a strategic, game-theoretic Eurasian gas trade model, the economic value of South Stream system to Gazprom is derived under different scenarios of market developments. The following sections focus on the derivation of the value of South Stream. For details of the derivation of the costs of South Stream, uncertainty analysis of these costs and related assumptions, see Appendix H.

4.3.1. Economic Value of South Stream investment

The logic of cost-benefit analysis is followed in the derivation of the economic value of the South Stream system under different scenarios and assumptions. The value of South Stream investment is derived by comparing Gazprom's anticipated total profit between 2011 and 2040 when the South Stream project is built with Gazprom's profit when it is not built.[93] This is shown in the following equation:

$$PV^{SS} = \sum_{t=2011}^{2040} \frac{(Profit_t^{+SS} - Profit_t^{-SS})}{(1 + Discount\ Rate)^{(t-2011)}} \tag{4.1}$$

where PV^{SS} is the present value of Gazprom's investment in the South Stream system, $Profit_t^{+SS}$ is Gazprom's annual profit when the South Stream system has been built, and $Profit_t^{-SS}$ is Gazprom's annual profit if the pipeline has not been built; the discount rate

[93] South Stream's economic lifetime is assumed to be 25 years. Since it is assumed that South Stream will be built by 2016, the time frame of the analysis goes up to 2040 to cover the lifetime of the project.

applied to this calculation is the South Stream project discount rate discussed in Appendix H. Gazprom's profit under different scenarios and assumptions is derived from the gas market model described in Chapter 2.

4.3.2. Economic Value of South Stream in terms of Risks of Transit Disruptions

The expected present value of the South Stream system in terms of risks of transit interruptions through Ukraine is computed as follows:

$$E[PV_d^{SS}] = PV^{SS} + P_{td}\left[\sum_{t=2011}^{2040} \frac{(Profit_{td}^{+SS} - Profit_{td}^{-SS})}{(1 + Discount\ Rate)^{(t-2011)}} - PV^{SS}\right] \tag{4.2}$$

where $E[PV_d^{SS}]$ is the expected NPV of South Stream investment under transit disruption scenario d, $Profit_{td}^{+SS}$ is Gazprom's profit under transit disruption scenario d when South Stream is built, $Profit_{td}^{-SS}$ is Gazprom's profit under transit disruption scenario d if the South Stream system is not built, and P_{td} is the probability of transit disruption d through Ukraine in year t, which is assumed to be a random variable with uniform distribution in [0;1].

Gas transit interruptions through Ukrainian pipelines are implemented as follows: (i) we run our gas simulation model under different demand scenarios, (ii) we record Russian gas transit quantities through each pipeline of the Ukrainian transit system, and (iii) we then set (exogenously) limits on these transit quantities according to the assumed transit disruption scenario d (see Section 4.5: Table 4.3).

One should note that the timing of disruptions through Ukraine, i.e. when exactly interruptions might occur in the time frame of our analysis (2011-2040), makes a difference to the expected NPV of South Stream investment, since a disruption in 2012, for example, has a different value to Gazprom than the value of an interruption occurring in 20 years, due to discounting (and the larger the discount rate the larger should be such differences). Thus, an 'impatient' Gazprom would prefer to have South Stream at its disposal as soon as possible if it expects transit disruptions through Ukraine in the near future. Therefore, deriving the expected NPV of South Stream under assumed disruption scenarios (Table 4.3) is not straightforward, since it is impossible to predict when disruptions through Ukraine might occur between 2011 and 2040 because such predictions depend on a range of known and unknown factors. Thus, for this analysis, it is assumed that a disruption through Ukraine might occur in any year between 2011 and 2040 with equal probability.

Further, it is assumed that Gazprom would not lose any cubic metres of natural gas (i.e. the gas molecules are still in Gazprom's fields) when transit through Ukraine is completely shut. In this sense, there might be little or even no economic loss to Gazprom when transit through Ukraine is disrupted because any gas not sold at that moment can be sold later (admittedly at lower than the present value). Thus, the derived economic value of South Stream under the risks of transit interruptions only reflects Gazprom's savings in terms of financial losses that might arise from transit interruptions through the Ukrainian route when South Stream is built compared to the scenario when the pipeline is not built.

4.4. Model Summary

A strategic gas simulation model, presented in Chapter 2, has been used to quantify the economic value of South Stream under different demand scenarios, transit fees through Ukraine and transit disruption scenarios. Computational gas market models, based on a non-cooperative game-theoretic framework, have been used extensively in recent research on structural issues of European and global gas market developments (see, e.g., (Boots et al., 2004; Zwart and Mulder, 2006; Holz et al., 2008; Egging et al., 2009b; Lise and Hobbs, 2009; Zwart, 2009)).[94] Security of gas supply to Europe (both long-term resource and infrastructure availability and short-term gas disruption events) has also been analysed using gas market models (see e.g., (Holz, 2007; Egging et al., 2008; Lise et al., 2008)).

The strategic gas market model applied to this analysis contains all gas producers and consumption markets in Europe (see Table 4.1). The model includes the following players: producers, transit countries, suppliers, consumers, transmission system operators (TSO) and LNG liquefaction and regasification operators. The objective of each player in the model is to maximize the profits from their core activities.

[94] For an exhaustive review of gas simulation models applied to the analysis of European gas markets see, e.g., (Smeers, 2008).

Table 4.1: Gas producing and consuming countries in the model

Consuming countries		Producing countries	
Finland	Slovak Republic	Algeria	Romania
Baltic States[95]	Czech Republic	Azerbaijan	Russia
Austria	Hungary	Denmark	Trinidad and Tobago
Belgium	Romania	Egypt	Turkmenistan
Spain and Portugal	Poland	Germany	UK
France	Turkey	Hungary	Ukraine
Netherlands		Italy	Uzbekistan
Italy		Kazakhstan	
UK		Libya	
Germany		Netherlands	
Slovenia		Nigeria	
Bulgaria		Norway	
Balkan States[96]		Oman	
Croatia		Poland	
Greece		Qatar	

Producers and consumers are connected by pipelines and by bilateral LNG shipping networks. Therefore, producers must pay transmission fees and LNG costs to transport gas to consuming countries. It is assumed that producers can exercise market power by playing a Cournot game against other producers. However, TSOs are assumed to be competitive and to grant access to the pipeline and LNG import infrastructure to those users who value transmission services the most.[97] This would result in transmission and LNG regasification fees based on long-run marginal costs and a congestion premium if infrastructure capacity constraints are binding. Although producers can exercise market power by manipulating sales to suppliers, it is assumed that producers are price-takers with respect to the cost of transmission and LNG services. These assumptions are consistent with other strategic gas models (Boots et al., 2004; Egging et al., 2008; Lise and Hobbs, 2008).

In each consuming country there are a certain number of gas suppliers who buy gas from producers and re-sell it to final customers, paying distribution costs. Following

[95] Baltic States: Estonia, Lithuania, Latvia; Iberian Peninsula: Spain and Portugal
[96] Balkan States: Serbia, Bosnia and Herzegovina, Macedonia and Albania
[97] As Smeers (2008) argues, the assumption of the efficient pricing of transmission costs is somewhat optimistic and diverges from the reality of natural gas transmission activities in European markets. However, recent agreements between private companies and European antitrust authorities (such as the capacity release programme agreed between GDF SUEZ, ENI, E.ON and the EC) promise much more competitive access to both transmission pipelines and LNG import terminals (EC, 2009a; EC, 2009b; EC, 2010).

Boots et al. (2004), the operation of suppliers is modelled implicitly via the effective demand curves facing producers in each country.[98]

Final prices for natural gas may differ among countries (markets). Partly, this is due to the geographical locations of consumers and producers - countries that are closer to gas sources enjoy lower prices than countries that are further from gas sources because of the considerable transportation costs, including possible congestion fees on transmission pipelines and transit countries' mark-ups due to the exercise of market power. Apart from differences in transport costs, gas prices can also differ significantly due to different degrees of competition among producers and suppliers in a particular national market.

4.5. Scenarios and Assumptions

Future gas demand in Europe, as well as gas prices, may greatly influence the economics of the South Stream project. The analysis of South Stream is carried under three scenarios of European gas demand (see Table 4.2). The base case scenario is based on the IEA's 2009 forecast (IEA, 2009), while for our high demand case we average the projected growth rates from the IEA's *World Energy Outlook* (WEO) published between 2000 and 2007. For our low demand case, we assume that European gas consumption will decline at a rate of 0.1% per annum, similarly to the WEO 2009's "450 Scenario". The gas prices used in the model are based on the IEA's (2009) price outlooks. Since it is assumed that the economic life time of the South Stream system is 25 years, and that the pipeline will come into operation in 2016, the period of the analysis is 2011-2040; thus it is assumed that gas demand, prices and all other parameters are constant after 2030.

[98] In the derivation of the effective demand curve, suppliers operating in each country are assumed to be identical. As Smeers (2008) argues, this assumption does not correspond to the reality of European downstream markets.

Table 4.2: Assumed growth rate of gas consumption and prices: 2010-2030

	High Demand Case	Base Case	Low Demand Case
Average Compound Annual Growth Rate of Gas Demand			
Western and Southern Europe	+2.07%	+0.7%	-0.1%
Central and Eastern Europe	+2.07%	+0.8%	-0.1%
Balkan Countries	+2.07%	+0.8%	-0.1%
Average Compound Annual Growth Rate of Gas Prices			
All consuming countries in the model	+1.4%	+1.4%	+0.3%

In order to derive the NPV of South Stream in terms of the risks of transit interruptions through Ukraine, the following disruption scenarios are assumed:

Table 4.3: Transit Disruption Scenarios through Ukraine

Disruption Scenarios	Duration of Disruptions	Frequency of Disruptions	Total days of disruptions
Moderate Disruption Case	3 weeks	5 disruptions in 2011-2040	105 days
Severe Disruption Case	6 weeks	10 disruptions in 2011-2040	420 days

The disruption scenarios are for analytical purposes only and do not constitute forecasts of transit disruptions through Ukraine. To simplify the analysis, it is assumed that the probabilities of disruptions in any period are independent (e.g. gas transit disruption in 2009 through Ukraine has no effect on the probability of future disruptions through Ukraine.). Also, it is not distinguished when exactly the disruption would occur during a particular year (winter or summer), which would require explicit modelling of storage in the gas simulation model. Therefore, the results should be treated as annual average values.

To derive the NPV of South Stream investment under different assumptions about transit fees through Ukraine, the following scenarios are considered:

Table 4.4: Scenarios of Transit Fees through Ukraine (US$/tcm/100km)

	Short-Run Transit Cost	Transit fee under current contract	High transit Fee
Transit fee	0.50	2.07	5.11

The transit fees assumed in Table 4.4 exclude fuel costs for compressors. This cost, which amounts to 3% of total transit volume (Ukrainska Pravda, 2009), is accounted for in the simulation model as additional gas provided by Gazprom in kind (see model formulation in Chapter 2).

It was reported that for gas transportation services through the Belarus' section of the Yamal-Europe pipeline, Gazprom pays US$ 0.50/tcm/100km to Beltransgaz (the operator of the Yamal-Europe pipeline) which includes only the operating and O&M costs of the pipeline. For this analysis, this value (US$0.5 per tcm/100km) is assumed for SRMC through the Ukrainian transit system.

According to the current long-term transit contract, the transit fee through Ukraine is determined based on a formula which specifies the dynamics of the transit fee as a function of the inflation rate in Europe and the gas import price for Ukraine (Ukrainska Pravda, 2009). The average value of the transit fee based on this formula is US$ 2.07/tcm/100 km (for details of the calculation of this value see Appendix E: Section 7.3.1).

For the high transit fee scenario we assume US$ 5.11/tcm/100km. This particular transit fee was taken from (Kovalko and Vitrenko, 2009a). These authors argue that US$ 5.11/tcm/100km is an economically justifiable transit fee that Gazprom should pay. The analysis presented by Kovalko and Vitrenko (2009a) contains a quite detailed financial and economic analysis of Naftogaz's transit activities.[99]

Further, in this analysis it was assumed that downstream gas suppliers in European markets are competitive. Similarly to the analysis of the Nord Stream system (see Chapter 3), for this enquiry it is assumed that producers and downstream suppliers act simultaneously to extract the whole monopoly profit from the market and then share that profit relative to their bargaining power. Therefore, we assume that Gazprom receives about half of the total revenue calculated as final prices (see Table 4.5).

[99] Both Kovalko and Vitrenko were senior officials at Naftogaz responsible for transit and supply pricing policy (until 2007, Mr. Kovalko was Deputy CEO of Naftogaz and Mr. Vitrenko was Chief Advisor to the CEO of Natogaz). Officials from Naftogaz of Ukraine suggested this article (Kovalko and Vitrenko, 2009a) as an example of what could be an "economically" justified transit price (Naftogaz of Ukraine, 2009).

Table 4.5: Real Border and Final prices (US$/tcm)

	Average gas price at German Border[a] [1]	**Average final price in Germany**[b] [2]	**Border price as % of final price** [3]
2002	121	246	49%
2003	153	285	54%
2004	163	329	50%
2005	223	426	52%
2006	305	545	56%
2007	310	644	48%
2008	446	734	61%
2009	349	649	54%
Average			***53%***

Source: [a]*(Gas Strategies, 2010);* [b]*(Eurostat, 2010)*
Note: [3]=[1]/[2]x100%

As was mentioned, since the Nord Stream pipeline is already under construction, in this analysis it is assumed that the pipeline will be operational by 2013 with a total transport capacity of 55 bcm per year. Further, Belarus' transit pricing and the possibility of exerting market power vis-a-vis Gazprom can also be simulated with the model. However, for this analysis we assume that Belarus' transit fees are fixed at 2010 levels. This would not affect our results since the Yamal-Europe route and the South Stream route are destined to reach distinctly different markets. All other market assumptions, such as gas infrastructure capacities and costs (production, transport etc.), used for this analysis are extensively documented in Appendix E.

4.6. Results

In this section, the main results of this analysis are presented. First, the costs of building and using the South Stream pipeline are presented in the next section. Then, in Section 4.6.2, the economic value of South Stream investment under different demand scenarios in Europe is discussed. In Section 4.6.3 the analysis of the transit risk premium is presented, and Sections 4.6.4 and 4.6.5 outline the bargaining value of South Stream.

4.6.1. The Costs of Building and Using South Stream

The first step in the analysis of the economics of the South Stream route is to compare the unit cost of transporting through this new system with that of the

Ukrainian route. This comparison requires a derivation of the total investment cost of the South Stream system. Then, on the basis of these cost estimates, levelised transportation costs, LTC, between different production fields (in Russia and in Central Asia) and a particular final gas market are calculated. The LTC through South Stream is derived by dividing the present value of the total investment cost of the South Stream system by the present value of the total volumes of gas transported over 25 years through this system. South Stream's investment cost was derived using the methodology presented in Appendix F and data described in Appendix H. Figure 4.1 shows the minimum, the average and the maximum values for each component of the South Stream system. These figures include the construction cost, the cost of compressors and the cost of debt financing.

The total investment cost of the South Stream system varies between US$ 23 bn and US$ 32 bn. The single largest component of the South Stream system is the offshore pipeline underneath the Black Sea, which accounts for about 60% of the total capital cost of the system.

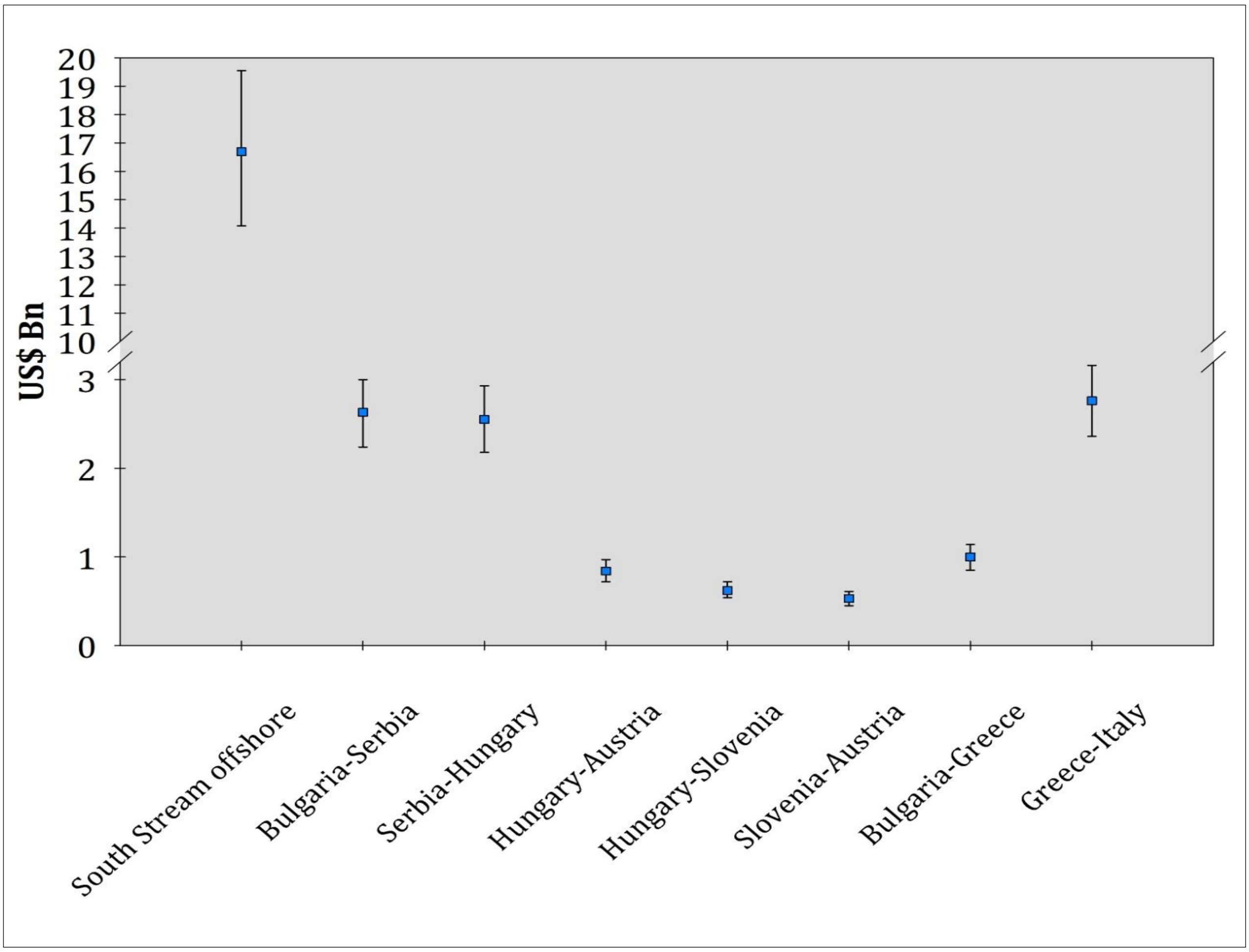

Figure 4.1: South Stream's Total Investment Cost

Figures 4.2 and 4.3 show the average levelised transportation costs (with 90% confidence intervals) from major gas production sites in Russia and Central Asia to Italy and the Balkan countries. The levelized cost through the South Stream system was derived assuming that the system would be fully utilised during its economic life-time. The levelized costs show how much each pipeline should charge in order to pay back its investment costs and annual O&M costs (for details of the calculation of levelized transport costs see Appendix G).

As envisaged by Gazprom (see Figure H.1 in Appendix H), the South Stream route allows the company to export gas to Italy through the northern route (South Stream North [N]), passing through Serbia, Hungary and Slovenia, and the southern route (South Stream South [S]), through Greece and under the Ionian Sea to South Italy. Thus, according to the cost estimates of the South Stream pipeline, it is cheaper to export gas to Italy via Ukraine if the gas originates from Russia or Turkmenistan (Figure 4.2). The southern route of the South Stream pipeline is a bit more expensive than its northern route due to a higher taxation rate in Greece and also due to the higher construction costs of the offshore pipeline that goes under the Ionian Sea. However, transporting gas from the Azeri-Russian border through South Stream appears to be cheaper than using the Ukrainian pipelines.

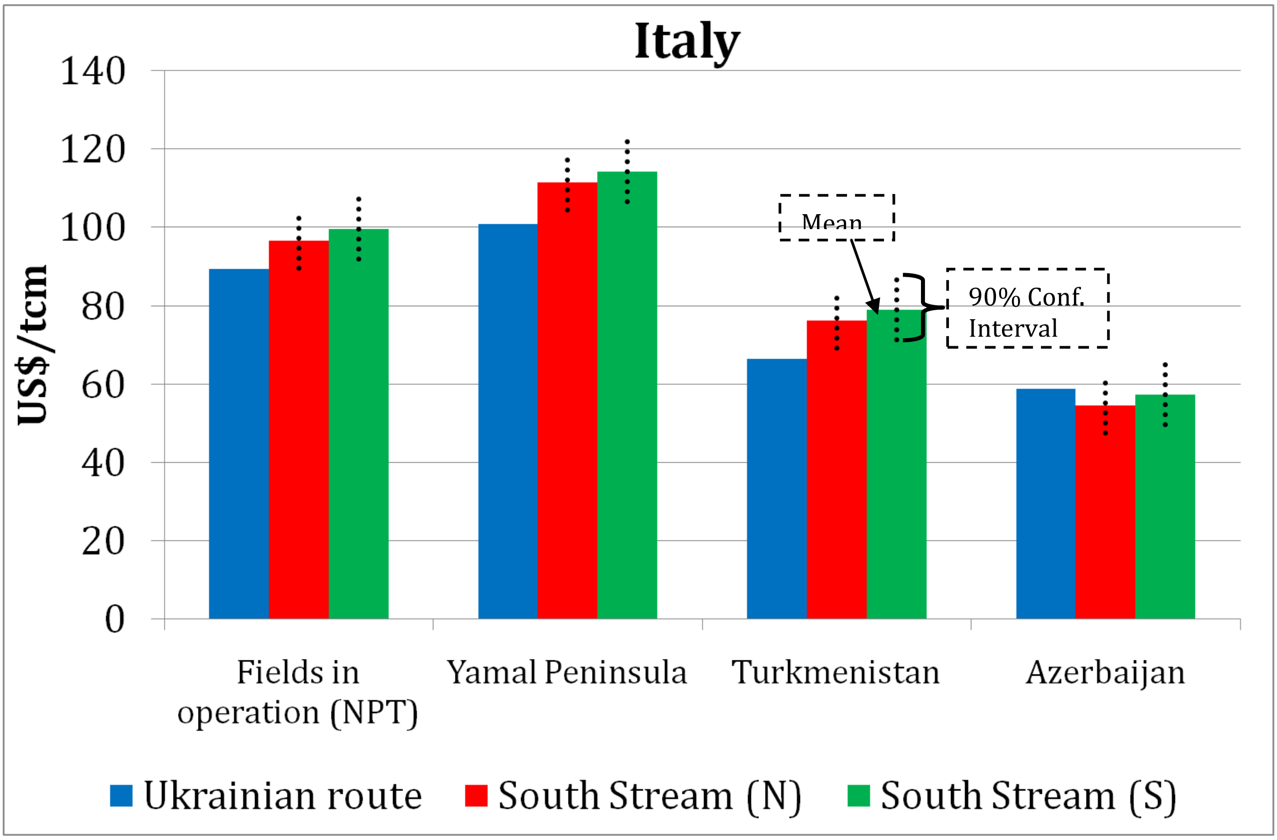

Figure 4.2: Transportation Costs to Italy[100]

South Stream can be used to supply gas along its route, e.g. to Bulgaria, Turkey, Greece and Serbia.[101] Figure 4.3 reports the average transport costs through the Ukrainian pipelines and South Stream to these markets. It is clear that, for these four markets, Gazprom should use the South Stream pipeline as it appears to be cost competitive compared to the Ukrainian route. However, one should note that these four markets are smaller than Gazprom's two largest markets – Germany and Italy. In 2009, Gazprom's total supplies to these four Balkan markets were 26 bcm, while its total supplies to Germany and Italy were 53 bcm (Gazprom, 2010b). Moreover, Gazprom has constructed the Blue Stream pipeline to Turkey, was partly based on debt financing, and Gazprom must ensure that the pipeline is sufficiently utilized; therefore, one should expect that Gazprom might divert gas going through the Ukrainian route to Balkan countries but not gas through the Blue Stream pipeline.

