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AN IMPERFECTLY COMPETITIVE MODEL OF THE WORLD NATURAL GAS MARKET

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Abstract[1]
In this paper we develop a model of global natural gas trade under imperfect competition where buyers and sellers (producers) are connected by a trading network. The market power of a producer depends on her supply capacity, her access to markets and the number of competitors she faces in each market. We apply this model to a natural gas trade network formed by using BP's Statistical Review of 2010 major trade flows. Later, we change model parameters exogenously to analyze various policy scenarios. We find that any exogenous change affecting Europe also has an effect in the Asia Pacific. The reason is that two big producers, Russia and the Middle East, are connected to both markets. We also find that shale gas development in North America reduces natural gas producers' market power all around the world.

[1]This is a revised version of the paper published on November 15, 2012.

1 Introduction

World natural gas production is concentrated in a small number of producers, the majority of which are state-owned companies. For instance, Russia's biggest natural gas producer, Gazprom, controls 70 percent of Russian natural gas reserves and produces 78 percent of all Russian natural gas.[2] Similarly, state-owned Sonatrach[3] dominates natural gas production and wholesale distribution in Algeria, while state-owned Sonelgaz controls retail distribution.[4] These state-owned companies have monopoly power in their domestic markets, but their ability to exploit it is limited since their actions are highly regulated by their governments.[5] Once they export natural gas via long distance pipeline or liquefied natural gas (LNG), they must compete with each other and sometimes with domestic suppliers in the European, Asian or North American markets. In contrast to supply, the demand for natural gas in these foreign markets is not as concentrated. In this paper, we assume that natural gas consumers (e.g., utility service providers) do not have any bargaining power and are passive agents. We then analyze the strategic behavior of world natural gas producers[6] and examine the impacts of exogenous changes on their behavior.

Long distance, and especially international, natural gas transportation infrastructure is expensive to construct and generally changes slowly. The high costs of developing large natural gas projects have also led to long-term contracts tying buyers to particular sellers. As a simplifying assumption, we consider a network structure where connections between buyers and sellers are fixed. In our model, a buyer and a seller must have a relationship, or "link" to trade. For instance, the Yamal pipeline from Russia to Europe is a link. The cost of building pipelines over long distances and the high cost of LNG shipment lead to differences in natural gas prices between regions. In our model, however, price discrimination by producers also contributes to price differentials between markets.

We modify Ilkilic (2010), who develops a bipartite network model for m markets and n firms in Cournot competition and analyzes how the structure of the network that connects suppliers with consumers affects the market outcome. Unlike Ilkilic (2010), we assume that each producer has a supply capacity constraint and solve for the equilibrium under this constraint. We show that our game can be represented as a potential game and solve for its equilibrium. We then consider various changes to the basic model in a number of scenarios.

As a consequence of imperfect competition within this given network structure, we find

[2]See http://www.nord-stream.com/about-us/our-shareholders/

[3]See Oil and Gas Directory Middle East, 2011.

[4]Other examples include Qatar Petroleum in Qatar, Nigerian National Petroleum Corporation in Nigeria, National Gas Company of Trinidad and Tobago in Trinidad and Tobago, Pertamina in Indonesia and Petronas in Malaysia.

[5]For instance, natural gas prices in Russia are regulated by the Federal Tariff Service of the Russian Federation.

[6]To make the model tractable, we need to have small number of players. For that reason, we aggregate producers and consumers based on their geographic locations as well as their role in global natural gas trade. For instance, we assume that Russia includes Armenia, Azerbaijan, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan and Russia.

that any exogenous change affecting Europe has an offsetting effect in the Asia Pacific, as two big producers, Russia and the Middle East, are connected to both markets. We find that if Russia and the Middle East collude, Russia supplies Europe only whereas the Middle East supplies the Asia Pacific only. We also find that shale gas development in North America reduces natural gas producers' market power around the world.

Section 2 reviews the literature on strategic interactions among natural gas market players. In Section 3, we present an overview of the world natural gas market in 2009. In Section 4, we define our Cournot game model and solve for its unique Cournot-Nash equilibrium. In Section 5, we calibrate the Cournot game parameters based on trade volumes from the 2009 world natural gas network in BP's Statistical Review of World Energy 2010 and natural gas prices in 2009. Section 6 is devoted to analyzing different policy scenarios. The paper concludes in Section 7.

