Energy Economics 44 (2014) 198–211

Contents lists available at ScienceDirect

Energy Economics

journal homepage: www.elsevier.com/locate/eneco

Strategic Eurasian natural gas market model for energy security and policy analysis: Formulation and application to South Stream

Chi Kong Chyong [a,*], Benjamin F. Hobbs [b]

[a] Energy Policy Research Group (EPRG), Cambridge Judge Business School, University of Cambridge, Trumpington Street, Cambridge CB2 1AG, UK
[b] Department of Geography & Environmental Engineering, The Johns Hopkins University, 3400 North Charles Street, Ames Hall 313, Baltimore, MD 21218, USA

ARTICLE INFO

Article history:
Received 22 January 2013
Received in revised form 9 April 2014
Accepted 11 April 2014
Available online 24 April 2014

JEL classification:
C61
C72
L13
L95
H43

Keywords:
Natural gas
Computational market equilibrium
Complementarity model
Nord Stream
South Stream
Gazprom
Energy security
Market power

ABSTRACT

The mathematical formulation of a strategic Eurasian natural gas market model is presented. The model represents horizontal oligopolistic relationships among producers, bilateral market power between producer (Russia) and transit (Ukraine) countries, detailed transport constraints, and operation decisions over a 20 year time horizon. To demonstrate the model's capabilities, a financial and market analysis of the proposed South Stream gas pipeline from Russia via the Black Sea to South Europe is summarized. Insights obtained include the following. First, expectations of high demand growth in Europe and/or transit risks do not justify the construction of the South Stream pipeline because under all demand and Ukraine transit interruption scenarios, the net benefits to the South Stream participants are negative (the NPV ranges from −$1.9 billion (bn) to −$7.4 bn). Second, Ukraine's perception of high transit market power vis-à-vis Russia may trigger the construction of the otherwise unprofitable South Stream project. Thus, under Ukraine's high transit market power scenario, the NPV of South Stream ranges between $2.4 bn and $24.5 bn. Third, we find that the South Stream investment increases the efficiency of the European gas market under the following conditions: (i) when gas demand in Europe grows 2% per year up to 2030, (ii) when Ukraine poses high transit market power, or (iii) under a combination of severe transit risks through Ukraine and low demand scenarios in Europe. It should be noted that the value of South Stream to both its project sponsors and the market as a whole is much higher when Ukraine exercises transit market power than under the high demand scenario. Therefore, whether Ukraine is likely to wield market power is crucial to the success of the South Stream project because that is the only scenario in which the project yields both a positive expected NPV to its sponsors and the highest value to the market as a whole.

1. Introduction

Natural gas plays a significant role in Europe's energy mix and is expected to grow in importance.[1] In 2010 major suppliers to the region – Norway, Russia and Algeria – together provided around 53% of all gas consumed in the EU. Russian gas alone accounts for half of these EU imports, or 6% of the EU primary energy supply (BP, 2011). Over 90% of Russian gas exports transit through Ukraine and Belarus before entering European markets. 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 January 2009, affecting millions of customers in southeast Europe and the western Balkans (Kovacevic, 2009; Pirani et al., 2009; Silve and Noël, 2010).

Since the breakup 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 South Stream projects, under the Baltic and the Black Sea, respectively.[2] Once operational, these two projects would have a total capacity larger than the current volume of gas being transported through Ukraine to Europe. The importance of these two projects to the security of supply to Europe is large: if built, their total export capacity would constitute 23% of the EU's current annual consumption, or 39% of the EU's total gas imports. Despite their importance to gas supply security for the EU, to our knowledge, in-depth and publically available studies of the economics of these projects are limited.

* Corresponding author at: EPRG, Judge Business School, University of Cambridge, UK. Tel.: +44 1223748197; fax: +44 1223339701.
E-mail address: k.chyong@jbs.cam.ac.uk (C.K. Chyong).

[1] In 2009, natural gas consumption in the European Union (EU) member states totalled 508 bcm (IEA, 2011), of which indigenous production accounted for 39% (calculations based on (BP, 2010; IEA, 2010)). By 2030, natural gas consumption in the EU is projected to grow at an annual growth rate of +0.8% (IEA, 2011) while the EU's indigenous gas production is anticipated to decline substantially (EC, 2008).

[2] The construction of the Nord Stream pipeline was officially finished in April 2012.

http://dx.doi.org/10.1016/j.eneco.2014.04.006
0140-9883/

Therefore, one of our research objectives is to develop a natural gas market model to analyze the economics of strategic gas pipeline investments in Eurasia, such as Nord Stream and South Stream. This paper has two objectives: (i) to detail the mathematical formulation of the model along with the assumptions and data used, and (ii) to demonstrate the model's capabilities by examining the economic rationale of Gazprom's investment in the South Stream pipeline. The question that we seek to answer in the case study is: what is the financial value of the South Stream investment to its project sponsors under different gas market and policy scenarios?