[100] South Stream (S) is the southern route of the proposed pipeline system, which will pass through Greece then under the Ionian Sea to South Italy near Otranto; South Stream (N) is the northern route, which will pass through Serbia, Hungary and Slovenia to the Austrian-Italian border, near Arnoldstein (for details see Appendix H: Figure H.1).

[101] Also, gas can be supplied to Hungary, Slovenia, and Austria along the South Stream route.

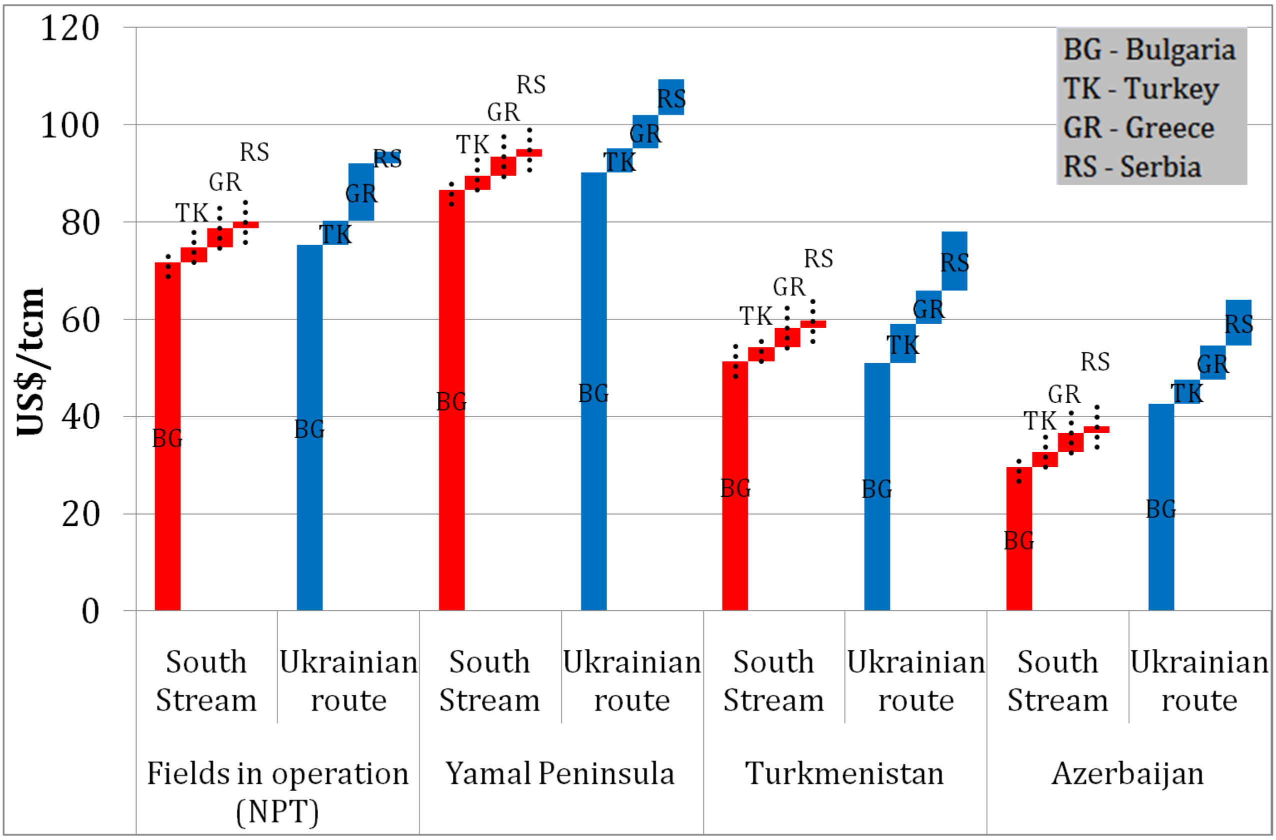

Figure 4.3: Transportation Costs to Southern Europe

In general, the estimated costs of building and using the South Stream pipeline show that the pipeline in its current configuration (i.e. proposed routes and capacities) is not a cost efficient project compared to the Ukrainian route. Therefore, meeting future gas demand and/or pre-empting competing supplies from the Caspian and Middle East regions may be more cost-efficient through Ukrainian pipelines. However, it should be noted that at this point it is still unclear whether the value of the South Stream system to Gazprom will be negative or positive, since this would largely depend on gas demand and prices in Europe, as well as on future transit fees through Ukraine and risks of Ukrainian transit interruptions. In the subsequent sections, the net present value of South Stream investment for Gazprom is discussed.

4.6.2. The Economic Value of the South Stream System

Using the strategic gas market simulation model described in Chapter 2, and following eq. (4.1), the net present value, NPV, of South Stream investment is derived. Figure 4.4 shows the NPV of South Stream investment to Gazprom under the three demand scenarios (see Table 4.2). The black boxes with solid lines represent the minimum, average and maximum economic values of Gazprom's investment in the South

Stream system, assuming average investment, operational and maintenance costs for the project (thus, the variability is due to the variance in discount rates only). The dotted lines show the impact on the project's maximum and minimum NPV of capital and operational expenditures reaching their maximum and minimum values.

In low and base case demand scenarios, the South Stream system brings negative value to Gazprom and only in the high demand case is the value of South Stream investment positive. The average NPV of the South Stream investment is US$ -6 bn in the low demand case, US$ -4.3 bn in the base case and US$ 1.1 bn in the high demand case.

In the best case, when gas demand in Europe is relatively high (at an annual growth rate of +2.07%), and the (total) investment and operational costs of the South Stream system are low, the economic value of the pipeline could be as high as US$ 4 bn over the lifetime of the system. However, in the worst case (i.e. a combination of the highest total investment and operational costs and the lowest gas demand scenario) the NPV of South Stream investment would be US$ -9.2 bn over the lifetime of the pipeline.

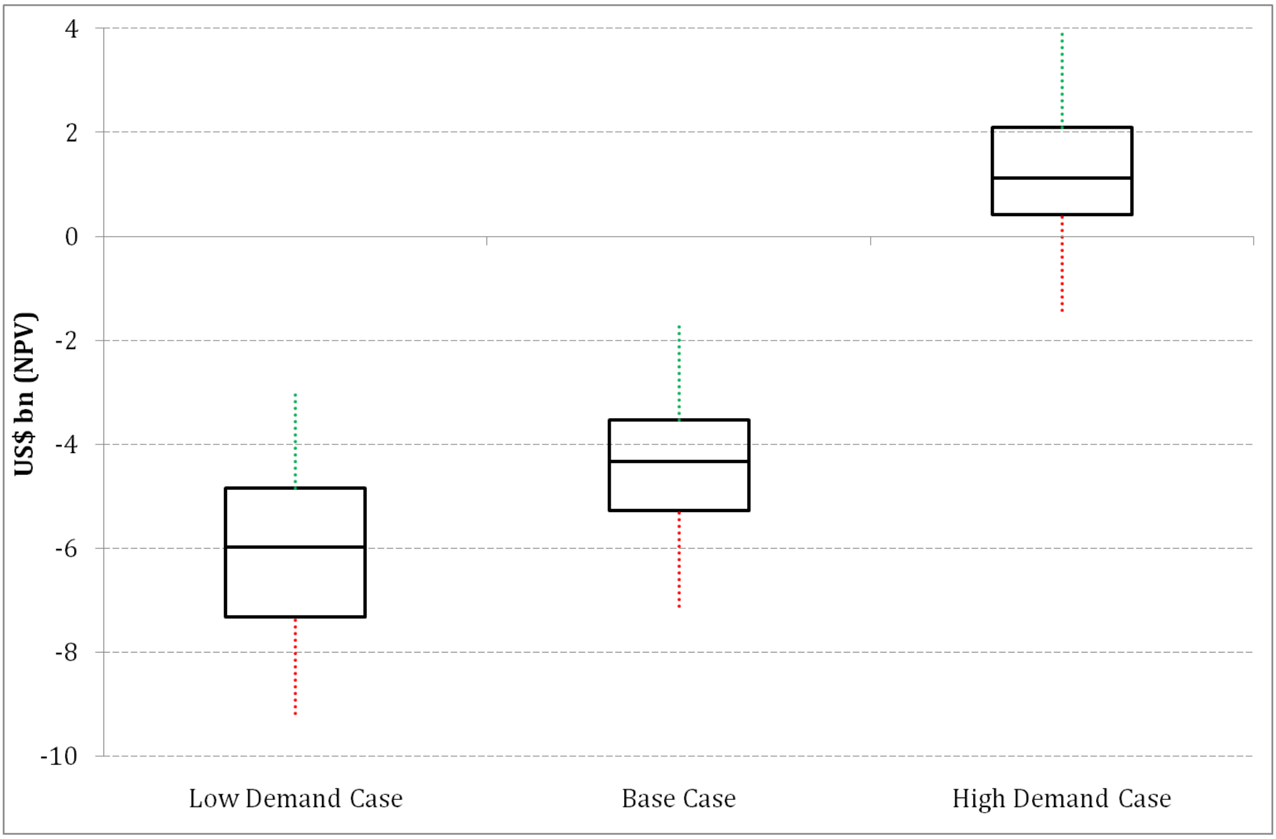

Figure 4.4: NPV of the South Stream System under Different Gas Demand Scenarios

In general, these results confirm the comparative analysis of transport costs through the South Stream and Ukrainian routes presented in Section 4.6.1. Thus, only high demand in Europe justifies construction of South Stream and the project should be viewed as a demand-driven project. If gas demand in Europe expands moderately, then using Ukrainian pipelines is more cost efficient for Gazprom than building South Stream. However, some experts conclude that the risks of transiting gas through Ukraine justify the costly construction of the South Stream system. The next section examines this issue.

4.6.3. The Economic Value of South Stream in terms of Risks of Transit Disruptions

Supporters of South Stream argue that the project will improve the security of gas supplies to Europe and that, if transit risk is taken into account, this might justify the construction of this costly pipeline. Gazprom originally planned that South Stream would have the capacity to deliver 31 bcm of gas; this volume has been seriously reconsidered after two recent “gas wars” (2006 and 2009) with Ukraine. The expected present value of the South Stream system in terms of risks of transit interruptions through Ukraine is computed based on eq. (4.3). Figure 4.5 presents the expected NPV of South Stream investment under different scenarios of transit interruptions and demand growth in Europe.

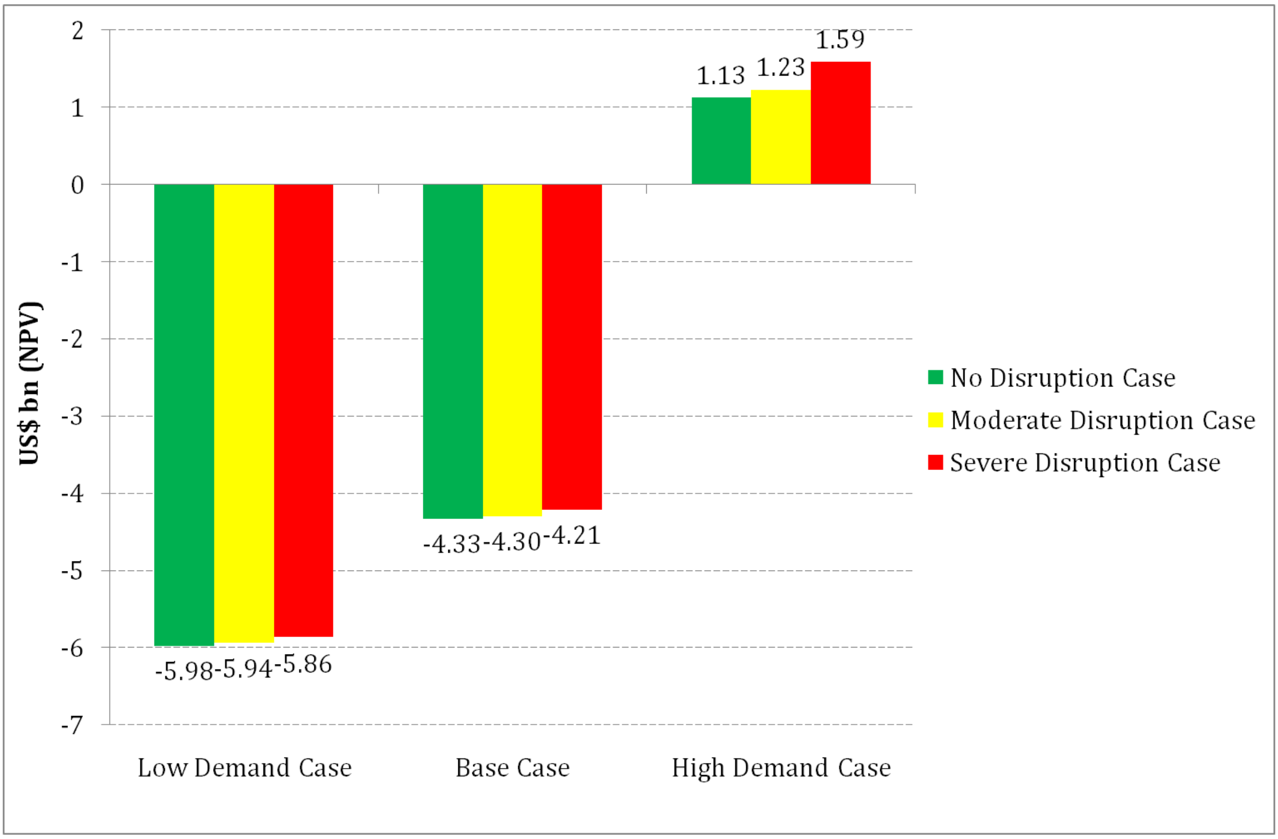

Figure 4.5: Impact of Transit Interruptions on the NPV of the South Stream System

Under the Base Case demand scenario and without any disruption the average NPV of the system is US$ -4.3 bn. In the moderate disruption case, the expected additional NPV of the system, reflecting its expected security premium value, is US$ 0.03 bn (i.e., -4.30-[-4.33]). Under the severe transit disruption scenario, the security value of the South Stream system would be US$ 0.12 bn (i.e., -4.21-[-4.33]). South Stream's expected security premium is rather marginal due to the effect of the operation of the Nord Stream pipeline. The Nord Stream pipeline will divert up to 50 bcm from Ukrainian pipelines and, therefore, Gazprom's loss in cases of transit disruption through Ukraine is smaller.

If one is sure that there will definitely be five (ten) disruptions (i.e., p_t=1, ∀t) between 2011 and 2040, then South Stream's security premium would be US$ 0.06 bn (US$ 0.24 bn). On the other hand, an expectation of no disruption through Ukraine between 2011 and 2040 (i.e., p_t=0, ∀t) results in no transit risks premium for South Stream.

In general, in all scenarios of gas demand in Europe, 'factoring' in risks of transit interruptions through Ukraine would only improve the NPV of the South Stream system marginally and the system's NPV would still be negative, which means that from Gazprom's perspective transit risks do not justify the construction of the South Stream pipeline, as was suggested by the policy literature (see e.g., Finon, 2010).[102]

The preceding results show that only if gas demand in Europe grows at more than 2% per year up to 2030 will the NPV of the South Stream investment be positive, albeit marginally (about US$ 1.1 bn over 25 years). However, that does not mean that there is no case for South Stream, only that the justification might largely rest on other considerations, which we will examine in the next section.

4.6.4. Impact of Transit Fees on the Value of South Stream

In the preceding analysis it was assumed that the Ukrainian transit fee over time is determined according to the 2009 long-term transit contract (see Table 4.4); however, if Ukraine raises (reduces) its transit fees, this will impact the cost efficiency of the South

[102] The economic value of South Stream to European consumers as a security of supply measure might be substantially higher than the security value found for Gazprom. This is due to the fact that the economic costs of 'unserved gas' to a particular country are substantially higher than the financial losses to Gazprom of not being able to export gas at market prices to that country when transit through Ukraine is interrupted.

Stream pipeline compared to Ukrainian pipelines, and thus the NPV of the project may be positive (negative). This section examines this issue.

Using eq. (4.1) and the gas simulation model (Chapter 2), the NPV of Gazprom's investment in South Stream is calculated according to different levels of transit fees. Figure 4.6 reports the results of these calculations. The dotted lines show the impact of the project's investment and O&M costs on South Stream's NPV. Thus, if Ukraine sets its transit fee based on the short-run marginal cost (SRMC), then the average NPV of South Stream investment over its economic life varies between US$ -18 bn and -3.3 bn, depending on the demand scenario in Europe. If Ukraine increases its transit to US$ 5.11/tcm/100km, then the average NPV of South Stream would vary between US$ 1 bn and 10 bn, depending on the assumed demand scenarios. Thus, Ukraine's demand for economically justifiable transit fees makes South Stream investment profitable and Ukraine risks being completely bypassed under this scenario.

It is important to note that the average value of South Stream investment under the high demand and high transit fee scenarios (Figure 4.6: "red" bar, US$ 10 bn) is <u>nine times</u> higher than its value under high demand but current transit fees (Figure 4.6: "blue" bar, US$ 1.1 bn). This means, among other things, that the NPV of South Stream investment is much more sensitive to changes in Ukraine's transit fee than to changes in gas demand in Europe.

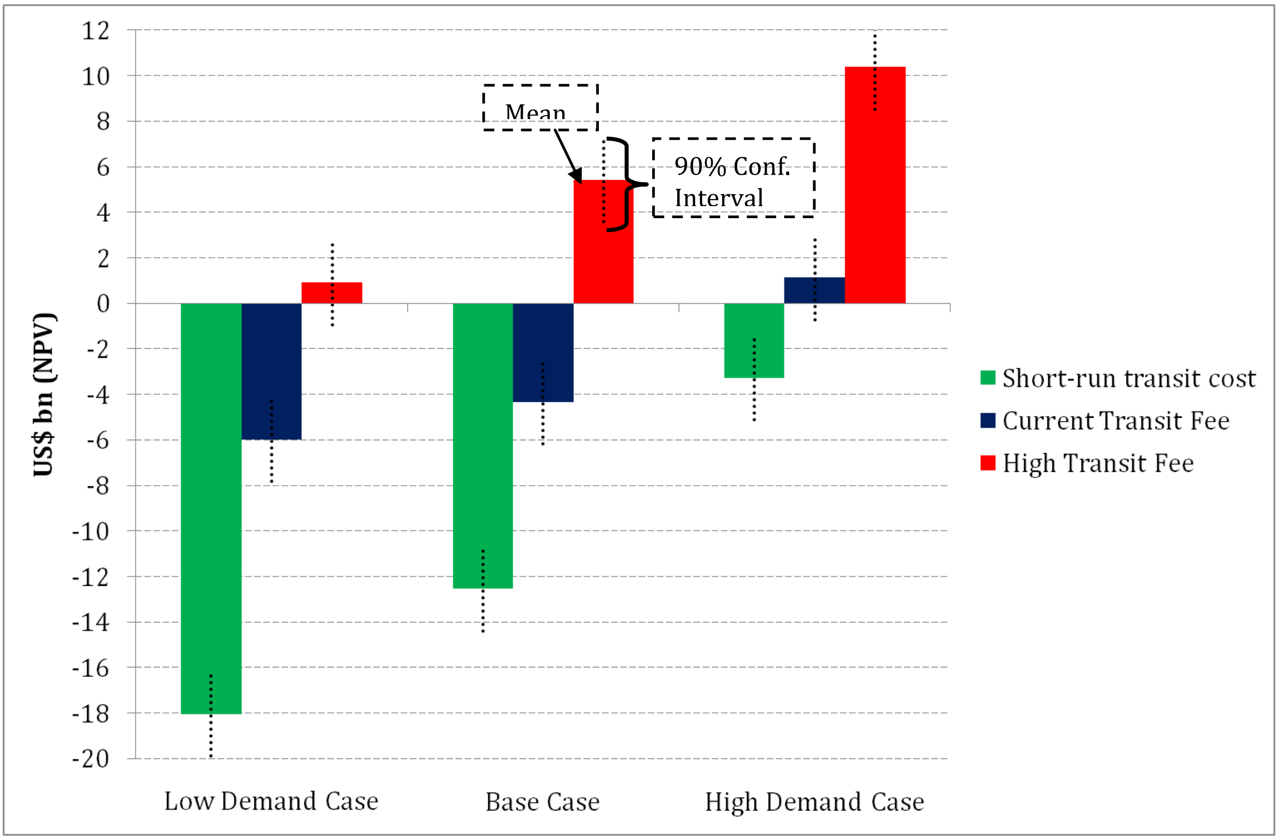

Figure 4.6: Impact of Transit Fees on the NPV of South Stream

4.6.5. South Stream's Value in the Context of Russo-Ukrainian Gas Bargaining

In this section it is argued that South Stream's main value for Gazprom is in cementing its monopoly position in the Ukrainian gas market and keeping Ukraine's import price in line with European prices without risking its supplies to Europe.

In light of the threat of being completely bypassed by the Nord Stream (already under construction) and South Stream projects, the question of why one should ever consider a scenario in which Ukraine raises its transit fee, given that it is rather counterintuitive since the transit fee through Ukraine should be reduced, is legitimate.[103] Moreover, some experts argue that Ukraine cannot raise or change its transit fees until the expiration of the 2009 long-term transit contract in 2019. These concerns are addressed in turn.

As was argued for the case of the Nord Stream pipeline, once the pipeline is built, one may expect Ukraine to slash its transit fee downwards (see Chapter 3: Section 3.9) to make its transit system as competitive as the Nord Stream route. However, this is not the case for South Stream, since the proposed pipeline system is not cost efficient

[103] Pirani (2007: p.87) noted that Ukraine (or its leadership) is very sensitive concerning being bypassed by Gazprom.

compared to the Ukrainian system (see Section 4.6.1: Figures 4.2 and 4.3). To put this in the perspective of bargaining literature, whereas the Nord Stream pipeline is a credible threat, South Stream appears not to be a credible option for Gazprom to bypass Ukraine. The reasoning is that if a competitive pipeline system is more cost efficient than the Ukrainian system, that is, by building it, Gazprom can improve its profits, then the threat of building it is deemed credible and Ukraine should reduce its transit fee to accommodate Gazprom's demand (for a lower transit fee). This reasoning is based on the premise that both Gazprom and Ukraine are aware of the costs and benefits of using the existing transit system and also of the alternatives (South Stream). Thus, if Ukraine knows the costs and benefits of South Stream then, according to the results presented in Section 4.6.1, there is no economic reason for Ukraine to reduce its transit fees.

Existing transit and supply arrangements agreed between Russia and Ukraine in 2009 should, in principle, provide status quo equilibrium because contracts are legally binding documents *per se*.[104] However, these contracts do not guarantee that either Ukraine or Russia will not "defect" from the current arrangements.[105] The April 2010 agreement (more precisely - addendums to the 2009 contracts) is an evidence that even long-term contracts between Ukraine and Russia in the gas sector can be changed easily.[106] Also, Ukraine's perception of current gas arrangements (especially the supply contract) with Russia as "extremely unfavourable" deals renders the status quo equilibrium rather unstable in practice (Kovalko and Vitrenko, 2009a; Kovalko and Vitrenko, 2009b; Korrespondent.net, 2010a).[107]

Therefore, the scenario of a high transit fee cannot be discarded, given South Stream's cost efficiency (see Section 4.6.1) and Ukraine's past behaviour and its

[104] This should also have been true of previous contracts, particularly the transit contract signed in 2001 and the transit and supply arrangements of 2006. For details of the 2009 agreements see (Pirani et al., 2009)

[105] For example, Hubert and Ikonnikova (2003, 2004) and Hubert and Suleymanova (2008) have made a rather strong assumption concerning the lack of credibility of long-term commitments by transit countries, in particular Ukraine. They noted that since transit countries are sovereign states with national energy companies that are often strongly connected with the governments, and there is no truly independent legal system, national institutions offer little protection against opportunistic re-contracting (Hubert and Suleymanova, 2008).

[106] The 2010 "Gas-Fleet" agreement, in which Russia granted a gas price discount of 30% from the price agreed in the 2009 long-term contract. The discount was granted in exchange for allowing Russia's naval fleet to remain in the Crimean peninsula until 2040. These developments call into question the stability of current gas transit and supply contracts, as these are now shown to involve not only economic considerations but also strategic-military issues. For details of the 2010 agreements see (Pirani et al., 2010).

[107] The Ukrainian Prime Minister Azarov was reported to have declared: *"...we will not work with this agreement for 10 years"* (Korrespondent.net, 2010a). The supply contract was signed after the January 2009 gas dispute and is meant to last for 10 years.

willingness to re-contract its current gas arrangements with Russia. Moreover, in the context of current Russo-Ukrainian gas bargaining, this scenario can be interpreted as Ukraine bargaining over a lower import price, which, in the case of a bilateral monopoly, is equivalent to raising its transit fee (see Appendix J for details of the bargaining model showing the relationship between transit fees and import prices).[108]

Indeed, during 2005-2009, when gas prices in Europe rose substantially, Gazprom's implicit transit cost through Ukraine was also very significant. Figure 4.7 shows the economic value of South Stream as a function of Gazprom's implicit cost of transit under the base case demand assumption (calculations of the implicit transit cost and the derivation of South Stream's value as a function of the transit cost are presented in Appendix K).

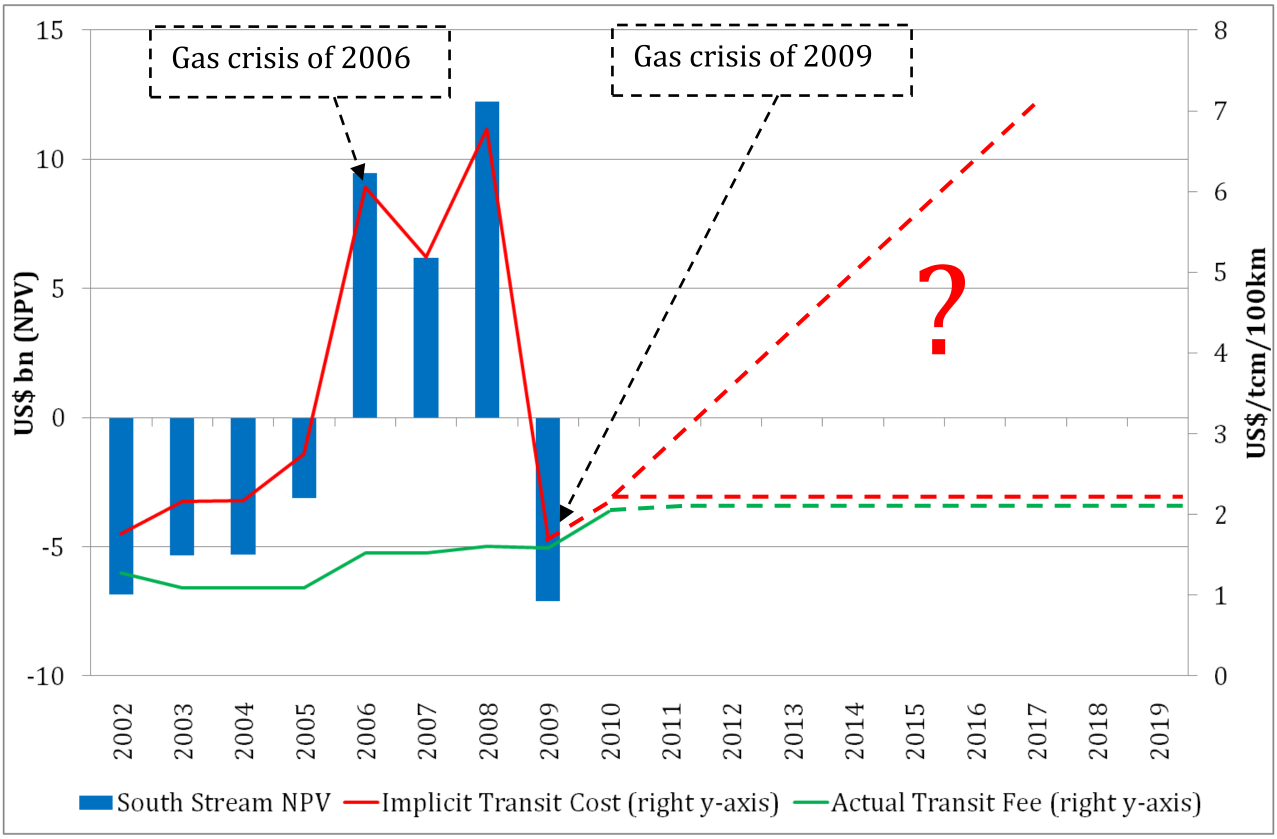

Figure 4.7: South Stream's Bargaining Value

Gazprom's implicit cost of using Ukrainian transit pipelines includes the actual transit fee that Gazprom pays to Ukraine plus the opportunity cost of Gazprom's supplies to Ukraine at prices which are below European prices. This opportunity cost is

108 Russo-Ukrainian gas relations are characterized as a bilateral monopoly. On one side, Ukraine is a near monopolist in transporting Russian gas to Europe, while on the other side, Russia is a sole supplier of around two-thirds of the total annual gas consumption in Ukraine.

attributed to Ukraine's transit monopoly and hence may be treated as part of the transit cost that Gazprom pays to Ukraine.[109]

As can be seen from Figure 4.7, South Stream's economic value will be significant if there are substantial discrepancies between European gas prices and the import price for Ukraine. For example, in 2006-2008, when the gas import price for Ukraine was about half the price paid to Gazprom by European importers (see Appendix K: Table K.1), the value of South Stream would be US$ 6-12 bn.[110] Since 2006, Gazprom has been consistently attempting to reduce the opportunity cost of transiting gas through Ukraine by equalizing the import price for Ukraine with the prices paid by its European customers. This strategy resulted in two transit disruptions (in 2006 and 2009), which badly hit Gazprom's and Ukraine's reputations as reliable gas suppliers; however, after the January 2009 gas crisis, Gazprom was able to completely eliminate the price differential and consequently the opportunity cost of transiting gas through Ukraine. Thus, in 2009 the value of Ukraine's export market was the second largest in Gazprom's export portfolio, just behind Gazprom's traditional market – Germany (Figure 4.8). Therefore, South Stream investment is required to safeguard this value without risking its supplies to Europe; otherwise, Ukraine may bargain and reduce this value substantially.

To summarize, given the possibility that Ukraine may bargain over higher transit fees or lower import prices, it is expected that South Stream's economic value will be derived primarily as <u>insurance</u> against Ukraine's future bargaining. Without South Stream, Gazprom would be required to transport at least 60 bcm per year through Ukraine, depending on gas demand in Europe. Thus, viewed as insurance against such opportunistic behaviour, South Stream investment has far greater value than insurance against risks of transit interruptions and/or as a demand-driven project.

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[109] Indeed, in 2003-2005 Gazprom supplied about 25 bcm per year to Ukraine in lieu of payment for Ukraine's transit services.

[110] These values of US$ 6-12 bn were calculated assuming that the decision to go ahead with the South Stream project was made in 2006-2008 under the base case gas demand and other assumptions as outlined in Section 5. For example, if Gazprom were to decide on the construction of South Stream in 2007 based on information about the cost and benefits of transiting through Ukraine in that year (2007), and assuming that the situation with Ukrainian transit would not change until 2032 (2007+25 years of life time of the South Stream pipeline), the NPV of South Stream evaluated in 2007 over 25 years would be about US$ 6 bn.

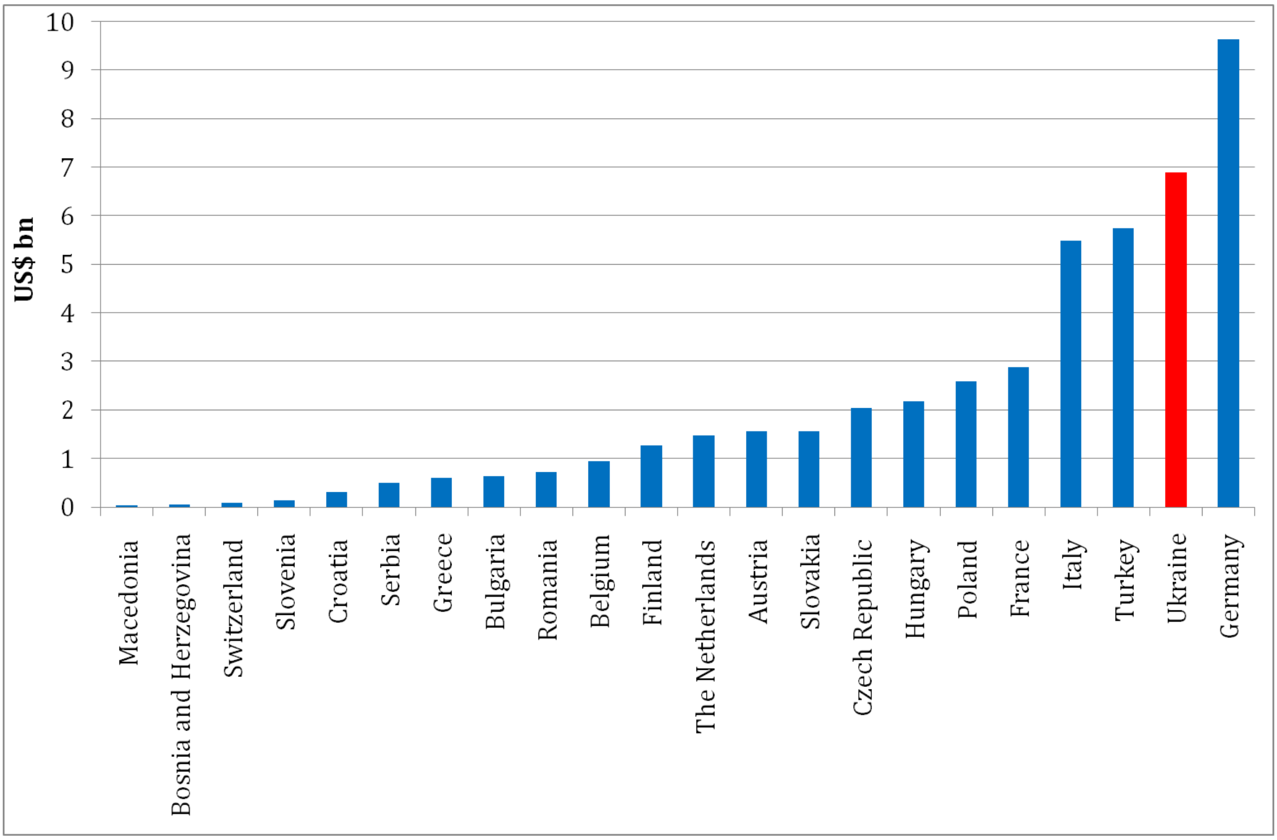

Figure 4.8: Values of Gazprom's Export Markets in 2009
Source: author's calculations based on (Gazprom, 2010b; Pirani et al., 2010)

4.7. Conclusions

South Stream's project sponsors argue that the major objective of the pipeline is meeting additional demand for natural gas in Europe while eliminating transit risks (Gazprom, 2010h). Policy literature on South Stream also suggests that risks of transit disruptions through Ukraine may justify South Stream investment. However, it was shown in this analysis that transit risks do not justify the construction of the South Stream pipeline because under the scenarios of transit interruptions the economic value of South Stream is negative.

Concerning higher gas demand as a factor that justifies Gazprom's investment in South Stream, it was found that only if demand in Europe grew at at more than 2% p.a. up to 2030 would the economic value of this investment be positive, albeit rather marginally (US$ 1.1 bn over 25 years). Although over the last twenty years gas demand in Europe has grown at more than 2% p.a., this growth rate is unlikely to be sustainable over the next twenty years (Noël, 2009). Moreover, there is a consistent view among experts that future growth in gas demand in Europe is unlikely to be higher than 0.7% p.a. (that is the Base case analysed here).[111]

It was shown here that only if Ukraine increased its transit fee considerably, the economic value of South Stream investment would range between US$ 1 bn and 10 bn, depending on assumed demand scenarios. Thus, as insurance against future bargaining from Ukraine, South Stream has far greater value than its value as insurance against transit interruptions and/or its value as a demand-driven project. The expert analysis and media commentary concerning Gazprom's investment in South Stream miss this important dimension. Gazprom's bypass strategy is not primarily about meeting future demand in Europe while eliminating transit risks. This strategy is about eliminating Ukraine's transit monopoly while preserving the value of Ukraine's gas market as much as possible without risking its gas supplies to Europe.

[111] Particularly, in (IEA, 2009) the International Energy Agency forecasted EU's demand growth at 0.7% p.a.; the EC in (EC, 2008b) expected its demand to grow at 0.6% p.a.; in November 2010, IEA revised its 2009 gas demand outlook downwards and projected that gas demand in the EU would grow at an annual growth rate of 0.4% (IEA, 2010b); In a recent study by Honoré (2011), from the Oxford Institute for Energy Studies, gas demand in Europe is expected to grow at 0.6% p.a. until 2020.

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APPENDIX A. Modelling vertically integrated companies

Suppose that a vertically integrated company has two subsidiary companies responsible for gas production (q) and gas sales (s). The aim is to show that modelling these two companies separately is equivalent to modelling the vertically integrated company as a single problem, provided that the relationships between subsidiary companies are competitive. Let us consider the case of a vertically integrated company as follows:

$$\max_{s,q\geq 0} \pi^I = sp(s) - qc \tag{A.1}$$

subject to

$$q \leq Q \quad (\lambda) \tag{A.2}$$

$$s - q = 0 \quad (\gamma - free) \tag{A.3}$$

where π^I is the profit of the vertically integrated company, $c>0$ – unit production cost, Q – production capacity, and $p(s)$ is the inverse demand function of the following form $p=b-as$.

Then, the KKT conditions for (A1) are

$$0 \leq s \perp p + \frac{\partial p}{\partial s} s + \gamma \leq 0 \tag{A.4}$$

$$0 \leq q \perp -c + \lambda - \gamma \leq 0 \tag{A.5}$$

$$0 \leq \lambda \perp (q - Q) \leq 0 \tag{A.6}$$

$$\gamma \perp (s - q) = 0 \tag{A.7}$$

If $s, q>0$ and $q<Q$, then it is easy to show that the solution to (A.4-A.7) is

$$s^* = q^* = \frac{b-c}{2a} \tag{A.8}$$

and the total profit of the integrated company is

$$\pi^I = \frac{b-c}{2a}\left(b - a\frac{b-c}{2a}\right) - c\frac{b-c}{2a} = \frac{(b-c)^2}{4a} \tag{A.9}$$

However, if $q>Q$, that is production constraint (A.2) is binding, then the solution to (A.4-A.7) is

$$s^* = q^* = Q \tag{A.10}$$

and

$$\pi^I = Q(b - aQ) - cQ = Q(b - aQ - c) \tag{A.11}$$

Now consider two separate problems – one for sales:

$$\max_{s \geq 0} \pi^S = s[p(s) - p^*] \tag{A.12}$$

and one for production:

$$\max_{q \geq 0} \pi^q = q[p^* - c] \tag{A.13}$$

subject to

$$q \leq Q \quad (\lambda) \tag{A.14}$$

where π^s is the profit from sales, π^p is the profit from production, and p^* is the wellhead price, which is determined by market clearing condition (A.15):

$$s - q = 0 \quad (p^* - free) \tag{A.15}$$

Below are the KKT conditions for (A.12):

$$0 \leq s \perp p + \frac{\partial p}{\partial s} s - p^* \leq 0 \tag{A.16}$$

and for (A.13):

$$0 \leq \mathrm{q} \perp \mathrm{p}^* - \mathrm{c} + \lambda \leq 0 \tag{A.17}$$

$$0 \leq \lambda \perp (\mathrm{q} - \mathrm{Q}) \leq 0 \tag{A.18}$$

If $s, q>0$ and $q<Q$, then the solution to (A.16-A.18) is

$$s^* = q^* = \frac{b - p^*}{2a} \tag{A.19}$$

$$p^* = c \tag{A.20}$$

and total profit is

$$\pi^I = \pi^s + \pi^p = \frac{b - p^*}{2a}\left(b - a\frac{b - p^*}{2a} - p^*\right) + \frac{b - p^*}{2a}(p^* - c) = \frac{(b - c)^2}{4a} \tag{A.21}$$

In case $q>Q$, that is (A.14) is binding, the solution to (A.16-A.18) is

$$s^* = q^* = Q \tag{A.22}$$

$$p^* = b - 2aQ \tag{A.23}$$

and the profit of the integrated company is

$$\pi^I = \pi^s + \pi^p = Q(b - aQ - p^*) + Q(p^* - c) = Q(b - aQ - c) \tag{A.24}$$

Since the resultant profits are identical, that is (A.21)=(A.9) and (A.24)=(A.11), modelling the separate activities of an integrated company as being price-taking (competitive) with respect to each other yields the same results as modelling the integrated company as one problem.

Q.E.D.

APPENDIX B. Bilateral Market Power in the FSU gas sector

This appendix describes a simple two-person bargaining game with transferable utility (gains are measured in a common currency, e.g. US$) between a buyer (Player *B*) and a seller (Player *S*). Player *B* is a downstream player in the sense that it makes a profit from re-selling gas bought from player *S* to final customers.

The bargaining game is said to be a game with transferable utility if, in addition to the strategy option available to players, each player can: *(i)* give any amount of money to any other player, or (*ii*) simply destroy money (Myerson, 1991). Each unit of net monetary outflow decreases the utility of a player by one unit. Thus, players' utilities are assumed to be linear in money, i.e. if player *B* decides to transfer *t* money to player *S*, then the loss in player *B*'s utility due to the transfer of *t* is the same as the gains received by *S* from this transfer *t*. When there is transferable utility, a two-person bargaining problem can be fully characterized by three numbers (Myerson, 1991: p. 385):

1. Π is the maximum transferable utility available to the players if they cooperate,
2. π_S^d is the disagreement payoff to player *S*, and
3. π_B^d is the disagreement payoff to player *B*.

According to Myerson (1991: p. 385), the Nash bargaining solution (Nash, 1953) of a game with transferable utility is:

$$\pi_S^* = \pi_S^d + \frac{1}{2}\left(\Pi - \pi_S^d - \pi_B^d\right) \qquad \text{(B.1)}$$

$$\pi_B^* = \pi_B^d + \frac{1}{2}\left(\Pi - \pi_S^d - \pi_B^d\right) \qquad \text{(B.2)}$$

which indicates that the seller's and the buyer's profits, π_S^* and π_B^*, are guaranteed by their disagreement payoffs ($\pi_S^d;\ \pi_B^d$) and half of the total surplus from cooperation.

The maximum transferable utility (or profit) Π is achieved if both players are modelled as a vertically integrated company (joint profit maximization), or (as argued in Appendix A) if buyers and sellers behave perfectly competitively. Therefore, sales/export relations between FSU countries in the model in the main text are assumed to be competitive. The connection between the model presented in the main text and the bargaining model in this appendix is that the former is used to define the maximum joint profit Π and the disagreement point ($\pi_S^d;\ \pi_B^d$). Having obtained Π and ($\pi_S^d;\ \pi_B^d$) from the equilibrium gas model, the analysis of the bargaining game is done ex-post.

APPENDIX C. Karush-Kuhn-Tucker Conditions

This appendix documents the first-order (Karush-Kuhn-Tucker, KKT) conditions for the profit maximization problems of market participants in the model described in Chapter 2.

1. *European Sub-model*

Producer's model

The KKT conditions for the producer's problem (2.14-2.16) are as follows

$$\forall s_{inc}^{I}: \quad 0 \le s_{inc}^{I} \perp \left(bp_c + \frac{\partial bp_c}{\partial s_{inc}^{I}} s_{inc}^{I} \Theta_{ic}^{I} + \beta_{in}^{I} \right) \le 0 \tag{C.1}$$

$$\forall q_{in}^{I}: \quad 0 \le q_{in}^{I} \perp \left(-\frac{\partial TPC_i(q_{in}^{I})}{\partial q_{in}^{I}} - \beta_{in}^{I} + \gamma_{in}^{I} \right) \le 0 \tag{C.2}$$

$$\forall x_{inn'}^{I}: \quad 0 \le x_{inn'}^{I} \perp (-tc_{inn'}^{*} + \beta_{in}^{I}) \le 0 \tag{C.3}$$

$$\forall xl_{inn'}^{I}: \quad 0 \le xl_{inn'}^{I} \perp \left(-p_n^{liq*} - SC_{nn'} - p_{n'}^{regas*} + \beta_{in}^{I}\right) \le 0 \tag{C.4}$$

$$\begin{aligned} \forall \beta_{in}^{I}: \quad 0 \le \beta_{in}^{I} & \\ & \perp \Bigg(s_{inc} \\ & + \sum_{n' \in N'(n)} \left[x_{inn'}^{I} + xl_{inn'}^{I} - \left(1 - loss_{n'n}^{pipe}\right) x_{in'n}^{I} - \left(1 - loss_{n'n}^{lng}\right) xl_{in'n}^{I} \right] \\ & - q_{in}^{I} \Bigg) \le 0 \end{aligned} \tag{C.5}$$

$$\forall \gamma_{in}^{I}: \quad 0 \le \gamma_{in}^{I} \perp (q_{in}^{I} - CAP_{in}^{PR}) \le 0 \tag{C.6}$$

Note that in (C.1) the mark-up term $\frac{\partial bp_c}{\partial s_{inc}^{I}} s_{inc}^{I}$ is multiplied with the exogenous 0-1 parameter Θ_{ic}^{I} (Θ_{ic}^{I}=0 if producer *i* behaves competitively, and Θ_{ic}^{I}=1 if producer *i* behaves *à la* Cournot in market *c*).