This research contributes both to the existing literature on natural gas market modeling and to the debate on Russia–EU–Ukraine natural gas security of supply. In particular, while natural gas market models have been formulated and used extensively in the economic analysis of gas market developments (among others, see, e.g., Boucher and Smeers (1985, 1987), Egging et al. (2008), Gabriel et al. (2012, 2005b), Holz et al. (2008), Lise et al. (2008), Zhuang and Gabriel (2008)), the model of this paper differs from earlier models in its detailed representation of the Former Soviet Union (FSU) gas sector. Among the new features of this model are the following: transit activities of Ukraine and Belarus are explicitly modeled, including transmission pipelines; Russian gas production is distinguished by its dominant producer – Gazprom – and independent gas companies,[3] as well as by its production regions (both current and future); and the Russian transmission system and export pipelines from Central Asia to Russia are included in the model. This level of detail in the representation of the FSU gas region is unique in the natural gas modeling literature.[4]

These modeling improvements facilitate analyses of current policy and economic debates concerning Russia's strategic natural gas export policy and particularly of economics and strategic issues regarding Gazprom's investment in the South Stream project. To our knowledge, this is the first detailed economic analysis of the South Stream investment and its impact on gas markets in Europe.

The rest of paper is organized as follows. The next section outlines our model and a comparison with other existing gas market models; the mathematical formulation of the model and detailed outline of data inputs and assumptions appears in Appendixes A–D (online). Model validation is discussed in Section 3, while Section 4 presents the results of the South Stream case study. The paper concludes with a summary of those results, and recommendations for future model developments.

2. Strategic Eurasian natural gas market model

2.1. Existing natural gas market models

In this section, we first give an overview of equilibrium models of natural gas markets and their applications. We then review previous research that used economic modeling to analyze natural gas market developments in the FSU countries.

Table 1 summarizes existing equilibrium natural gas market models published in the public domain. Example of these are the deterministic version of the World Gas Model (WGM) developed by Egging et al. (2010, 2009b) and its stochastic version developed by Egging (2013) as well as the Global Gas Market Model (COLUMBUS) developed by Hecking and Panke (2012). WGM and COLUMBUS have been used for analysis of various gas policy questions including possible cartelization (Egging et al., 2009b; Gabriel et al., 2012) and market effects of disruptions of major gas pipeline exports to Europe (Egging et al., 2008) and disruptions of global LNG trade (Growitsch et al., 2013). A distinctive feature of the WGM and COLUMBUS models compared to other global

Table 1
Existing publicly available models of natural gas markets.

Model	WGM	Stochastic WGM	GaMMES	GASTALE	GASMOD	NAT-GAS	EPRG-GMM	BIWGTM	EWI-TIGER	EWI-Columbus	FRISBEE	MIT-EPPA
Type[a]	MCP	SMCP	MCP	MCP	MCP	MCP	MCP	CGE	LP	MCP	PE	CGE
Market power	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	No	No
Coverage	Global	Global	Europe + LNG	Europe + LNG	Europe + LNG	Europe + LNG	Europe + FSU + LNG	Global	Europe + LNG	Global	Global	Global
Nodes	41	19	15	7	28	11	138	460	>1000	215	13	n/a
Timeframe	2030	2040	2040	2030	2025	2035	2030	2040	2020	Flexible	2030	2100
Seasons	2	2	2	3	1	2	1	1	12	Flexible	1	1
Demand Sectors	3	1	3 sectors & interfuel substitution	3	1	1	1	1	2	2	3	n/a
Granularity	5 years	5 years	5 years	5 years	Yearly	5 years	Yearly	5 years	Monthly	Flexible	Yearly	5 years
Capacity expansion[b]	End.	End.	End.	End.	Exog.	End.	Exog.	End.	End.	End.	End.	End.

[a] MCP — mixed complementarity problem, SMCP — stochastic mixed complementarity problem, CGE — computable general equilibrium, LP — linear programming, and PE — partial equilibrium.
[b] End. — endogenous and Exog. — exogenous.

[3] Oil producers and small gas companies in Russia.
[4] In this paper, "FSU countries" refer to Russia, Ukraine, Belarus, Moldova, Kazakhstan, Uzbekistan, Turkmenistan and Azerbaijan. Although Estonia, Lithuania and Latvia were also members of the USSR, we refer to them instead as Western European countries.