Efficient TSO Model (Non-FSU)

The KKT conditions for the efficient TSO model (2.17-2.18) are as follows:

$$\forall d_{nn'}^{TSO}: \quad 0 \le d_{nn'}^{TSO} \perp \left(tc_{nn'}^{*} - \frac{\partial TC_{nn'}^{TSO}(d_{nn'}^{TSO})}{\partial d_{nn'}^{TSO}} + \gamma_{nn'}^{TSO} \right) \le 0 \tag{C.7}$$

$$\forall \gamma_{nn'}^{TSO}: \quad 0 \le \gamma_{nn'}^{TSO} \perp (d_{nn'}^{TSO} - CAP_{nn'}^{TSO}) \le 0 \tag{C.8}$$

LNG model

The KKT conditions for the liquefaction maximization problem (2.19-2.20) are as follows:

$$\forall q_n^{liq}:\ \ 0 \le q_n^{liq} \perp \left(p_n^{liq*} - \frac{\partial TC^{liq}(q_n^{liq})}{\partial q_n^{liq}} + \gamma_n^{LIQ}\right) \le 0 \tag{C.9}$$

$$\forall \gamma_n^{LIQ}:\ \ 0 \le \gamma_n^{LIQ} \perp \left(q_n^{liq} - CAP_n^{LIQ}\right) \le 0 \tag{C.10}$$

and the KKT conditions for the LNG regasification problem (2.21-2.22) are

$$\forall q_{n'}^{regas}:\ \ 0 \le q_{n'}^{regas} \perp \left(p_{n'}^{regas*} - \frac{\partial TC^{regas}(q_{n'}^{regas})}{\partial q_{n'}^{regas}} + \gamma_{n'}^{REGAS}\right) \le 0 \tag{C.11}$$

$$\forall \gamma_{n'}^{REGAS}:\ \ 0 \le \gamma_{n'}^{REGAS} \perp \left(q_{n'}^{regas} - CAP_{n'}^{REGAS}\right) \le 0 \tag{C.12}$$

2. FSU sub-model

Supplies to the domestic market

The followings are the KKT conditions for maximization problem (2.23-2.25):

$$\forall s_{tf}^{T}:\ \ 0 \le s_{tf}^{T} \perp \left(P_f^{Reg} - DC_f + \alpha_f^T + \beta_f^T\right) \le 0 \tag{C.13}$$

$$\forall h_{tkn}^{T\leftarrow K}:\ \ 0 \le h_{tkn}^{T\leftarrow K} \perp \left(-p_{ktn}^{K\to T*} - \beta_f^T\right) \le 0 \tag{C.14}$$

$$\forall h_{t}^{T\leftarrow G}:\ \ 0 \le h_{t}^{T\leftarrow G} \perp \left(-bp_f^{G\to T*} - \beta_f^T\right) \le 0 \tag{C.15}$$

$$\forall \alpha_f^T:\qquad \alpha_f^T \perp \left(s_{tf}^T - D_f\left(P_f^{REG}\right)\right) = 0 \tag{C.16}$$

$$\forall \beta_f^T:\ \ \ 0 \le \beta_f^T \perp \left(s_{tf}^T - \left[\sum_{k\in K(t)} \sum_{n\in N(k)} h_{tkn}^{T\leftarrow K} + h_t^{T\leftarrow G}\right]\right) \le 0 \tag{C.17}$$

FSU Gas Production

KKT conditions for FSU gas production problem (2.26-2.28) are:

$$\forall s_{ktn}^{K\to T}:\ \ 0 \le s_{ktn}^{K\to T} \perp (p_{ktn}^{K\to T*} + \beta_{kn}^K) \le 0 \tag{C.18}$$

$$\forall s_{kn}^{K\to G}:\ \ 0 \le s_{kn}^{K\to G} \perp (p_{kn}^{K\to G*} + \beta_{kn}^K) \le 0 \tag{C.19}$$

$$\forall q_{kn}^K:\ \ \ 0 \le q_{kn}^K \perp \left(-\frac{\partial TCP_k(q_{kn}^K)}{\partial q_{kn}^K} - \beta_{kn}^K + \gamma_{kn}^K\right) \le 0 \tag{C.20}$$

$$\forall \beta_{kn}^K:\ \ \ 0 \le \beta_{kn}^K \perp \left(\sum_{t\in T(k)} s_{ktn}^{K\to T} + \sum_{n\in N(k)} s_{kn}^{K\to G} - q_{kn}^K\right) \le 0 \tag{C.21}$$

$$\forall \gamma_{kn}^{K}: \quad 0 \le \gamma_{kn}^{K} \perp (q_{kn}^{K} - CAP_{kn}^{PR}) \le 0 \tag{C.22}$$

Gazprom Export

The following KKT conditions are for Gazprom Export's maximization problem (2.29-2.30):

$$\forall s_{nc}^{G}: \quad 0 \le s_{nc}^{G} \perp \left(bp_c + \frac{\partial bp_c}{\partial s_{nc}^{G}} s_{nc}^{G} \Theta_c^{G} + \beta_n^{G} \right) \le 0 \tag{C.23}$$

$$\forall s_{tnf}^{G}: \quad 0 \le s_{tnf}^{G} \perp \left(bp_f^{G \to T*} + \beta_n^{G} \right) \le 0 \tag{C.24}$$

$$\forall h_{kn}^{G \leftarrow K}: \quad 0 \le h_{kn}^{G \leftarrow K} \perp (-p_{kn}^{K \to G*} - \beta_n^{G}) \le 0 \tag{C.25}$$

$$\forall x_{nn\prime}^{G}: \quad 0 \le x_{nn\prime}^{G} \perp (-tc_{nn\prime}^{*} + \beta_n^{G}) \le 0 \tag{C.26}$$

$$\forall xl_{nn\prime}^{G}: \quad 0 \le xl_{nn\prime}^{G} \perp \left(-p_n^{liq*} - SC_{nn\prime}^{G} - p_{n\prime}^{regas*} + \beta_n^{G} \right) \le 0 \tag{C.27}$$

$$\begin{aligned} \forall \beta_n^{G}: \quad 0 \le \beta_n^{G} & \\ \perp \Bigg(& s_{nc}^{G} + \sum_{t \in T(G)} s_{tnf}^{G \to T} \\ & + \sum_{n\prime \in N\prime(n)} \left[x_{nn\prime}^{G} + xl_{nn\prime}^{G} - \left(1 - loss_{n\prime n}^{pipe}\right) x_{n\prime n}^{G} - \left(1 - loss_{n\prime n}^{lng}\right) xl_{n\prime n}^{G} \right] \\ & - \sum_{k \in K(G)} h_{kn}^{G \leftarrow K} \Bigg) \le 0 \end{aligned} \tag{C.28}$$

Note that, similarly to producer *i,* Gazprom Export's mark-up term $\frac{\partial bp_c}{\partial s_{nc}^{G}} s_{nc}^{G}$ is multiplied with the exogenous parameter Θ_c^{G} (Θ_c^{G}=0 if Gazprom Export behaves competitively in market *c*, Θ_c^{G}=1 if Gazprom Export is a Cournot player in market *c).*

Transit pricing through Ukraine and Belarus

To represent market power in gas transits through Ukraine and Belarus, the conjectured transit demand curve approach is applied with the following slope:

$$\frac{\partial x_{uu\prime}^{G}}{\partial tf_{uu\prime}} \stackrel{\text{def}}{=} M_{uu\prime} < 0 \tag{C.29}$$

then, taking eq. (C.29) into account, the following are the first-order (KKT) conditions for the transit country profit maximization problem (2.31-2.32):

$$\forall tf_{uu\prime}: \quad 0 \le tf_{uu\prime} \perp (x_{uu\prime}^{G} + M_{uu\prime} tf_{uu\prime}) \le 0 \tag{C.30}$$

$$\forall d_{uu'}^{TR}: \quad 0 \leq d_{uu'}^{TR} \perp \left(p_{uu'}^{TR*} - \frac{\partial TC_{uu'}^{TR}(\cdot)}{\partial d_{uu'}^{TR}} + \gamma_{uu'}^{TR} \right) \leq 0 \tag{C.31}$$

$$\forall \gamma_{uu'}^{TR}: \quad 0 \leq \gamma_{uu'}^{TR} \perp (d_{uu'}^{TR} - CAP_{uu'}^{TR}) \leq 0 \tag{C.32}$$

APPENDIX D. Sensitivity Analysis of Nord Stream Investment's Impact on Social Welfare

In order to assess how discount rates affect the impact of Nord Stream investment on social welfare, some sensitivity analyses have been conducted. This appendix document results from these analyses (Table D.1).

As one can see from Table D.1, different assumptions about discount rates affect Nord Stream investment's impact on social welfare. The higher the discount rate the lower the impact of Nord Stream investment on social welfare. The primary reason for this is that the net benefit of Nord Stream investment to society tends to increase over the life-time of the project.

In general, the conclusion that Nord Stream investment has a positive impact on overall market efficiency is robust under variety of discount rates (3%-15%).

Table D.1: Annualized Net Gains (Losses) Resulting from Investment in Nord Stream (US$ bn/year)

	Successive market power			**Double Marginalization**			**Upstream Oligopoly**			**Perfect Competition**		
	A	B	C	A	B	C	A	B	C	A	B	C
Gazprom Profit	2.4	2.3	1.8	1.5	1.4	1.2	3.8	3.5	2.1	-3.7	-4.1	-5.4
Profit of Transit Countries	-1.1	-1.0	-0.7	-0.6	-0.5	-0.4	-0.7	-0.7	-0.7	0.0	0.0	0.0
Profit of other producers	-6.1	-6.1	-6.2	-5.1	-5.1	-5.0	-12.6	-11.4	-6.9	-43.7	-43.2	-39.8
Trader Profit	2.8	2.8	2.4	2.4	2.4	2.2	0.0	0.0	0.0	0.0	0.0	0.0
Consumer Surplus	4.4	4.3	4.2	3.6	3.6	3.3	16.1	14.3	8.1	64.1	63.0	56.6
Social Welfare	**2.4**	**2.2**	**1.4**	**1.8**	**1.7**	**1.3**	**6.6**	**5.7**	**2.6**	**16.7**	**15.6**	**11.4**

Note: A – 3% Discount rate; B – 5% Discount rate; C – 15% Discount rate

APPENDIX E. Data and Assumptions for the Base Case

1. Structural Assumptions

In the Base Case it is assumed that only producers behave imperfectly by behaving a là Cournot. This assumption was chosen because the results obtained under this market power scenario are more consistent with historical data than other market power assumptions (double marginalization and perfect competition assumptions). Sensitivity analysis of alternative structural assumptions is discussed in Appendix I. Gas producers located in the following countries are assumed to be perfectly competitive:[112]

- Germany
- Italy
- Poland
- Romania
- Hungary.

Moreover, gas produced in these countries is prioritized for domestic consumption and is not exported.[113]

2. Natural Gas Demand

In this model, the linear demand function for natural gas is used as specified by eq. (2.10) in Chapter 2: Section 2.3.4.1 "Supplier Model". The price elasticity of the demand function is as follows:

$$\varepsilon_c = -\frac{\partial Q_c^0}{\partial p_c^0} \frac{p_c^0}{Q_c^0} \qquad \text{(E.1)}$$

Then, using (E.1), the parameters of the linear demand function are as follows:

---

[112] This assumption seems plausible since the import requirements of European countries are much higher than their indigenous production. Moreover, security of supply concerns would not allow domestic production to be "withheld" for strategic reasons. Smeers (2008: p. 25) argues that modelling domestic EU producers as a competitive fringe that cannot exercise market power is more adequate. Holz et al. (2008) made a similar assumption.

[113] Holz et al. (2008) made a similar assumption concerning the EU's indigenous gas production.

$$A_c = -\frac{p_c^0}{\varepsilon_c Q_c^0} \text{ and } B_c = p_c^0\left(1+\frac{1}{\varepsilon_c}\right) \qquad \text{(E.2)}$$

Linear inverse demand functions are specified at assumed elasticity and 2009 price-quantity pairs (see Table E.1).

Table E.1: Market Prices (US$/tcm), Consumption (bcm) and Assumed Elasticity for 2009

Country	Consumption[a]	Price[b]	Elasticity[c]
Western and Southern Europe			
Finland	4.3	611.2	-0.7
Baltic States[114]	4.6	525.2	
Austria	8.8	583.5	
Belgium	18.5	593.8	
Spain and Portugal	38.7	622.3	
France	44.5	607.1	
Netherlands	48.8	625.3	
Italy	81.3	654.8	
UK	90.8	513.7	
Germany	92.6	648.9	
Eastern Europe and Balkans			
Slovenia	1.0	687.3	-0.7
Bulgaria	2.7	594.1	
Balkan States[115]	2.7	542.3	
Croatia	2.9	388.8	
Greece	3.5	704.4	
Slovak Republic	6.1	583.9	
Czech Republic	8.2	547.5	
Hungary	11.3	565.0	
Romania	13.8	276.7	
Poland	16.4	442.2	
Turkey	35.1	475.9	
FSU			
Moldova	3.0	245.0	-0.5
Belarus	17.9	190.0	
Ukraine	59.0	187.0	
Russia	429.5	60.5	

Source: [a] (IEA, 2010a); [b] for FSU countries (Pirani et al., 2010); for all other countries - (IEA, 2010a; Eurostat, 2010); [c] for FSU countries (Tarr and Thomson, 2004), for all other markets (Holz et al., 2008).

[114] Baltic States: Estonia, Lithuania, Latvia; Iberian Peninsula: Spain and Portugal
[115] Balkan States: Serbia, Bosnia and Herzegovina, Macedonia and Albania

In order to analyse future scenarios (up to 2030) of gas market developments using the model, projections of both gas demand and prices are needed. For the Base Case, the IEA's WEO 2009 forecast ("reference case") is used (IEA, 2009). Therefore, the following compound annual demand growth rate (CAGR) is assumed for the Base Case (2010-2030):

- +0.7% for Western and Southern Europe
- +0.8% for Eastern Europe and Balkans
- +0.4% for FSU Countries.

Since energy demand forecasts face many uncertainties, a sensitivity analysis is conducted on the demand forecast for the Base Case results (see Appendix I). For gas price projection it is assumed that gas prices will increase at a CAGR of 0.8% (2010-2030), which is based on the forecast of natural gas prices made by the EC (2008b).

3. Production Capacities

To use the model to explore future scenarios of gas market developments it is necessary to make assumptions about future production capacities. This section reports the assumptions for the Base Case. The Base Case forecast of production capacities for most countries in this model is based on the reference case of IEA's WEO 2009 (IEA, 2009) (see Table E.2).

The data on the Romanian and Polish gas production outlooks are based on (EC, 2008b). The Hungarian production profile was obtained from projections made by experts from the Hungarian Energy Office (Kőrösi, 2006).[116] For the Norwegian and Russian production forecasts, (Soderbergh et al., 2009) and (Soderbergh, 2010) are relied on, respectively. The authors provide detailed forecasts of natural gas production in Norway (Table E.2 row 12-14) and Russia (Table E.2 row 19-22) by major producing regions. Their forecasts have been modelled using a bottom-up approach, building field-by-field, and then adding production from contingent and undiscovered resources. The Russian production forecast provided by Soderbergh (2010) is quite close to Russia's official gas production forecast (Shmatko, 2009). In Appendix I the results of the sensitivity analysis on the Norwegian and Russian production forecasts are provided. Ukrainian production is assumed to decrease at an average rate of 1.2% p.a. The decline

[116] The forecast was up to 2015, so the projection of Hungarian gas production was extended based on the average growth rate assumed in (Kőrösi, 2006)

rate is based on the gas production forecast for Eastern Europe (EC, 2008b).[117] The production outlook of Central Asian countries and countries from the Middle East and North Africa (MENA) and Latin America (Trinidad and Tobago) are derived as production less domestic demand (i.e. export capacities). Production and demand forecasts for these countries are derived from the reference case of the IEA's WEO 2009 (IEA, 2009).

Table E.2: Natural Gas Production Capacities (bcm/y)

		2009	2015	2020	2025	2030
1	Algeria	62	76	86	94	103
2	Azerbaijan	8	11	18	25	33
3	Denmark[a]	9	6	3	2	1
4	Egypt	18	17	15	11	7
5	Germany	14	13	13	12	11
6	Hungary	3	1	1	0	0
7	Italy	8	7	7	7	6
8	Kazakhstan	4	10	18	26	34
9	Libya	11	14	19	26	35
10	Netherlands	79	71	64	52	43
11	Nigeria	37	44	56	78	109
12	Norway: Barents Sea	6	14	22	25	24
13	Norway: North Sea	64	66	62	55	48
14	Norway: Norwegian Sea	43	43	46	37	31
15	Oman	12	3	0	0	0
16	Poland	6	5	5	5	5
17	Qatar	70	140	150	166	185
18	Romania	11	10	10	9	9
19	Russia: Western Siberia	671	665	565	470	379
20	Russia: Orenburg	19	10	10	5	1
21	Russia: Yamal Peninsula	0	100	170	270	350
22	Russia: Shtokman	0	0	5	33	64
23	Trinidad and Tobago	34	34	38	43	48
24	Turkmenistan	27	74	84	94	104
25	UK	62	44	31	23	19
26	Ukraine	21	20	18	17	16
27	Uzbekistan	15	15	15	16	17

Source: [a] (DEA, 2010)

[117] The justification for this assumption is that the production fields in Ukraine are mature, which is quite similar to those of some Eastern European countries such as Romania and Hungary; thus, without any publically available data on Ukrainian gas production forecasts, this assumption is relied upon.

4. Pipeline Capacities

Table E.3 presents the cross-border pipeline capacities used in the model. There is no explicit modelling of intra-country transmission systems in the current version of the model, i.e. unlimited transmission capacities within a country are assumed. The primary source of cross-border pipeline capacities is (ENTSOG, 2010). In addition, various other sources are relied on for cross-border pipelines not covered in (ENTSOG, 2010).

Table E.3: Capacities of Cross-border Pipelines (bcm/y)

From	To	Capacity	From	To	Capacity
Algeria	Spain	11.14	Italy	Slovenia	0.91
Algeria	Italy	34.26	Kazakhstan[d]	Russia	54.80
Austria	Germany	8.39	Libya	Italy	9.99
Austria	Italy	37.06	Netherlands	UK	15.33
Austria	Slovenia	2.45	Netherlands	Belgium	28.03
Austria	Hungary	4.19	Netherlands	Belgium	14.70
Azerbaijan[a]	Russia	10.00	Netherlands	Germany	13.54
Azerbaijan[b]	Turkey	7.00	Netherlands	Germany	31.81
Belarus	Lithuania	10.50	Netherlands	Germany	9.08
Belarus	Poland	30.60	Norway	UK	13.87
Belarus	Poland	5.25	Norway	UK	25.55
Belarus[c]	Ukraine	28.90	Norway	France	19.71
Belarus[c]	Ukraine	6.00	Norway	Belgium	15.33
Belgium	UK	25.39	Norway	Germany and Netherlands	42.38
Belgium	Netherlands	10.21	Poland	Germany	30.60
Belgium	Germany	9.25	Romania	Bulgaria	26.50
Belgium	France	28.04	Russia[e]	Belarus (Yamal-Europe)	33.00
Bulgaria	Macedonia	0.76	Russia[f]	Belarus (Northern Lights)	51.00
Bulgaria	Greece	3.54	Russia[c]	Ukraine (Sudja)	113.00
Bulgaria	Turkey	15.35	Russia[c]	Ukraine (Sokhranivka)	135.10
Czech Republic	Germany	15.55	Russia[e]	Turkey (Blue Stream)	16.00
Czech Republic	Germany	37.57	Russia	Latvia	5.40
France	Switzerland	7.14	Russia	Finland	8.15
France	Spain	3.12	Slovak Republic	Czech Republic	40.46
Germany	Poland	1.12	Slovak Republic	Austria	52.44
Germany	Austria	3.51	Slovenia	Croatia	1.74
Germany	Switzerland	17.34	Spain	France	1.25
Germany	France	20.03	Turkey	Greece	0.99

Germany	Belgium	15.88	Ukraine[c]	Poland	5.00
Germany	Netherlands	13.38	Ukraine[c]	Slovakia	92.60
Germany	Czech Republic	12.89	Ukraine[c]	Hungary	13.20
Hungary	Croatia	6.64	Ukraine[c]	Romania	4.50
Hungary	Serbia	4.57	Ukraine[c]	Moldova	3.50
Hungary	Romania	1.66	Ukraine[c]	Romania	26.80

Source: [a] (Korotkov, 2009); [b] (BP, 2010b); [c] (Naftogaz of Ukraine, 2010b); [d] (Yenikeyeff, 2008); [e] (Gazprom, 2008); [f] (Yafimava, 2009).

Future pipeline capacities included in the model are presented in Table E.4. The reported capacities and start times of these pipelines are based on the official plans of the respective project sponsors (except for the South Stream system). The assumption in this work about the South Stream route is based on (South Stream AG, 2010a). The exact capacities of the pipelines which are part of the system are not yet known. Therefore, the reported capacities are assumptions. It is assumed that the start time of the South Stream system is 2016, in line with Gazprom's official plan (Gazprom, 2010h).

Table E.4: Future Pipelines in the Model

From	To	Capacity (bcm/y)	Start time
	Nord Stream System		
Russia	Germany (Baltic offshore)	55.0[a]	2011-2012
Germany	Czech Republic (OPAL)	35.0[b]	2011
Germany	Germany, Rehden (NEL)	20.0[c]	2012
Czech Republic	Germany (Gazelle)	32.0[d]	2011
	South Stream System		
Russia	Bulgaria[118]	63.0	2016
Bulgaria	Serbia	43.0	2016
Bulgaria	Greece	20.0	2016
Greece	Italy	20.0	2016
Serbia	Hungary	43.0	2016
Hungary	Austria (Baumgaren)	21.5	2016
Hungary	Slovenia	21.5	2016
Slovenia	Austria (Arnoldstein)	21.5	2016
	Algerian Export Pipelines		
Algeria	Spain (Medgaz)	8.0[e]	2010
Algeria	Italy (Galsi)	8.0[f]	2014

Source: [a] (Nord Stream AG, 2010a); [b] (OPAL, 2010); [c] (NEL, 2010); [d] (NET4GAS, 2010); [e] (Medgaz, 2010); [f] (Galsi, 2010)

[118] South Stream offshore

5. LNG Capacities

As for LNG, all producers who currently export LNG to Europe, as reported in (BP, 2010a), are included. The liquefaction capacities of LNG exporters included in the model are assumed to grow at rates as reported in WEO 2009 up to 2013 (IEA, 2009) (see Table E.5 below). Any attempt to look beyond that date for developments in liquefaction capacities is rather speculative, so it is assumed that liquefaction capacities are at the level of 2013 thereafter. This gas market model is a regional model which does not include other demand regions such as the North American and Asia Pacific regions, which are important LNG importing regions. Therefore, not all LNG exports might be available for European consumption. However, for this analysis it is assumed that any demand for LNG from Europe may be satisfied, given the export capabilities of LNG producers. This might be true if European gas demand was high, which would push gas prices upwards and thus make LNG exporters willing to export more LNG to Europe. Another justification for this assumption is rapid developments in unconventional gas in North America which will free LNG capacities for Europe in the future.

As for regasification capacities in Europe, the model includes all regasification terminals as of 2009. The forecasting of LNG regasification capacities in Europe is based on (Gas Strategies, 2007). The Gas Strategies regasification data were gathered in 2007 during high energy prices and strong demand in Europe, and thus some of the LNG regasification projects may look very speculative now. For this reason, for the Base Case it is assumed that 50% of the Gas Strategies forecast of LNG regasification capacities will materialize (see Table E.5). This assumption is checked with a sensitivity analysis (see Appendix I).

Table E.5: LNG Liquefaction and Regasification Capacities (bcm/y)

	2009	2015	2020	2025	2030
LNG Liquefaction					
Algeria	28	41	41	41	41
Egypt	16	16	16	16	16
Libya	1	1	1	1	1
Nigeria	30	31	31	31	31
Norway	6	6	6	6	6
Oman	15	15	15	15	15
Qatar	73	105	105	105	105
Russia's Shtokman	0	0	20	20	20
Trinidad and Tobago	20	20	20	20	20

LNG Regasification					
Belgium	9	9	9	9	9
France Atlantic	13	23	23	23	23
France Mediterranean	13	17	17	17	17
Italy	12	65	65	65	65
Netherlands	0	12	12	12	12
North-West Spain[a]	15	20	20	20	20
Poland	0	3	3	3	3
South-East Spain	44	66	66	66	66
UK	47	72	72	72	72

[a] Includes capacity of LNG terminal in Portugal

6. Production Costs

Usually, natural gas production comes from several fields simultaneously with distinct cost structures. We assume that the cheapest gas fields are developed and produced first. This leads to an increasing marginal cost function in the following form (Golombek and Gjelsvik, 1995):

$$TPC'(q) = \kappa + \rho q + \mu \, ln\left(1 - \frac{q}{CAP^{PR}}\right) \tag{E.3}$$

$$\kappa, \rho > 0, \mu < 0, q < CAP^{PR}$$

where κ is the minimum per unit cost, ρ is the linearly increasing per unit cost, and μ is the maximum per unit production cost. The parameters for the production cost function for each producer in our model are presented in Table E.6. These parameters were computed based on a large number of sources.

Table E.6: Parameters of Production Cost Function

Country	Region	Parameters of Marginal Production Cost Function		
		κ	ρ	μ
Russia	Western Siberia Fields[a]	15.12	0	-3.13
	Orenburg[b]	2.08	0	-2.71
	Yamal Peninsula[b]	7.65	0	-9.97
	Shtokman Field[b]	10.81	0	-14.08
Ukraine[c]		5.9	0	-7.69
Central Asia[f]		5.36	0	-6.98
Norway	North Sea[b]	5.63	0	-7.33
	Norwegian Sea[b]	4.99	0	-6.50
	Barents Sea[b]	11.24	0	-14.64
UK[e]		83.69	0.0293	-4.88

Netherlands[e]	27.90	0.1116	-9.35
Denmark[e]	55.79	0.2036	-9.35
Germany[e]	83.69	0.0209	0
Italy[e]	83.69	0.2357	0
Poland[e]	83.69	0.5551	0
Hungary[e]	83.69	1.0182	0
Romania[e]	83.69	0.2315	0
Algeria[d]	22.97	0.1104	-2.50
Egypt[d]	27.74	0.3634	-4.00
Libya[d]	24.42	0.3431	-3.50
Qatar[d]	6.51	0.1317	-6.10
Oman[h]	1.713	0	-2.232
Trinidad and Tobago[e]	27.90	0.0683	-7.67
Nigeria[e]	27.90	0.0781	-7.67

[a] Derived using data in (World Bank, 2009)
[b] Derived using data in (OME, 2001; IEA, 2003; IEA, 2009; World Bank, 2009)
[c] Derived using data in (Pirani, 2007)
[d] Derived using data in (OME, 2001; IEA, 2003; IEA, 2005; IEA, 2009; World Bank, 2009)
[e] Source: (Egging et al., 2008)
[f] Derived using data in (IEA, 2009); Includes: Azerbaijan, Turkmenistan, Uzbekistan, Kazakhstan
[h] Derived using data in (OME, 2001)

7. Transport Costs

7.1. Transmission costs within EU

Existing transmission tariffs in European countries are extremely complex and vary greatly from one pipeline system to another. For transmission costs in Western European countries we rely on a comprehensive study by Arthur D. Little (2008), who provides a detailed comparison of gas transportation tariffs charged by the transmission system operators of 12 West European countries.

For transmission tariffs through other countries, not covered in (Arthur D. Little, 2008), we use official tariffs published by the TSO of the respective country (e.g., through Hungary, Slovakia, the Czech Republic, etc.). Lastly, when data on transmission costs are not published, transmission costs are estimated using the methodology discussed in (van Oostvoorn, 2003).

7.2. Transmission costs within Russia

7.2.1. The existing transmission system

Following the World Bank (2009), it is assumed that, in Russia at least, transmission costs for gas exports should be priced at the long-run marginal cost (LRMC) of a new transmission pipeline. Up-to-date publicly available estimates of LRMCs for gas transmission within Russia are rather rare and inconsistent (Table E.7).

For instance, OME (2001) estimated the LRMC of transporting gas from Russia's production regions to different export routes at US$ 2.00/tcm/100km. On the other hand, the World Bank (2009) estimated the LRMC of gas transmission in Russia at US$ 1/tcm/100km and, specifically for gas transportation on the Yamal Peninsula (difficult terrain), at US$ 2.5/tcm/100km.[119]

The gas transmission tariff approved by the Russian Federal Tariff Service (FTS) might be a good approximation of LRMC, assuming that the FTS retains a two-tier system of transmission tariffs with gas exports being priced at the LRMC of a new transmission pipeline and the domestic market benefiting from depreciated long-installed pipelines (FTS, 2010; World Bank, 2009).[120]

Table E.7: Estimates of the LRMC of Gas Transmission in Russia (US$/tcm/100km)

	OME (2001)	World Bank (2009)	FTS (2010)[a]	IEA (2009)	Tarr and Thomson (2004)	Average
LRMC	2.0	1.0	1.9	1.6	1.0	1.5
LRMC (difficult terrain)	n/a	2.5	n/a	n/a	n/a	2.5

Note: [a] Calculated at the official exchange rate of RUB 30.51 per 1 US$ as of 23 August 2010 (CBR, 2010)

Since the pipeline costs are essentially linear in terms of distance over similar terrain (ECT, 2006), total transmission costs between Russia's production regions and export points are simply the product of distances between producing regions and export points and the average values of LRMC reported in Table E.7.[121] Resultant transmission costs for Russia are presented in Table E.8.

Table E.8: LRMC of Gas Transmission in Russia (US$/tcm)

TO / FROM	Russia-Ukraine border (Sudja)	Russia-Ukraine border (Sokhranivka)	Russia-Belarus border (Smolensk)	Nord Stream (Vyborg)	Blue and South Streams (Dzhubga)
Nadym-Pur-Taz (Urengoi Field)	48.20	47.94	42.88	52.83	54.86
Volga (Orenburg Field)	26.30	16.31	31.96	40.96	23.97
Yamal Peninsula (Bovanenkovo	63.05	62.78	42.53	52.48	69.70

[119] These estimates are based on 12% of the real rate of return (World Bank 2009: p. 247)
[120] However, the cost differential between these two markets is negligible, since there are increasing needs to rehabilitate and expand the existing grid (see e.g., (FTS, 2010) and (World Bank, 2009: p. 247)).
[121] Calculations of transmission costs on the Yamal Peninsula are based on the LRMC reported by World Bank (2009) (Table C.7, second row).

Field)					
Shtokman	42.16	46.42	37.90	32.25	57.61
Alexandrov Gai[a]	18.77	8.78	24.50	33.50	16.51
Azerbaijan-Russia Border	19.92	15.28	31.96	46.82	12.76

Note: [a] Alexandrov Gai is the compressor station near the Kazakhstan-Russia border. This is the gas import point from Central Asia into Russia.

7.2.2. Nord Stream and South Stream

Transportation costs through the Nord Stream and South Stream systems were calculated in two steps:

(i) The initial construction costs of the Nord Stream and South Stream systems were estimated, and then

(ii) the levelized transportation costs (LTC) over the economic life of the gas pipeline projects were derived.

The LTC through the Nord Stream and South Stream pipelines includes construction costs, capital costs, operating and maintenance costs and profit tax. Appendix G contains a detailed outline of the methodology and data input required for derivation of the levelized transport cost. The initial estimates of the construction costs of the Nord Stream system and relevant data and assumptions required for the LTC calculations are in Appendix H (Section 1). The construction costs of the South Stream system were derived using the pipeline cost methodology discussed in Appendix F. Other input data and assumptions needed for the calculation of the LTC through the South Stream system are outlined in Appendix H (Section 2). Tables E.9 and E.10 outline the results of the estimates of LTCs for the Nord Stream and South Stream systems.

Table E.9: Levelized Transportation Costs through the Nord Stream System (US$/tcm)

	Gryazovets-Vyborg	Nord Stream Offshore	Opal	Nel	Gazelle
Average	20.6	21.1	4.9	11.1	2.5
Max	26.1	30.2	6.2	13.7	3.1
Min	15.5	13.8	3.7	8.6	2.0

Table E.10: Levelized Transportation Costs through the South Stream System (US$/tcm)

From	To	Max	Average	Min
Offshore pipelines				
Russia (Dzhubga)	Bulgaria (Varna)	23.7	16.9	11.4
Greece (Igoumenitsa)	Italy (Otranto)	15.9	11.8	8.3
Onshore pipelines				
Bulgaria (Varna)	Serbia (Zajecar)	11.2	8.4	6.0
Bulgaria (Varna)	Greece (Petrich)	9.2	6.9	4.9
Greece (Petrich)	Greece (Igoumenitsa)	12.0	9.0	6.4
Serbia (Zajecar)	Hungary (Subotica)	11.3	8.5	6.1
Hungary (Subotica)	Austria (Baumgarten)	7.6	5.7	4.0
Hungary (Subotica)	Slovenia	5.6	4.2	3
Slovenia	Austria (Arnoldstein)	5.0	3.7	2.7

For South Stream in Bulgaria, it is assumed that the pipeline will be connected to the existing grid there; therefore, for sales to Macedonia through South Stream, Gazprom should pay the existing transit fee because it uses the existing transmission system of Bulgaria. The same is true for Gazprom's sales to Turkey through South Stream.

7.3. Transport costs through Ukraine, Belarus and Central Asia

7.3.1. The exogenous transit fee through Ukraine

According to the current long-term transit contract (Ukrainska Pravda, 2009), since 2010 the transit fee through Ukraine, T_n, has been determined as follows:

$$T_n = A_n + K_n \tag{E.4}$$

$$A_n = 0.5 \times A_{2010} + 0.5 \times [A_{n-1} \times (1 + I_{n-1})] \tag{E.5}$$

$$K_n = \frac{0.03 \times P_n}{L} \times 100 \tag{E.6}$$

where A_{2010}=US$2.04/tcm/100km; for 2010, $A_{n-1}=A_{2010}$; I_n is the inflation rate in the European Union; for 2010 I_{n-1}=0; K_n is the fuel gas component of the transit fee formula, which is determined monthly; P_n is the Ukrainian annual average import price; L – transit distance through Ukraine (1240 km); Subscript n – relevant year of transportation.

In the gas simulation model, fuel gas required for compressors along pipelines is assumed to be provided in kind by producers/shippers.[122] Therefore, K_n is not considered as part of the transit fee through Ukraine (i.e., K_n=0) in the forecasting of the transit fee through this country. The forecasting of the transit fee through Ukraine up to 2030 is based on the transit pricing formula specified by eq. (E.5). According to (E.5), the calculation of the transit fee requires the forecasting of the inflation rate. Possible future values of the inflation rate have been simulated, taking its value as an uncertain variable with a historical distribution of the average inflation rate in 1997-2009. The average value of the transit fee obtained from the simulations is US$ 2.065/tcm/100km.[123] Thus, based on this value Table E.11 shows transit cost for pairs of the Ukrainian transit system entry-exit points.

Table E.11: Transit fee through Ukraine (US$/tcm)

		Entry points			
		Russia (Sudja)	Russia (Sokhranivka)	Belarus (Kobryn)	Belarus (Mozyr)
Exit points	Poland (Drozdovychi)	n/ap	n/ap	7.83	n/ap
	Slovakia (Uzhgorod)	24.64	30.68	11.42	14.69
	Hungary (Beregovo)	24.64	30.68	11.42	14.69
	Romania (Tekovo)	24.64	30.68	11.42	14.69
	Moldova (Anan'iv)	n/ap	19.58	n/ap	n/ap
	Romania (Orlovka)	n/ap	23.99	n/ap	n/ap

Note: n/ap – Not applicable

7.3.2. The transit fee through Belarus

In 2010 Gazprom pays US$ 1.88/tcm/100km to Beltransgaz as the transit fee for using the Belarus transit system (Northern Light, which is owned by Beltransgaz) (Gazprom, 2010f). Based on this transit fee, Table E.12 shows transit cost for pairs of the Belarus Northern Light system entry-exit points.

[122] Most transit/transmission operators in Europe (e.g. BOG in Austria, NET4GAS in Czech Republic, and Eustream in Slovakia) ask shippers to provide fuel gas in kind.
[123] The minimum value is US$ 2.06/tcm/100km and the maximum value is US$ 2.08/tcm/100km.

Table E.12: Transit fee through Belarus' Northern Light system (US$/tcm)

		Entry points
		Russia (Smolensk)
Exit points	Lithuania (Kotlovka)	8.61
	Poland (Brest)	11.28
	Ukraine (Kobryn)	11.28
	Ukraine (Mozyr)	6.84

For gas transportation services through the Belarus section of the Yamal-Europe pipeline, Gazprom pays only US$ 0.49/tcm/100km to Beltransgaz since Gazprom is the sole owner of the pipeline section (Ryabkova, 2010). This fee includes only the operating and O&M costs of the pipeline.

7.3.3. The marginal cost of using transmission pipelines in Ukraine and Belarus

Since the transit systems of Ukraine and Belarus (the Northern Light system) were built during the Soviet era using similar materials and technology to those used for the construction of the Russian transmission system, it is assumed that the LRMC through Ukraine and Belarus is similar to the LRMC in Russia (Table E.7, average value). Table E.13 reports the LRMC through Ukraine and Belarus.

Table E.13: LRMC through Ukraine and Belarus (US$/tcm)

		Russia (Sudja)	Russia (Sokhranivka)	Belarus (Kobryn)	Belarus (Mozyr)	Russia (Smolensk)
Belarus	Lithuania (Kotlovka)	n/ap				6.86
	Poland (Brest)					8.99
	Ukraine (Kobryn)					8.99
	Ukraine (Mozyr)					5.45
Ukraine	Poland (Drozdovychi)	n/ap	n/ap	5.75	n/ap	n/ap
	Slovakia (Uzhgorod)	18.10	22.53	8.39	10.79	
	Hungary (Beregovo)	18.10	22.53	8.39	10.79	
	Romania (Tekovo)	18.10	22.53	8.39	10.79	
	Moldova (Anan'iv)	n/ap	14.38	n/ap	n/ap	
	Romania (Orlovka)	n/ap	17.62	n/ap	n/ap	

Note: n/ap – Not applicable

7.3.4. The Central Asia-Centre Pipeline

In 2008, the transit fee through the Central Asia-Centre pipeline which brings Central Asian gas into Russia was US$ 1.4/tcm/100km (Yenikeyeff, 2008). This value is assumed in the Base Case scenario.

7.4. *Other transport costs*

7.4.1. *The Norwegian pipeline system*

The calculation of transport costs through the Norwegian transmission system is as follows. Efficient pricing of gas transmission through the Norwegian system is assumed, i.e. based on the LRMC of the new transmission system being similar to the existing one. The current value of the investment cost of the Norwegian transmission pipelines is based on (NPD, 2010). For the calculation of LRMC through a particular transmission pipeline, a 10% real interest rate is assumed. The economic life-time of a pipeline is assumed to be 25 years and corporate income tax is 28% (Norwegian Ministry of Finance, 2010). The results of the calculations are presented below (Table E.14).

Table E.14: LRMC of the Norwegian Transmission System (US$/tcm)

TO / FROM	UK (St. Fergus)	UK (Easington)	France (Dunkerque)	Belgium (Zeebrugge)	Germany and Netherlands (Emden/Dornum)
North Sea (Troll Field)	54.46	7.78	11.81	36.81	21.94
Norwegian Sea (Asgard Field)	64.22	15.56	21.57	46.58	31.71
Barents Sea (Snøhvit Field)	86.59	37.92	43.94	68.94	54.08

Since there is no pipeline connection between the Barents Sea and the existing Norwegian transmission system, a new pipeline with a capacity of 20 bcm/y is assumed. This capacity corresponds to the forecast of peak production from the Barents Sea (which is around 25 bcm less the liquefaction capacity of Snøhvit LNG plant, 6 bcm/y). This assumption is necessary for the calculation of marginal transportation costs from the Barents Sea to different pipeline export points.

7.4.2. *The Algerian and Libyan export pipelines*

Transport costs for Algerian and Libyan gas through export pipelines are based on (OME, 2001).

7.5. *Pipeline Losses*

Pipeline losses of 0.125% per 100 km are assumed (Desertec, 2010). It should be noted that these losses are fuel gas for running compressors that are installed along onshore pipelines.

7.6. *LNG Liquefaction, shipping and regasification costs*

In this model version, a constant marginal cost for LNG liquefaction and regasification is assumed, i.e. $\frac{\partial TC^{liq}(q_n^{liq})}{\partial q_n^{liq}} = mc_{liq} > 0$ and $\frac{\partial TC^{regas}(q_{n'}^{regas})}{\partial q_{n'}^{regas}} = mc_{reg} > 0$. Based on (EIA, 2003), mc_{liq}=US$ 49/tcm and mc_{reg}=US$ 12.50/tcm. The calculation of the LNG shipping cost is as follows. A representative harbour in each country was chosen and approximate distances were calculated between each pair of LNG countries in the model. Then, taking into account distances and assuming that a LNG vessel cruises at an average speed of 20 knots,[124] approximate voyage days between a liquefaction site and a regasification terminal were estimated (see Table E.15).

Table E.15: Voyage Days from Liquefaction Sources to Regasification Countries[125]

		Liquefaction Country								
		Norway	Russia[a]	Algeria	Libya	Qatar	Oman	Egypt	Trinidad & Tobago	Nigeria
Regasification country	UK	4.3	4.4	3.8	6.2	13.7	12.7	7.0	8.8	9.8
	Germany	3.6	4.2	4.8	7.1	14.6	13.6	8.0	9.1	10.8
	Italy	8.0	8.7	2.4	3.0	10.3	9.3	3.8	9.9	9.9
	France Atlantic	4.9	5.3	3.6	5.9	13.4	12.4	6.8	8.0	9.6
	France Mediterranean	7.9	8.4	2.1	3.2	10.0	9.5	3.9	9.5	9.5
	North-West Spain	5.2	5.8	2.8	5.0	12.7	11.7	6.0	8.1	8.1
	South East Spain	7.3	7.8	1.5	3.4	10.9	9.9	4.3	8.9	8.9
	Zeebrugge	3.9	4.4	4.3	6.6	14.1	13.1	7.5	9.3	10.2
	Turkey	9.8	10.4	3.9	2.4	8.6	7.6	2.1	11.5	11.5
	Poland	3.9	4.4	5.8	8.1	15.6	14.6	9.0	10.1	11.8
	Greece	9.5	10.2	3.6	2.0	8.6	7.6	2.1	11.2	11.2

Source: own calculations based on (Sea Rates, 2010)
Note: [a] Shtokman Field

Finally, shipping costs are obtained as the product of voyage days and the assumed daily charter rate for LNG vessels. The charter rate varies greatly due to several factors – the price of the vessel, financial costs and the O&M costs of the ship, as well as the global LNG demand and supply situation. For example, according to (EIA, 2003), the daily

[124] This speed has been accepted in the LNG vessel market as the most optimal speed for LNG carriers (MAN Diesel A/S, 2010).
[125] In addition to cruising days, the voyage days reported in Table E.15 also include the one day required for loading and unloading of LNG (Coyle and Patel, 2009).

charter rate could be as low as US$ 27,500 per day and as high as US$ 150,000 per day. The current (2010) charter rate for spot vessels is reported at US$ 37,500 per day (LNG OneWorld, 2010). An average charter rate of US$ 71,500 per day is assumed. Following the California Energy Commission (2003), the fuel losses during LNG liquefaction, shipping and regasification applied in the model are as follows:

- Liquefaction – 9%;
- Shipping – 0.15% per day;
- Regasification – 2.5%.

APPENDIX F. Pipeline Cost Methodology

Cost calculations for onshore pipelines follow the bottom-up engineering model as described in (World Bank, 2009). The results of this model are presented in Figure F.1 below.

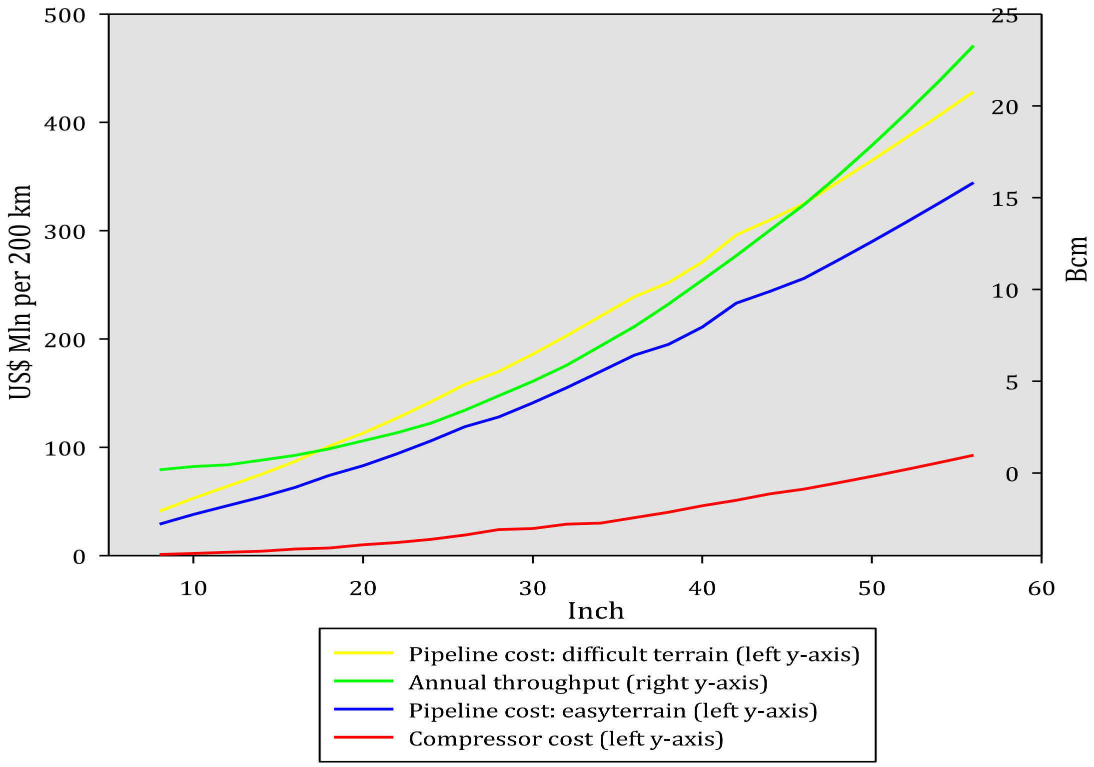

Figure F.1: Pipeline and Compressor costs
Source: (World Bank, 2009)

The assumption for pipeline pressure is 40/60 bar.g (suction/delivery), which corresponds to the design of most regional gas transmission systems (World Bank, 2009). Using higher pressure pipelines, for example 100 bar.g pipes with a diameter of 56 inches, could yield 32 bcm/year of throughput. However, the costs of pipelines and compressors would also rise significantly. Using the data provided in Figure F.1, the estimated total costs of onshore pipelines are:

for easy terrain

$$PC_i^{onshore} = 0.0947D_i^2 + 2.5829D_i + 3.9135 \quad \text{(F.1)}$$

and for difficult terrain

$$PC_i^{onshore} = 0.0947D_i^2 + 4.0829D_i + 3.9135 \quad \text{(F.2)}$$

where $PC_i^{onshore}$ – cost of pipeline *i* (including compressors cost), D_i – diameter of the pipeline *i*.

Publicly available data and information on offshore pipeline costs are rather limited. Data were assembled on offshore pipeline projects built during 2002-2008 in the US (EIA, 2010a) and offshore pipelines in the Norwegian North Sea system (NPD, 2010). The data points are quite limited in number (41 projects in total – see Table F.1 for descriptive statistics) for very precise econometric analysis; however, a sensitivity analysis will be provided on the obtained costs to gain some possible South Stream cost ranges.

Table F.1: Descriptive Statistics of Offshore Pipeline Projects

	Sample Size	Mean	Max	Min	Std Dev	Std. Error
Cost (2008 US$ mln)	41	924.30	5311.30	3.36	1305.01	203.81
Pipeline Capacity (mmcm/a)	41	8754.70	27010.00	0.70	8657.88	1352.13
Pipeline length (km)	41	234.80	1200.00	1.61	290.81	45.42

Using the assembled data, the equation is estimated in the following form:

$$ln(PCC_i^{offshore}) = C_i + \alpha ln(Distance_i) + \beta ln(Capacity_i) \tag{F.3}$$

where $PCC_i^{offshore}$ is per unit capital cost of offshore pipeline *i*,

The first estimation of eq. (F.3) indicates that there is a positive autocorrelation (DW=1.107). The autocorrelation is removed by transforming the data. The resulting estimation of eq. (F.3), which satisfies the major assumptions of the classical regression model, is presented in Table F.2 below.

Table F.2: Offshore Pipeline Cost Model

	Unstandardized Coefficients		Standardized Coefficients	t	R	R^2	F	Durbin-Watson
Coefficients	B	Std. Error	Beta					
Ci	10.417	0.842		6.846	0.873	0.762	60.973	1.910
α	0.903	0.131	0.585	6.882				
β	-0.773	0.073	-0.897	-10.555				
Dependent Variable: $ln(PCC_i^{offshore})$								

The negative coefficient β (-0.773) means that there are economies of scale associated with the capacity of a pipeline. A higher capacity results in a reduction of the capital cost per unit of pipeline capacity.

APPENDIX G. Levelized Transportation Cost Calculation

The levelized transportation cost through a gas pipeline is calculated using eq. (G.1).

$$LTC = \frac{PV\ of\ Total\ Life - cycle\ Cost}{PV\ of\ Total\ Gas\ Transported\ over\ the\ economic\ life\ of\ the\ pipeline} \qquad (G.1)$$

Present Value of Total life-cycle cost = (1)+(2)+(3)+(4)+(5)

(1)	**Investment Costs=***E(PCC) + E(CCS) + other costs*	**E(PPC)** is the Expected Pipeline Construction Cost; **E(CCS)** is the Expected Cost of Compressor Stations;
	$E(PCC) = IEC_p \times CF_p$	**IEC_p** is the Initial Estimated Cost of constructing a particular pipeline of the Nord Stream system;
	$E(CCS) = IEC_c \times CF_c$	**CF_p** is the uncertain cost factor of pipeline construction. This is a random variable which is uniformly distributed between [0.9; 1.3]; [126] **IEC_c** is the Initial Estimated Cost of compressor stations; **CF_c** is the uncertain cost factor for compressor stations. Again, this is a random variable which is uniformly distributed between [1; 1.3]; **Other costs include:** Upfront payment to obtain financing (in case of Nord Stream offshore only) – this is a one-off payment to secure the financial proposal issued by lenders to the borrower (usually termed commitment fees).

[126] The lower bound represents a 10% discount on the initial cost estimates because in 2006-2009 steel and construction prices increased far above historical rates. The upper bound (1.3) allows the cost of a pipeline to be inflated by 30% from IEC_p. An increase in cost by 30% from initial project budget is based on Barinov (2007), who surveyed the cost overruns (and their reasons) of capital intensive projects with a focus on oil and gas industry in the CIS.

(2)	$$-\sum_{n=1}^{N} \frac{Depreciation_n}{(1 + Discount\ Rate)^n} \times Tax\ Rate$$	This is the present value of depreciation tax benefit over the economic life of the pipeline (N=25). The depreciation is determined by the straight-line method. For simplicity, we assume zero scrap value and decommissioning costs at the end of the depreciation period. The assumption is made because the depreciation period is much shorter than technical lifetime of a gas pipeline.
(3)	$$+\sum_{n=1}^{N} \frac{O\&M_n}{(1 + Discounr\ Rate)^n} \times (1 - Tax\ Rate)$$	This is the present value of the annual operating and maintenance costs of the pipeline and compressor stations. Annual O&M for the pipeline is determined as a % of the capital costs of the pipeline (item 1 above).
(4)	$$+\sum_{n=1}^{N} \frac{Cost\ of\ Debt\ Financing_n}{(1 + Discount\ Rate)^n} \times (1 - Tax\ Rate)$$	The present value of annual payments for debt financing (where applicable) is added to the total life-cycle costs of the pipeline.
(5)	$$+\sum_{n=1}^{N} \frac{Loan\ Amortization_n}{(1 + Discount\ Rate)^n}$$	This is the present value of loan amortization (where applicable). In the case of 100% equity financing (e.g. the Gryazovets-Vyborg pipeline on Russian territory) this item is not included in the total lifecycle cost of the pipeline.
	Present Value of Total gas transported over the life-cycle cost is derived as follows:	
(6)	$$\sum_{n=1}^{N} \frac{Utilization\ Rate \times Pipeline\ Desi}{(1 + Discount\ Rate)^n}$$	The utilization rate (%) is the average transportation capacity usage rate over the economic life of the pipeline (N=25). We assume a 100% utilization rate but we also show calculations for the case of a 75% utilization rate.

Box G.1: Calculation of Levelized Transportation Costs

All necessary inputs and assumptions for the calculation of levelized transportation costs (LTC) through Nord Stream and South Stream are provided in Appendix H below.

APPENDIX H. Data and Assumptions for the Derivation of the Costs of Nord Stream and South Stream

1. Nord Stream

1.1. Investment Costs

1.1.1. Gryazovets-Vyborg Pipeline

The construction costs of the Gryazovets-Vyborg (GV) pipeline in Russia are presented in Table H.1.

Table H.1: Construction Costs of the Gryazovets-Vyborg Pipeline

	Construction Cost (US$ Bn)	Length of Pipeline laid (km)
2006	0.73	144
2007	1.05	156
2008	0.88	163
2009	1.39	134
2010	2.34	320
Total	6.39	917

[a] Based on the official average annual exchange rates for the respective years obtained from Central Bank of Russian Federation (CBR, 2010).
Source: (Gazprom, 2005; Nazarova, 2009; Korchemkin, 2010; Nazarova, 2010)

The total cost of compressors to be installed along the Gryazovets-Vyborg pipeline was derived as follows. The Ukrainian producer of industrial equipment, Frunze, reported that it has produced four 25 MWh compressor units for installation at the beginning of the Gryazovets-Vyborg pipeline (Frunze, 2010). The reported total cost of these compressors is US$52 mln (Ukrrudprom, 2010). Thus, if the total compressor power along the pipeline will be 1266 MWh, then the estimated cost of the compressors to be equipped along the pipeline should be around US$ 660 mln. However, as was reported by Gazprom, the Portovaya Compressor station (366 MWh), which will compress gas before entering the Nord Stream offshore line, will be equipped with Rolls-Royce compressor units with very advanced technology (52 MWh per compressor unit) (Gazprom, 2010i). It is thus reasonable to assume that 366 MWh of compressors purchased from Rolls-Royce might cost Gazprom considerably more than those from a Ukrainian producer. We have factored this in as a cost overrun on purchasing compressors for the pipeline. Therefore, the expected costs of the compressor stations along the Gryazovets-Vyborg pipeline are calculated as:

$$E(CCS_{GV}) = 1266MWh \times US\$52mln \times CF_C \tag{H.1}$$

1.1.2. Nord Stream Offshore

Initial estimates of the construction costs of the Nord Stream offshore are based on the official figure of €7.4 bln, as quoted by Nord Stream AG, NSAG, (Nord Stream AG, 2010a). However, as noted above, there might be overruns or delays which would affect project costs.[127] Major drivers of construction cost uncertainty include the uncertain costs of steel, construction, engineering and procurement. The expected construction cost for the offshore pipeline is:

$$E(PCC_{NSO}) = €7.4 \times CF_C \tag{H.2}$$

1.1.3. OPAL, NEL and Gazelle Pipelines

The capital costs of OPAL and NEL are quoted at €1 bln each (OPAL, 2010; NEL, 2010). For the Gazelle project, the official figure for the capital cost is €400 mln (NET4GAS, 2010). As a starting point for the calculation of the expected construction costs of these pipelines we use these official figures:

$$E\left(PCC_{Opal}\right) = €1bln \times CF_p \tag{H.3}$$

$$E(PCC_{Nel}) = €1bln \times CF_p \tag{H.4}$$

$$E(PCC_{Gazelle}) = €400mln \times CF_p \tag{H.5}$$

1.2. Financial Costs: Discount and Interest Rates

1.2.1. Gryazovets-Vyborg Pipeline

Since Gazprom is financing the construction of the Gryazovets-Vyborg pipeline, the discount rate applied to the project is based on Gazprom's weighted-average cost of capital, WACC, in 2003-2009 (see Table H.2). We treat WACC as a random variable which is uniformly distributed in the following range [0.889; 0.1541], with a lower (upper) bound corresponding to the minimum (maximum) WACC in 2003-2009.

[127] Indeed recent news, quoting a representative of the Nord Stream pipeline, reported that the cost of the offshore pipeline could rise to €8.8 bln (Neftegaz, 2010).

1.2.2. Nord Stream Offshore

Debt Financing

At the end of August 2009, Nord Stream's offshore owner and operator confirmed that Request for Proposals for the raising of senior debt for financing Phase 1 development have been issued to the commercial bank market. According to NSAG, the construction of the offshore pipeline is to be financed with 30% equity from shareholders (Gazprom, BASF/Wintershall, E.ON Ruhrgas, Gasunie and GDF-Suez) and 70% senior debt. As of mid-March 2010, Nord Stream AG has completed a financial deal with the commercial banking market on the financing of the first phase of construction. Nord Stream AG has procured a total debt requirement of approximately €3.9 bln for Phase 1 from a combination of the following (Mangham, 2009):

- A syndicated covered loan of up to €3.1 bln provided by a pool of 26 commercial banks. The loan is covered by the Export Credit Guarantee Programmes of Germany (Hermes) and Italy (SACE), as well as the Untied Loan Guarantee Programme of Germany (UFK).
- A syndicated loan facility on an uncovered basis for an amount of up to € 800 mln.

The structure of the loan guarantee is as follows:

- € 3.1 bln loan as a 16-years loan facility covered by the export credit agencies Hermes and Sace, as well as by Germany's loan guarantee programme (UFK), which covers political and commercial risks similarly to Hermes. Hermes will cover €1.6 bln, UFK - €1 bln and Sace - €500 mln.
- There is also an €800 mln, 10-year uncovered commercial loan.

The pricing of the debts is as follows:

- The €800 mln commercial uncovered loan pays a margin of 275 basis points (bps) over EURIBOR pre-completion, 430 bps until year 7 and 450 bps thereafter. The commitment fee is 110 bps.
- The Hermes, UFK and Sace loans pay a margin of 160 bps, 180 bps and 165 bps over EURIBOR respectively. The commitment fees are 65 bps, 75 bps and 65 bps, respectively.

Based on these financial conditions, the interest rate on the debt finance is expressed as follows:

$$I_{NSO}^{D} = c \times (\sum_{j} a_{j\times}[p_j + EURIBOR]) + (1 - c) \times (\sum_{T} a_T \times [p_T + EURIBOR]) \quad \text{(H.6)}$$

where c is the share of covered loan in the total debt finance, a_j is the share of each export credit agency in the total covered loan, p_j is the price of each covered loan, a_T is the share of the total length of the covered loan with a price p_T, and EURIBOR is the Euro interbank deposit rate.

As can be seen from the financial conditions for phase I, the loan is a long-term deal and the pricing of that loan is based on EURIBOR, so we need the trend of EURIBOR for 16 years into the future (the length of the covered loan). We assume that EURIBOR is a random variable with a distribution similar to its trend in 1999-2009. This makes the EURIBOR trend in our cash-flow model random.

Equity Financing

Since there are no details yet of the financial conditions of the second phase of the Nord Stream offshore pipeline, we assume that the remaining investment costs are financed by NSAG shareholders. The costs of equity financing are discussed below.

Project Discount Rate

Taking into account the cost of debt financing and using the data on the cost of capital for the Nord Stream investors (see Table H.2), we have derived the WACC of the offshore pipeline, which serves as the basis for the discount rate of the cash-flow model:[128]

$$DR_{NSO} = \left[d_{NSO} \times I_{NSO}^{D} + (1 - d_{NSO}) \times \left(\sum_{i} e_i \times WACC_i \right) \right] + 1\% \quad \text{(H.7)}$$

where d_{NSO} is the share of debt financing in the NSO project, e_i - share of each shareholder in equity financing, $WACC_i$ is the cost of capital of each shareholder respectively, I_D – the weighted-average interest rate on the debt.

[128] We assume that the WACC of the other two shareholders of the Nord Stream offshore, Gasunie and GDF SUEZ, are similar to those of E.On and BASF, since data on the capital costs of Gasunie and GDF SUEZ were not publicly available. This assumption would not substantially undermine our results since both Gasunie and GDF SUEZ have relatively small shares in NSAG.

The WACC of each investor in the project is assumed to be a random variable which is uniformly distributed with minimum and maximum values as specified in Table H.2.

Table H.2: WACCs of Shareholders of Nord Stream AG

	Gazprom	BASF	E.ON Ruhrgas
2002	n/a	n/a	n/a
2003	8.98%	n/a	10%
2004	9.03%	n/a	9%
2005	8.91%	n/a	9%
2006	9.13%	10%	9%
2007	11.32%	9%	9%
2008	15.07%	10%	9%
2009	15.41%	9%	9%
Min	**8.98%**	**9%**	**9%**
Max	**15.41%**	**10%**	**10%**

Source: (BASF, 2007; BASF, 2010a; Bernotat, 2010)

1.2.3. OPAL, NEL and Gazelle projects

According to BASF's 2009 annual report (BASF, 2009), Wingas has borrowed €500 mln to finance the OPAL project. The interest rate, I^{D}_{opal}, on this loan is 2.5%. However, no information on the length of this loan has been provided. Thus, we assume that it is a short-term loan (3 years), taking into account its relatively small size. We ran a sensitivity analysis on this assumption and found that a short-term loan of 3 years will result in just a 7.8% increase in the levelized transportation cost compared to a longer-term loan of 10 years. Thus, the assumption of the length of the loan contributes minimally to the cost calculations. The discount rate for the OPAL project is derived as follows:

$$DR_{opal} = \left[d_{opal} \times I^{D}_{opal} + \left(1 - d_{opal}\right) \times WACC_{opal}\right] \quad \text{(H.8)}$$

where d_{opal} is the share of debt financing, I^{D}_{opal} is the interest rate on the loan; $WACC_{opal}$ is the capital cost of Opal's major investor (BASF and E.ON) and is treated as a random variable with uniform distribution from [0.09; 0.10].

No public information is available on the financing details of the other two pipelines, Nel and Gazelle. We assume that they are fully financed by the project sponsors, i.e. Wingas and NET4GAS (former RWE Transgas Net, owned by RWE AG (RWE, 2010b)). We use BASF's WACC (see Table H.2) for the discount rate in cost calculations for the Nel project. For the Gazelle project discount rate we use RWE's WACC (9%-10%) in 2002-2009 (RWE, 2010a).

1.3. O&M Costs

Information on the operating and maintenance (O&M) costs of pipelines is difficult to obtain because the considered pipelines are not yet in operation, so common practice in the literature is followed and O&M costs are assumed to be a fixed fraction of the investment costs of the pipeline (ECT, 2006; Krey and Minullin, 2010). The annual O&M costs of pipelines are assumed to be 0.3% of the expected investment costs (Wintershall, 2010). For annual O&M costs of compressor stations, 4% of the expected cost is assumed (Wintershall, 2010).

1.4. Taxation and Depreciation

Depreciation and taxation are based on the taxation system of the country through which the pipeline passes. For pipelines in Germany (OPAL and NEL), the effective corporate tax rate, including trade tax and solidarity tax, is between 29-32% (CFE, 2010), so we assume a rate of 30%. For the Gazelle pipeline, according to KPMG, the relevant corporate tax in the Czech Republic in 2010 would be 19% (KPMG, 2009).

For the Nord Stream offshore pipeline, according to Nord Stream AG, the taxation issue would mainly be under Swiss jurisdiction as the company is registered in Kanton Zug with a headquarters of around 140 staff (Nord Stream AG, 2010b). According to the tax system of Switzerland and Kanton Zug (Müller-Studer, 2009), Nord Stream AG enjoys special tax privileges because the company falls under the category of 'mixed company', i.e. a company whose main operations are not in Switzerland.[129] The corporate tax for this type of company is 10.125% (Müller-Studer, 2009).

2. South Stream

2.1. Capacity and timing of the project

The assumed South Stream route is based on the recent publicly available project documentation from the developers (see Figure H.1 below) (South Stream AG, 2010a).

[129] At least 80% of operations should be outside Switzerland (Müller-Studer, 2009).

The exact capacities of the pipelines, which are part of the South Stream system, are not known yet. Therefore, the reported capacities here are assumptions (see Table H.3, below). The assumed start date of the South Stream system is 2016 (Gazprom, 2010h). It is assumed that, like the Nord Stream project, South Stream will be launched in stages. In 2016, half of the assumed capacity of each pipeline section of the system will be operational. The system's designed capacity (63 bcm) will be available from 2017.

Table H.3: South Stream Pipeline System

From	To	Number of lines	Capacity per line (bcm)	Total Capacity
Offshore pipelines				
Russia (Dzhubga)	Bulgaria (Varna)	4	15.75	63.00
Greece (Igoumenitsa)	Italy (Otranto)	2	10.00	20.00
Onshore pipelines				
Bulgaria (Varna)	Serbia (Zajecar)	2	21.50	43.00
Bulgaria (Varna)	Greece (Petrich)	1	20.00	20.00
Greece (Petrich)	Greece (Igoumenitsa)	1	20.00	2016
Serbia (Zajecar)	Hungary (Subotica)	2	21.50	43.00
Hungary (Subotica)	Austria (Baumgarten)	1	21.50	21.50
Hungary (Subotica)	Slovenia	1	21.50	21.50
Slovenia	Austria (Arnoldstein)	1	21.50	21.50

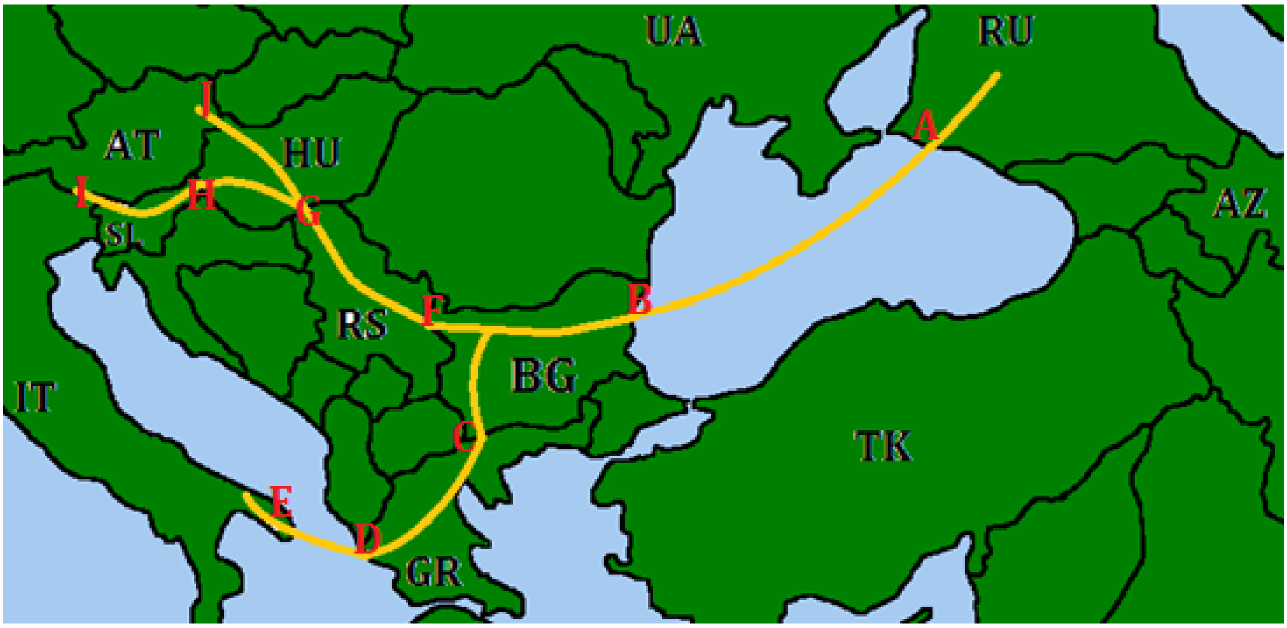

Figure H.1: Assumed Route for the South Stream Pipeline System
Source: based on South-Strea.info

2.2. Cost of capital and project discount rate

Since feasibility studies of South Stream's pipeline sections have not started yet, it is necessary to make assumptions about the cost of capital and relevant project discount rates. These assumptions are based on publicly available information and particularly use data on the financing of South Stream's sister project – Nord Stream (see Appendix H, Section 1.2.2).

It is assumed that the financing strategy for the South Stream offshore project is similar to that for the Nord Stream project. Therefore, the construction of the offshore pipeline would be financed with 30% equity from shareholders (Gazprom, ENI) and 70% debt. The cost of capital for debt financing is assumed to be similar to the Nord Stream financing cost (see Appendix F, Section 1.2.2).

Gazprom's weighted-average cost of capital (WACC) is assumed to be to be in the range of 8.89%-15.41% (Zak, 2006; Lyutyagin, 2010), while the WACC of European energy utility companies is assumed to be 9%-10% (similar to the WACC of such companies as E.ON or BASF, see Table H.2).

It is assumed that Gazprom's stake in all the pipeline sections of the South Stream system is 51%, while its European partners hold the remainder.

2.3. Project cost overrun

The costs of large-scale pipeline projects may overrun or their construction may be delayed, which would affect project costs. Major drivers of construction cost uncertainty include the costs of steel, construction, engineering and procurement. Taking into account uncertainties in project implementation (in terms of delays and budget overruns), the expected construction cost of each pipeline section of the South Stream system is determined as follows:

$$E(TC_n) = CF \times PC_n \tag{H.9}$$

where $E(TC_n)$ is the expected total cost (including compressor costs where appropriate) of the pipeline section n of the South Stream system; and PC_n is the estimated initial project cost. The costs of the pipeline and compressors are estimated (where appropriate) for each section of the South Stream system based on the methodology described in Appendix F above, and CF is the cost factor of pipeline construction, which is a random variable which is assumed to be uniformly distributed between [0.9; 1.3]. The lower bound represents a 10% discount on the initial cost estimates because in 2006-2009 steel and construction prices increased far above historical rates. The upper bound (1.3) allows the cost of a pipeline to be inflated by 30% from the initial estimate,

PC_n. An increase in costs of 30% above the initial project budget is based on (Barinov, 2007).

2.4. O&M costs

The annual O&M costs of the South Stream pipelines are assumed to be 0.3% of the expected investment costs (Wintershall, 2010). For the annual O&M costs of compressor stations, 4% of the expected cost is assumed (Wintershall, 2010).

2.5. Taxation and depreciation

The taxation and depreciation applied to pipeline projects is based on the taxation system of the country through which the pipeline passes:

- Bulgarian corporate tax is assumed to be maintained at 2010 levels - 10% (IFC, 2010a);
- Corporate tax in Greece is 25% (IFC, 2010b). The offshore part of the project between Greece and Italy is assumed to be under Greek tax jurisdiction;
- Serbian corporate tax is at the level of 2010 - 10% (IFC, 2010d);
- Hungary – 16% (IFC, 2010c);
- Slovenia – 22% (IFC, 2010e).

The operator of South Stream offshore pipeline, South Stream AG, is registered in Kanton Zug, Switzerland (South Stream AG, 2010b). The taxation procedure applied to companies registered in Kanton Zug is briefly discussed above (Appendix H, Section 1.4). The corporate tax applied to the operation of the South Stream AG is 10.125%.

APPENDIX I. Model Validation and Sensitivity Analysis

In this appendix, model validation with historical data (2008-2009) and different sensitivity analyses are documented. In Section 1 of this appendix, the model is calibrated with historical data from 2008-2009 and the model results are compared under different assumptions of market power with historical data. In Sections 2 and 3, the sensitivity of model results to changes in exogenous assumptions (such as demand, production, pipeline and LNG capacities, conjectured transit demand slope) is tested.

1. Consistency with historical data

The results of the model calibrated to the 2008-2009 data are presented in Tables I.1a, I.1b and I.2. In general, double marginalization (where both producers and traders exert market power in sequence) result in much higher final prices and lower quantities than in reality. This is generally in line with the theory of double-marginalization (Spengler, 1950). On the other hand, the perfect competition assumption inflates the results quite substantially. In this case, the average final price in Europe is much lower than the observed real price, and consumption is also much higher than the real data.

In general, the results obtained from the upstream oligopoly assumption are in line with historical data. Also, they are more consistent with real data than the results obtained from the other two market power assumptions.

There is one common feature in the three market power scenarios - the diversity of the gas sources plays a crucial role in the results in terms of final prices and consumption. Less diverse countries in terms of supply sources always enjoy higher prices and lower consumption than in reality. In contrast, countries with a diverse supply portfolio enjoy lower prices and higher consumption compared to reality. In general, this observation is line with economic intuition regarding market power and competition. Therefore, the model behaves in a predictable way which is in line with fundamental economic intuition and theory.

Table I.1a: Model Validation with Historical Data: 2008-2009

	CONSUMPTION (bcm)						PRICES (US$/tcm)					
	real data		model results		Difference		real data		model results		Difference	
	2008 [1]	2009 [2]	2008 [3]	2009 [4]	2008 [3]/[1]	2009 [4]/[2]	2008 [5]	2009 [6]	2008 [7]	2009 [8]	2008 [7]/[5]	2009 [8]/[6]
UPSTREAM OLIGOPOLY												
Austria	9	9	8	9	94%	98%	584	583	637	604	109%	104%
Belgium	19	18	19	20	100%	109%	618	594	622	518	101%	87%
Bulgaria	4	3	3	2	73%	79%	391	594	545	775	139%	130%
Balkans	3	3	2	2	74%	77%	471	542	649	720	138%	133%
Baltic States	6	5	4	4	72%	80%	303	525	424	678	140%	129%
Czech Republic	9	8	7	7	83%	90%	528	547	657	629	124%	115%
Germany	98	93	104	100	106%	108%	734	649	667	574	91%	88%
Finland	5	4	4	3	80%	80%	726	611	938	784	129%	128%
France	46	45	47	48	102%	109%	600	607	580	531	97%	88%
Greece	4	4	4	4	100%	101%	883	704	885	696	100%	99%
Croatia	3	3	2	2	68%	73%	338	389	491	538	146%	138%
Hungary	13	11	11	10	86%	90%	527	565	632	645	120%	114%
Spain and Portugal	43	39	40	39	94%	101%	602	622	652	613	108%	98%
Italy	88	81	97	97	110%	120%	585	655	502	472	86%	72%
Netherlands	49	49	45	50	94%	102%	566	625	617	604	109%	97%
Poland	16	16	16	16	97%	98%	502	442	525	453	105%	103%
Romania	16	14	17	15	107%	113%	350	277	316	227	90%	82%
Slovakia	6	6	5	5	73%	78%	521	584	724	766	139%	131%
Slovenia	1	1	1	1	95%	102%	604	687	650	668	108%	97%
Turkey	37	35	32	32	88%	92%	585	476	681	531	116%	112%
UK	99	91	102	99	103%	109%	612	514	586	446	96%	87%
Average [a]	***27.3***	***25.6***	***27.2***	***27.0***	***100%***	***106%***	***603***	***582***	***597***	***527***	***99%***	***90%***
DOUBLE MARGINALIZATION												
Austria	9	9	8	8	87%	87%	584	583.5	689	688	118%	118%
Belgium	19	18	17	18	88%	95%	618	593.8	724	638	117%	107%
Bulgaria	4	3	2	2	57%	60%	391	594.1	632	936	161%	158%
Balkans	3	3	2	2	57%	58%	471	542.3	759	865	161%	160%
Baltic States	6	5	3	3	57%	60%	303	525.2	488	823	161%	157%
Czech Republic	9	8	7	6	75%	78%	528	547.5	715	722	135%	132%
Germany	98	93	90	86	92%	92%	734	648.9	823	720	112%	111%
Finland	5	4	3	3	61%	61%	726	611.2	1130	954	156%	156%
France	46	45	42	42	92%	95%	600	607.1	671	653	112%	108%
Greece	4	4	3	3	79%	80%	883	704.4	1145	907	130%	129%
Croatia	3	3	2	2	54%	57%	338	388.8	558	630	165%	162%
Hungary	13	11	9	8	69%	71%	527	565.0	762	799	144%	141%
Spain and Portugal	43	39	40	38	94%	99%	602	622.3	652	631	108%	101%
Italy	88	81	85	80	96%	99%	585	654.8	617	668	106%	102%
Netherlands	49	49	41	43	84%	87%	566	625.3	694	738	123%	118%
Poland	16	16	13	13	80%	80%	502	442.2	647	570	129%	129%
Romania	16	14	15	13	92%	96%	350	276.7	391	291	112%	105%
Slovakia	6	6	4	4	59%	60%	521	583.9	827	921	159%	158%
Slovenia	1	1	1	1	79%	80%	604	687.3	783	883	130%	129%
Turkey	37	35	26	26	71%	75%	585	475.9	824	649	141%	136%
UK	99	91	85	81	86%	89%	612	513.7	736	593	120%	115%
Average [a]	***27.3***	***25.6***	***23.6***	***22.8***	***87%***	***89%***	***603***	***582***	***710***	***662***	***118%***	***114%***

[a] Average final prices are quantity-weighted

Table I.1b: Model Validation with Historical Data: 2008-2009

	CONSUMPTION (bcm)						PRICES (US$/tcm)					
	real data		model results		Difference		real data		model results		Difference	
	2008 [1]	2009 [2]	2008 [3]	2009 [4]	2008 [3]/[1]	2009 [4]/[2]	2008 [5]	2009 [6]	2008 [7]	2009 [8]	2008 [7]/[5]	2009 [8]/[6]
PERFECT COMPETITION												
Austria	9	9	9	10	105%	110%	584	583.5	546	498	93%	85%
Belgium	19	18	20	20	107%	110%	618	593.8	558	510	90%	86%
Bulgaria	4	3	3	4	73%	153%	391	594.1	541	148	138%	25%
Balkans	3	3	3	3	87%	105%	471	542.3	557	503	118%	93%
Baltic States	6	5	3	7	51%	155%	303	525.2	515	110	170%	21%
Czech Republic	9	8	8	9	98%	106%	528	547.5	545	498	103%	91%
Germany	98	93	115	107	117%	115%	734	648.9	553	505	75%	78%
Finland	5	4	6	7	120%	159%	726	611.2	517	100	71%	16%
France	46	45	48	49	104%	111%	600	607.1	563	516	94%	85%
Greece	4	4	5	5	123%	134%	883	704.4	589	360	67%	51%
Croatia	3	3	2	2	53%	78%	338	388.8	566	511	168%	131%
Hungary	13	11	13	12	98%	110%	527	565.0	539	485	102%	86%
Spain and Portugal	43	39	42	40	97%	104%	602	622.3	629	587	105%	94%
Italy	88	81	89	92	101%	114%	585	654.8	574	527	98%	81%
Netherlands	49	49	49	55	102%	113%	566	625.3	553	505	98%	81%
Poland	16	16	16	16	95%	98%	502	442.2	536	454	107%	103%
Romania	16	14	11	18	71%	133%	350	276.7	495	145	141%	52%
Slovakia	6	6	6	7	98%	111%	521	583.9	539	492	104%	84%
Slovenia	1	1	1	1	105%	118%	604	687.3	564	509	93%	74%
Turkey	37	35	38	43	103%	122%	585	475.9	557	327	95%	69%
UK	99	91	104	107	105%	118%	612	513.7	569	385	93%	75%
Average [a]	***27.3***	***25.6***	***28.1***	***29.3***	***103%***	***115%***	***603***	***582***	***722***	***667***	***120%***	***115%***

[a] Average final prices are quantity-weighted

Table I.2: Model Validation with Historical Data - Total Expenditure on Gas Consumption

	Real Data		Market Power Scenarios	Model Results		Difference	
	2008 [1]	2009 [2]		2008 [3]	2009 [4]	2008 [5]	2009 [6]
Total Expenditure on gas Consumption (US$ bln)	345	312	Double Marginalization	352	317	102.0%	101.6%
			Upstream Oligopoly	341	298	98.8%	95.6%
			Perfect Competition	333	281	96.3%	89.9%

Note: [5]=[3]/[1]; [6]=[4]/[2]

2. Sensitivity analysis: Demand parameters and infrastructure capacities

The assumed gas demand projection and infrastructure capacities to be installed between 2010 and 2030 are rather uncertain parameters in the Base Case. Therefore, the robustness of the Base Case results is tested against the following sensitivity scenarios that reflect uncertainties in the model parameters (Box I.1):

Sensitivity Scenarios	Description
N1	Elasticity of demand is 100% lower than was assumed in the Base Case, i.e ε_n=-1.4
N2	Elasticity of demand is 100% higher than was assumed in the Base Case, i.e ε_n=-0.35
N3	Russian and Norwegian production capacities are 20% higher than they were assumed to be in the Base Case (see Table E.2 for production capacities assumed in the Base Case)
N4	Russian and Norwegian production capacities are 20% lower than they were assumed to be in the Base Case
N5	High demand case: gas demand in 2010-2030 is assumed to grow at a CAGR of: • +1.40% for Western and Southern Europe; • +1.60% for Eastern Europe and Balkans; • +1.20% for FSU Countries.
N6	Low demand case: gas demand in 2010-2030 is assumed to grow at a CAGR of: • +0.35% for Western and Southern Europe; • +0.40% for Eastern Europe and Balkans; • +0.30% for FSU Countries.
N7	LNG regasification and liquefaction capacities are 100% higher than was assumed for the Base Case (see Table E.5 for the Base Case LNG capacities)
N8	LNG regasification and liquefaction capacities are 100% lower than was assumed for the Base Case
N9	Cross-border pipeline capacities between EU member states (including the Turkish-Greek interconnector) are 100% higher than was assumed in the Base Case (see Table E.3 and E.4 for cross-border pipeline capacities);
N10	Cross-border pipeline capacities between EU member states (including the Turkish-Greek interconnector) are 100% lower than was assumed in the Base Case.

Box I.1: Sensitivity Scenarios

The results of the sensitivity analysis are summarized in the following Table I.3. The robustness of the model output is measured with the following criteria:

$$\frac{R_N^S - R_{BC}}{R_{BC}} \bigg/ \frac{I_N^S - I_{BC}}{I_{BC}} = C_I^R \tag{I.1}$$

where R_N^S is the output parameter under sensitivity scenario N (e.g. final prices or profits), R_{BC} is the same output parameter under the Base Case scenario, I_N^S is the input parameter under sensitivity scenario N (e.g. parameter for elasticity of demand or production capacities etc.), and I_{BC} is the same input parameter under the Base Case scenario. Thus, if:

- $|C_I^R| \in [0;0.2]$, then, holding all other input parameters unchanged, changes in parameter *I* are <u>not critical</u> to the output, *R;*
- $|C_I^R| \in (0.2;0.5]$, then changes in parameter *I* are <u>moderately critical</u> to the output, *R;*
- $|C_I^R| \in (0.5;1]$, then changes in parameter *I* are <u>critical</u> to the output, *R;*
- $|C_I^R| \in (1; +\infty)$, then changes in parameter *I* are <u>very critical</u> to the output, *R*.

Table I.3: Sensitivity Analysis of the Base Case results

Country	Base case [1]	Sensitivity Scenarios N1 [2]	N2 [3]	N3 [4]	N4 [5]	N5 [6]	N6 [7]	N7 [8]	N8 [9]	N9 [10]	N10 [11]
FINAL PRICES (US$/tcm)[a]											
Austria	700	581	998	697	806	735	690	697	703	606	798
Belgium and Luxembourg	532	553	614	525	602	593	505	391	671	500	517
Bulgaria	885	659	1368	883	992	908	883	883	887	887	884
Balkans	816	625	1256	814	923	839	814	814	818	818	864
Baltic States	775	580	1208	773	888	796	774	775	776	776	775
Czech Republic	654	572	913	651	751	694	641	629	686	652	683
Germany	605	566	794	600	699	654	587	570	655	598	644
Finland	897	661	1400	894	1010	918	896	897	898	898	896
France	425	486	502	420	523	481	405	366	582	422	440
Greece	453	476	573	450	541	505	436	399	630	442	467
Croatia	611	484	928	608	719	633	609	609	612	605	610
Hungary	814	630	1242	811	921	838	811	812	815	815	812
Spain and Portugal	450	497	563	447	518	504	432	404	580	427	470
Italy and Switzerland	420	471	503	417	505	472	403	379	512	410	450
Netherlands	608	596	755	600	678	665	583	501	717	574	683
Poland	508	499	688	506	609	560	489	452	541	480	524
Romania	290	268	366	287	400	323	282	289	291	291	289
Slovakia	871	662	1346	869	979	893	869	870	873	873	870
Slovenia	715	612	1085	713	797	742	712	727	714	716	801
Turkey	539	456	742	537	647	576	530	430	604	537	539
UK	389	456	432	373	472	448	365	317	518	358	403
Gazprom Profit, US$ bn	117.7	141.5	131.1	124.6	108.0	138.4	111.9	106.7	140.3	120.9	118.4
Statoil Profit, US$ bn	49.9	53.7	60.3	50.7	51.9	56.6	47.3	43.7	62.3	47.4	53.2
Producer Profit: Rest of World, US$ bn	125.7	144.3	146.4	125.2	160.8	149.1	119.1	119.0	132.7	121.5	136.4
Transit Profit, US$ bn	1.0	2.3	0.6	1.1	0.5	1.3	0.9	0.8	1.4	1.4	0.9
Consumer Surplus, US$ bn	386.9	257.4	579.1	391.4	330.1	382.5	383.6	427.8	327.3	398.5	370.5
Social Welfare, US$ bn	681.3	602.3	917.4	688.9	651.2	727.8	662.8	698.1	663.9	689.7	679.3
Consumption: Western and Southern Europe, bcm/y	564	645	489	568	525	583	552	592	516	573	550
Consumption: Eastern Europe and Balkans, bcm/y	112	134	96	112	96	116	109	119	107	113	111

[a] reported values are averages (2010-2030)

The robustness criteria (I.1) are presented in Table I.4. Table I.4 is the "traffic light" of the sensitivity of the Base Case results to changes in important assumptions. As can be seen, across our ten sensitivity scenarios only two input parameters have the most critical impacts on model results – the elasticity of demand and the production capacities of the two largest producers in the model (Russia and Norway) ("red and yellow" highlights in Table I.4). A decrease in production capacities (scenario N4) is more critical to the model results than an increase in production capacities (scenario N3). In general, a one percentage point (p.p.) decrease in the production forecast of Russia and Norway relative to the Base Case forecast changes the final prices by more than 0.5 p.p. for most of the countries in this model (with a few countries seeing changes in prices of more than 1 p.p.). Changes in other inputs have very little effect on the model's results – a 1 p.p. change in all other input parameters only changes the model results by 0-0.2 p.p. ("green" highlight throughout Table I.4). In general, the model results are fairly robust to changes in major structural input parameters.

Table I.4: Results of Sensitivity Scenarios - Changes Relative to the Base Case Results

Country	Sensitivity Scenarios									
	N1	**N2**	**N3**	**N4**	**N5**	**N6**	**N7**	**N8**	**N9**	**N10**
	FINAL PRICES									
Austria	-0.17	0.43	-0.02	0.76	0.05	-0.01	0.00	0.00	-0.13	0.14
Belgium and Luxembourg	0.04	0.15	-0.07	0.66	0.11	-0.05	-0.26	0.26	-0.06	-0.03
Bulgaria	-0.26	0.55	-0.01	0.60	0.03	0.00	0.00	0.00	0.00	0.00
Balkans	-0.23	0.54	-0.02	0.65	0.03	0.00	0.00	0.00	0.00	0.06
Baltic States	-0.25	0.56	-0.02	0.73	0.03	0.00	0.00	0.00	0.00	0.00
Czech Republic	-0.13	0.40	-0.03	0.74	0.06	-0.02	-0.04	0.05	0.00	0.04
Germany	-0.06	0.31	-0.04	0.78	0.08	-0.03	-0.06	0.08	-0.01	0.06
Finland	-0.26	0.56	-0.01	0.63	0.02	0.00	0.00	0.00	0.00	0.00
France	0.14	0.18	-0.06	1.15	0.13	-0.05	-0.14	0.37	-0.01	0.04
Greece	0.05	0.27	-0.04	0.97	0.12	-0.04	-0.12	0.39	-0.02	0.03
Croatia	-0.21	0.52	-0.02	0.89	0.04	0.00	0.00	0.00	-0.01	0.00
Hungary	-0.23	0.53	-0.02	0.66	0.03	0.00	0.00	0.00	0.00	0.00
Spain and Portugal	0.11	0.25	-0.03	0.76	0.12	-0.04	-0.10	0.29	-0.05	0.04
Italy and Switzerland	0.12	0.20	-0.04	1.01	0.12	-0.04	-0.10	0.22	-0.02	0.07
Netherlands	-0.02	0.24	-0.06	0.58	0.09	-0.04	-0.18	0.18	-0.06	0.12
Poland	-0.02	0.35	-0.01	1.00	0.10	-0.04	-0.11	0.07	-0.06	0.03
Romania	-0.08	0.26	-0.04	1.90	0.11	-0.03	0.00	0.00	0.00	0.00
Slovakia	-0.24	0.55	-0.01	0.62	0.02	0.00	0.00	0.00	0.00	0.00
Slovenia	-0.14	0.52	-0.01	0.57	0.04	0.00	0.02	0.00	0.00	0.12
Turkey	-0.16	0.37	-0.02	1.00	0.07	-0.02	-0.20	0.12	-0.01	0.00
UK	0.17	0.11	-0.22	1.06	0.15	-0.06	-0.19	0.33	-0.08	0.03
Producer Profit: Rest of World	0.15	0.17	-0.02	1.39	0.19	-0.05	-0.05	0.06	-0.03	0.09
Gazprom Profit	0.20	0.11	0.30	-0.41	0.18	-0.05	-0.09	0.19	0.03	0.01
Statoil Profit	0.07	0.21	0.08	0.20	0.13	-0.05	-0.12	0.25	-0.05	0.07
Transit Profit	1.16	-0.46	0.05	-2.39	0.21	-0.15	-0.21	0.30	0.31	-0.17
Consumer Surplus	-0.33	0.50	0.06	-0.74	-0.01	-0.01	0.11	-0.15	0.03	-0.04

Social Welfare	-0.12	0.35	0.06	-0.22	0.07	-0.03	0.02	-0.03	0.01	0.00
Consumption: Western Europe	0.14	-0.13	0.03	-0.35	0.03	-0.02	0.05	-0.09	0.02	-0.02
Consumption: Eastern Europe	0.19	-0.14	0.02	-0.72	0.04	-0.03	0.06	-0.04	0.01	-0.01

Legend:	$\lvert C_I^R \rvert \in [0;0.2]$	$\lvert C_I^R \rvert \in (0.2;0.5]$	$\lvert C_I^R \rvert \in (0.5;1]$	$\lvert C_I^R \rvert \in (1;+\infty)$

3. Sensitivity analysis: conjectured transit demand slope

The sensitivity analysis on the conjecture transit demand slope parameter was carried out under the assumption that producers and transit countries exert market power while traders are perfectly competitive. The following sensitivity scenarios (Box I.2) were run to check the robustness of the results against different assumptions about the conjectured transit demand slope, *M*.

Scenarios	**Description**
A	This scenario is described in Section 4.2.2. The following conjectured transit parameters are assumed: $M_{uu'} = -F \times CAP_{uu'}^{TR}$, $F = 1\%$ where $CAP_{uu'}^{TR}$ is the capacity of the transit pipeline *(u,u')* (for details of transit pipeline capacities see Table E.3)
B	In this scenario, the following conjecture parameters are assumed: $M_{uu'} = -F \times CAP_{uu'}^{TR}$, $F = 25\%$
C	The conjecture parameters for this scenario are as follows: $M_{uu'} = -F \times CAP_{uu'}^{TR}$, $F = 50\%$
D	For this scenario, the conjecture transit parameters are as follows: $M_{uu'} = -F \times CAP_{uu'}^{TR}$, $F = 75\%$
E	In this scenario, it is assumed that transit countries have extremely limited bargaining power vis-a-vis Gazprom: $M_{uu'} = -F \times CAP_{uu'}^{TR}$, $F = 100\%$ This situation is possible when Gazprom has alternative routes that have a capacity equal to the capacities of transit pipelines (e.g., when Gazprom completes the construction of Nord Stream and South Stream, which will allow it to totally bypass Ukraine as a major transit corridor)

Box I.2: Scenarios of the Market Power of Transit Countries

As can be seen from Table I.5 below, the important conclusion is that different assumptions about the transit conjecture parameter only substantially affect the profits of transit countries. In general, different transit conjecture parameters only slightly modify the model results - within a range of 1% from the Base Case results.

Table I.5: Sensitivity Analysis: Market Power of Transit Countries

Country	Base case	Sensitivity Scenarios									
		A	B	C	D	E	Change (%)				
	[1]	[2]	[3]	[4]	[5]	[6]	[2]/[1]	[3]/[1]	[4]/[1]	[5]/[1]	[6]/[1]
FINAL PRICES (US$/tcm)[a]											
Austria	700	700	692	692	692	692	100.0%	98.8%	98.8%	98.8%	98.8%
Belgium and Luxembourg	532	532	530	530	530	529	99.9%	99.5%	99.5%	99.5%	99.5%
Bulgaria	886	888	879	878	878	878	100.1%	99.1%	99.1%	99.1%	99.1%
Balkans	817	818	808	808	808	808	100.1%	99.0%	99.0%	98.9%	98.9%
Baltic States	776	775	775	775	775	775	99.9%	100.0%	100.0%	100.0%	100.0%
Czech Republic	655	654	648	648	648	648	99.8%	99.0%	98.9%	98.9%	98.9%
Germany	605	604	599	599	599	599	99.9%	99.0%	99.0%	99.0%	99.0%
Finland	897	897	897	897	897	897	100.0%	100.0%	100.0%	100.0%	100.0%
France	425	424	420	420	420	420	99.9%	98.9%	98.9%	98.8%	98.8%
Greece	454	453	450	449	449	449	99.9%	99.1%	99.1%	99.1%	99.1%
Croatia	611	613	603	602	602	602	100.2%	98.6%	98.5%	98.5%	98.5%
Hungary	814	816	806	805	805	805	100.2%	98.9%	98.9%	98.9%	98.9%
Spain and Portugal	450	450	447	447	447	447	99.9%	99.4%	99.3%	99.3%	99.3%
Italy and Switzerland	421	421	416	416	416	416	100.0%	98.9%	98.9%	98.8%	98.8%
Netherlands	608	608	605	605	605	605	100.0%	99.5%	99.5%	99.5%	99.5%
Poland	508	538	505	504	504	504	105.8%	99.3%	99.2%	99.2%	99.2%
Romania	291	292	282	282	282	282	100.5%	97.1%	96.9%	96.9%	96.8%
Slovakia	872	870	863	863	863	863	99.8%	99.0%	99.0%	98.9%	98.9%
Slovenia	715	715	709	709	709	709	100.0%	99.2%	99.2%	99.2%	99.1%
Turkey	540	541	540	540	540	540	100.1%	100.0%	100.0%	100.0%	100.0%
UK	390	389	387	387	387	387	99.9%	99.5%	99.4%	99.4%	99.4%
Gazprom Profit, US$ bln	117.7	119.2	121.6	121.7	121.8	121.8	101.3%	103.4%	103.5%	103.5%	103.5%
Producer Profit: Rest of World, US$ bln	175.6	177.8	175.7	175.6	175.6	175.6	101.2%	100.0%	100.0%	100.0%	100.0%
Transit Profit, US$ bln	1.0	2.2	0.2	0.1	0.1	0.1	212.3%	17.8%	9.3%	6.4%	4.9%
Consumer Surplus, US$ bln	386.9	386.4	389.5	389.5	389.5	389.6	99.9%	100.7%	100.7%	100.7%	100.7%
Social Welfare, US$ bln	***681.3***	***685.6***	***687.0***	***687.0***	***687.0***	***687.0***	100.6%	100.8%	100.8%	100.8%	100.8%
Consumption: Western and Southern Europe, bcm/y	564	564	566	566	566	566	100.0%	100.3%	100.3%	100.3%	100.3%
Consumption: Eastern Europe and Balkans, bcm/y	112	111	113	113	113	113	99.2%	100.6%	100.6%	100.6%	100.6%
Transit through Ukraine, bcm/y	60	55	63	63	63	63	92.0%	106.2%	106.3%	106.4%	106.4%
Transit through Belarus, bcm/y	29	13	30	30	30	30	43.6%	102.7%	102.7%	102.7%	102.7%
Transit fee through Ukraine, US$/tcm	17.45	34.59	5.83	5.09	4.83	4.69	198.2%	33.4%	29.2%	27.7%	26.9%
Transit fee through Belarus, US$/tcm	10.37	55.62	5.81	4.27	3.75	3.49	536.6%	56.1%	41.2%	36.2%	33.7%

Appendix J. Russo-Ukrainian Gas Bargaining Game

Before Gazprom's "gas wars" with Ukraine, Russia used to supply gas for Ukrainian consumption at concessional prices, i.e. prices that were below European prices netted back to Ukraine. This appendix shows through the Nash bargaining model how concessional sales to Ukraine are connected with Ukraine's transit fees.

Suppose that the total surplus, Π^e, from Gazprom's sales to Europe transiting Ukraine totals:

$$\Pi^e = q^e(p^e - c_u - c_r) \tag{J.1}$$

where q^e and p^e are Gazprom's gas sales and price to Europe, c_u is the marginal cost of gas transit through Ukraine, and c_r is the marginal production cost. Further, let Π^u be the total surplus from selling gas for Ukrainian consumption:

$$\Pi^u = q^u(p^* - c_r) \tag{J.2}$$

where p^* is the alternative cost of meeting Ukraine's import demands, q^u; p^* could be average price at a European hub, Norwegian price or Russian price at German border netted back to Ukraine.

Finally, let us denote the total surplus from the Russo-Ukrainian gas trade (transit plus supplies) as $\Pi=\Pi^e+\Pi^u$ and say that Ukraine receives π_u, which maximizes

$$\max_{\pi_U} \mathrm{NP} = {\pi_U}^{\alpha}(\Pi - \pi_U)^{(1-\alpha)} \tag{J.3}$$

where NP is the Nash product, α and (1-α) are the Ukrainian and Russian bargaining powers, respectively, and $(\Pi - \pi_U)$ is Russia's rent from exporting gas to Europe and Ukraine.

The maximization problem (J.3) implies that

$$\frac{d\mathrm{NP}}{d\pi_u} = \left(\frac{\alpha\Pi}{\pi_U}\right)\left(\frac{\pi_U}{\Pi - \pi_U}\right)^{\alpha} = 0 \tag{J.4}$$

and the solution to (J.4) is

$$\pi_u^* = \alpha\Pi = \alpha[q^e(p^e - c_u - c_r) + q^u(p^* - c_r)] \tag{J.5}$$

Eq. (J.5) indicates that an efficient contract will charge opportunity costs for transit services and gas supplies, with transit fees and/or import prices to transfer an appropriate share, π_u^*, of the total surplus, Π, to Ukraine. This share is proportional to its relative bargaining power vis-a-vis Russia (α).

Assuming that the relative bargaining power of each party does not change over time, Ukraine's rent in the gas trade, π_u, is increasing in: (*i*) the price of Russian gas in Europe, p^e, and (*ii*) the alternative cost of meeting Ukraine's import demand, p^*. Thus, as the alternative cost of meeting Ukraine's import demand, p^*, increases, Ukraine's share in the total rent, π_u, also rises. For Gazprom, this means that the opportunity cost of transporting gas through Ukraine raises substantially if the company does not break Ukraine's transit monopoly when p^* increases. This is because Gazprom's supplies to Ukraine could be sold under much higher prices in Europe than the price supplied to Ukraine due to its important position as a near transit monopolist.

APPENDIX K. Implicit Transit Costs through Ukraine

This appendix documents calculation of implicit transit costs through Ukraine.

Table K.1: Deriving Gazprom's Implicit Transit Costs through Ukraine

	Actual Transit Fee, US$/tcm/ 100km	Transit volume, bcm	Actual Import Price, US$/tcm	European Import Price, US$/tcm	Import from Russia, bcm	Gazprom's Opportunity Cost, US$ mn	Implicit Transit Cost, US$/tcm/100km
	[1]	[2]	[3]	[4]	[5]	[6]	[7]
2002	1.28	121	59	87	26	732	1.76
2003	1.09	129	50	116	26	1704	2.16
2004	1.09	137	50	126	24	1832	2.17
2005	1.09	136	50	171	23	2791	2.74
2006	1.53	129	95	228	54	7211	6.05
2007	1.52	115	130	234	50	5241	5.19
2008	1.61	120	180	335	49	7663	6.77
2009	1.58	96	233	237	30	135	1.70

Notes: [6]=[5]x([4]-[3]); [7]=[1]+([6]/[2]/D)x100; D – Transit Distance = 1240km
Sources: Own estimates based on various sources

For each demand scenario analysed, the NPV of South Stream investment was derived under three different values of transit fees, as indicated in Chapter 4: Table 4.4 Then, the NPV of South Stream as a function of transit fees through Ukraine under the three demand scenarios are approximated using a simple linear regression, as shown in Figure K.1.

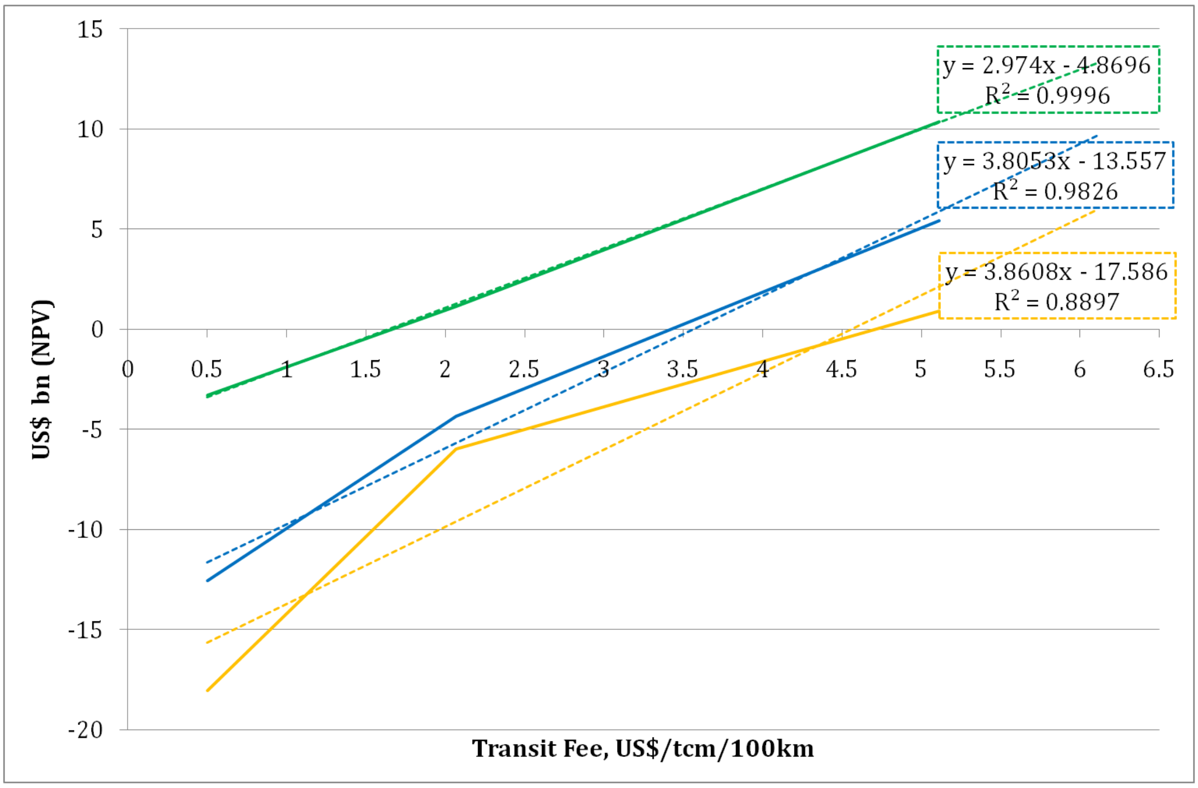

Figure K.1: Dependence between South Stream's Value and Transit Fees through Ukraine

APPENDIX L. Russia's Current Gas Export Routes to Europe

As of 2008, Russia's overall gas export capacity through pipelines to Europe, including Turkey, is around 214 billion cubic metres (bcm) (see Table L.1). There are two main routes which Gazprom currently uses to export gas to Europe: through Ukraine and Belarus.

Table L.1 Gazprom's Existing Export Options

Transit		
Final Markets	Design Capacity, bcm/y	Actual volume transported in 2008, bcm/y
Through Ukraine		
To Western and Eastern Europe	92.6	75.5
To Poland	5.0	4.8
To Hungary, Serbia and Bosnia-Herzegovina	13.2	12.1
To Romania	4.5	2.0
To Romania, Bulgaria, Greece, Macedonia and Turkey	26.8	22.5
Through Belarus[130]		
To Poland and Germany	36.3	35.2
To Lithuania	6.4	2.8
Direct Sales		
To Finland	8.1	4.8
To Latvia and Estonia	5.4	1.3
To Turkey via Blue Stream	16.0	9.3
Total	214.3	170.3
Share of Ukraine in Transportation of Russian Gas Exports, %	66.3	68.6
Share of Belarus in Transportation of Russian Gas Exports, %	19.9	22.3

Sources: Own calculations based on (ENTSOG, 2010; Naftogaz of Ukraine, 2010b; Gazprom, 2010b; Yafimava, 2009)

Direct gas sales to final markets constitute some 9% of total exports to Europe (including Turkey). The rest of Gazprom's exports are transported through Ukraine and Belarus. Before 2003, nearly 95% of all Russian gas exports went through Ukraine.[131] Due to past conflicts between Russia and Ukraine over the terms of the gas trade, including transit fees, import prices and debt clearance by Ukraine, Russia has initiated several pipeline projects to bypass Ukraine. One of these projects is the Yamal-Europe I gas pipeline which traverses Belarus and Poland. The total throughput of Yamal I is 30.6 bcm/year (ENTSOG, 2010). Yamal-Europe I serves as the basis of Russia's northern gas

[130] We only report export capacity through Belarus to Poland and Germany; export capacity through Northern Light which re-enters Ukraine has been omitted in this table for simplicity.
[131] Authors' own calculations based on Gazprom (2010a), Naftogaz of Ukraine (2010), Yafimava (2009).

export corridor to Europe. The delivery point through Yamal-I is at Mallnow on the Germany-Poland border (near Frankfurt-am-Oder).

The majority of Russian gas exports to Europe still traverse the southern gas export corridor, via Ukrainian territory. In 2008, around 68% (see Table L.1) of all Russian gas exports to Europe were transported through Ukraine. The delivery points of Russian gas through Ukraine are: (*i*) the Ukrainian-Slovak border, (*ii*) Baumgarten Gas Hub (Austria), and (*iii*) the Czech-German border (Waidhaus and Olbernhau).

APPENDIX M. The Nord Stream pipeline system

The Nord Stream pipeline system (NSPS) is Gazprom's third gas export corridor, alongside its traditional Ukrainian route and the Belarus-Poland-Germany route, as described in Appendix L. The Nord Stream system consists of four pipelines (see maps below):

1. *Onshore Connection in Russia: Gryazovets-Vyborg Pipeline*

This pipeline is intended to connect Russia's gas transmission system with the offshore section of the Nord Stream pipeline system. The pipeline length is 917 km and the design capacity is 55 bcm/y. The pipeline runs from Gryazovets in Russia's Vologda Oblast to Vyborg northeast of St Petersburg on the Gulf of Finland. According to Gazprom, as of December 2009 597 km of pipeline were constructed. The pipeline will start operation in 2011 and will reach its designed capacity by late 2012. The estimated cost of the pipeline is around €4.5 bln (for details, see Appendix F).

2. *Offshore Pipeline Underneath the Baltic Sea*

Nord Stream AG was incorporated in 2005 for the purpose of carrying out a feasibility study, building and operating the offshore pipeline. Nord Stream AG is jointly owned by Gazprom (51%), BASF SE/Wintershall Holding AG (15.5%), E.ON Ruhrgas AG (15.5%), N.V. Nederlandse Gasunie (9%) and GDF Suez (9%).

The length of the offshore line is 1220 km and will be laid across the Baltic Sea, from Vyborg, Russia, to Greifswald, Germany. The pipeline will consist of two parallel lines. The first one, with a capacity of 27.5 bcm/y, is due for completion in late 2011. The second line is due to be completed in late 2012, doubling annual capacity to 55 bcm. According to Nord Stream AG, total investment in the offshore pipeline is projected at €7.4 billion (Nord Stream AG, 2010a).

3. *Onshore Connection in Germany: NEL and OPAL pipelines*

The OPAL[132] pipeline is intended to connect the landing point of Nord Stream's offshore part at Lubmin near Greifswald to Germany's existing gas pipeline grid. The line will carry natural gas from Lubmin to Olbernhau on the Czech border. The length of the pipeline is 470 kilometres south to Olbernhau on the Czech border. The capacity of the

[132] Ostsee-Pipeline-Anbindungs-Leitung – Baltic Sea Pipeline Link

project is 35 bcm/y. The line is planned to operate from late 2011. According to the project sponsors, the estimated cost of the line is around €1 bn (OPAL, 2010).

The NEL[133] pipeline will bring gas coming from Nord Stream offshore westward, with the possibility of supplying the Netherlands and beyond through BBL/IUK to the UK gas market. The pipeline is expected to start operation in late 2012. The line will run from Lubmin to Achim, near Rehden (~440 km), with a design capacity of 20 bcm/y. The official cost estimate of the pipeline is €1 bn (NEL, 2010).

4. *Onshore Connection in the Czech Republic: Gazelle pipeline*

The Gazelle pipeline will be connected with OPAL at Hora Svaté Kateřiny to bring gas from Nord Stream across the Czech Republic to Rozvadov, near Waidhaus, on the Czech-German border. The pipeline length is between 166 and 235 km, with a design capacity of 30-33 bcm/y. According to the project investor, NET4GAS (Czech's TSO), the investment cost is estimated at €400 mln and the pipeline will start operation in 2011 (NET4GAS, 2010). Formally, the Gazelle pipeline is not part of the Nord Stream system. NET4GAS, which is the owner of the Gazelle project, has no stake in Nord Stream AG (the operator of the Nord Stream offshore pipeline), but for simplicity we consider the project to be part of the Nord Stream system.

Figure M.1: Gryazovets-Vyborg Pipeline in Russia

133 Norddeutsche Erdgas-Leitung – Northern German Gas Link

Source: (Gazprom, 2010c)

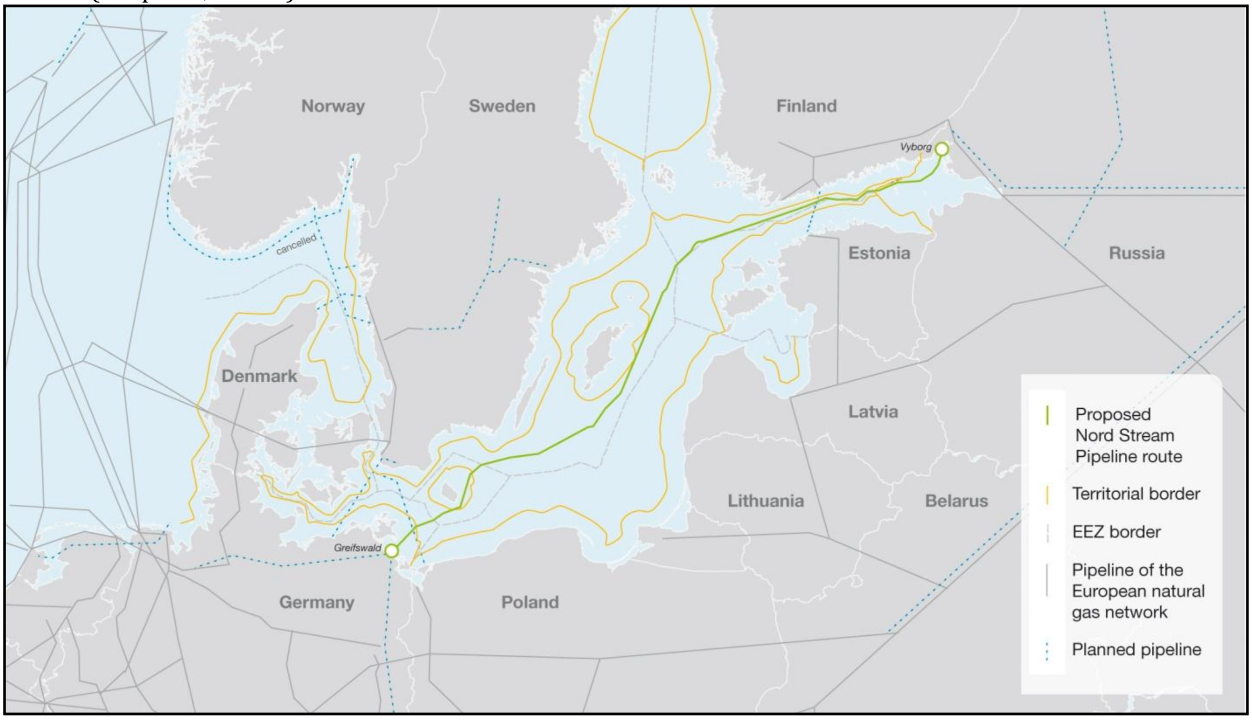

Figure M.2: Nord Stream Offshore Pipeline
Source: (Nord Stream AG, 2010c)[134]

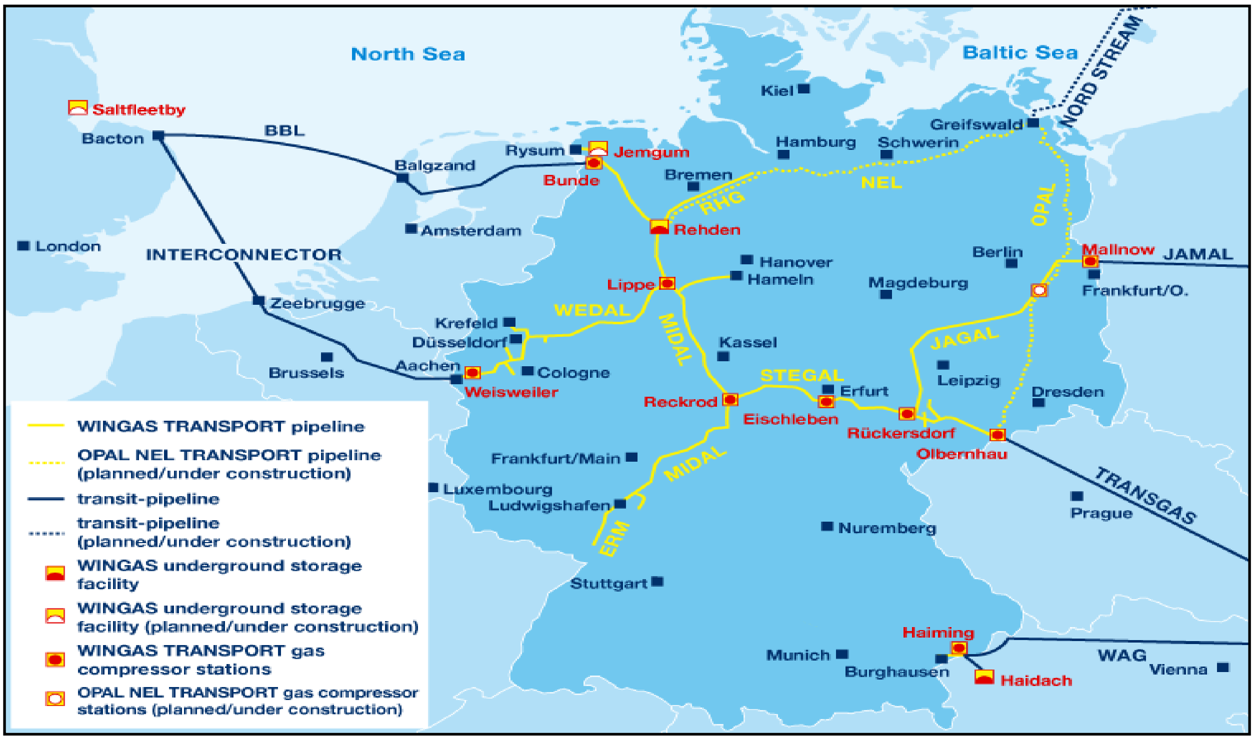

Figure M.3: Onshore connection in Germany: Opal and Nel pipelines
Source:(Wingas, 2010)[135]

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[134] With permission from Nord Stream AG
[135] With permission from WINGAS

Figure M.4: Gazelle Pipeline in Czech Republic
Source: original map from ENTSOG (2010)