2 Related literature

Strategic interactions among natural gas market players have been widely studied. Mathiesen et al. (1987) were the first to claim that the natural gas market is best described by a Cournot game, as the majority of natural gas trade is based on long-term, take-or-pay contracts. Later, Golombek et al. (1995 and 1998) studied the European natural gas market as a Cournot game. They analyzed the effects of liberalization in Europe by distinguishing between upstream and downstream agents and arguing that deregulation increased upstream competition while leaving downstream markets regulated. The cost parameters and elasticity parameters of Golombek et al. (1995) were disaggregated by country[7] and hence have been widely used. For instance, the GASTALE model by Boots et al. (2004) used the marginal cost parameters in Golombek et al. (1995), which was the first paper to apply the successive oligopoly model[8] in natural gas production and trading in a large-scale simulation. However, Golombek et al. (1995) make simplifying assumptions, such as requiring symmetry among traders and taking domestic supply to be exogenous.

Holz et al. (2006) developed a strategic model of European gas supply, GASMOD, as a two-stage game. In the first stage, upstream exporters are Stackelberg leaders over downstream domestic wholesale traders. In the second stage, downstream traders take the prices determined by the upstream exporters as given and compete with each other to supply domestic markets. In particular, unlike GASTALE, GASMOD assumes that domestic production is endogenous. However, neither GASTALE nor GASMOD considers the European natural gas market as a network.

[7]They provide the price elasticities for Belgium, France, Netherlands, Italy, United Kingdom and West Germany and the cost parameters for Algeria, Commonwealth of Independent States, Netherlands, Norway and United Kingdom.

[8]This is a model in which the upstream natural gas producers supply to the downstream traders to serve consumers located in the foreign country.

Gabriel et al. (2005) using a mixed complementarity[9] approach developed an equilibrium model of natural gas markets. Their model not only covers multiple seasons and years; it also allows for many different sectors or agents: producers, storage operators, peak gas operators, pipeline operators, marketers, and consumers. Marketers and consumers interact strategically, while other trades are competitive. Marketers are price takers when purchasing natural gas from storage operators, pipeline operators, and peak gas operators but behave strategically when selling to end-use consumers. At any consumption node, there are several marketers who are connected to all four sectors; these sectors are residential, commercial, industrial and power. Their network graph is complete[10] and each marketer is only at one consumption node. Gabriel et al.'s (2005) model has been applied to North American, European and world natural gas markets.[11] In Gabriel et al.'s (2005) model the structure of the network is not the main consideration. In their model, the "network" has a special feature: a strategic player at any consumption node is connected to all markets at that node. Furthermore, each strategic player is connected to only one consumption node, and all players at a given node have the same objective function.[12] This simplifies the problem because there will be a representative strategic player on each consumption node, and the Cournot equilibrium is symmetric.[13] By contrast, both in reality and also in our model, the market power of each natural gas producer depends on its ability to access markets, and different producers will supply a different set of several markets.

The application of oligopolistic market models by Gabriel et al. (2005) to study natural gas markets differs from ours in two more ways. Their method depends on the existence of a solution to a system of equations and inequalities that result from mixed complementarity (Kuhn-Tucker) conditions, whereas ours relies on a constrained function minimization procedure. We explicitly use the literature on network resource allocation problems with coupled constraints to show how one can derive a minimization procedure that is equivalent to the constrained noncooperative game.

The solution approach that we use, which was introduced by Monderer and Shapley (1997), is called potential games. It has been applied in the electrical engineering literature on wireless networks and communication network problems.[14] A final difference between our model and Gabriel et al. (2005) is the kind of equilibrium that they try to establish.

[9] A mixed complementarity model consists of set of simultaneous (linear or nonlinear) equations that are mix of strict equalities and inequalities, with each inequality linked to a bounded variable in a complementarity slackness condition (Rutherford 1995).

[10] Formally, their graph is a complete bipartite graph meaning that every node of the first set (marketers) is connected to every node of the second set (end use consumers).

[11] For its application to the North American natural gas market, see Gabriel et al. (2005), to the European natural gas market see Egging and Gabriel (2006), Egging et al. (2008) and Holz (2009) and to the world natural gas market see Egging et al. (2010).

[12] Each marketer is connected to same sources, pipeline operators, storage operators and peak gas operators and purchases the natural gas at the same price.

[13] The best response function of a player will be the same as his competitors' best response functions due to the symmetry of the Cournot game.

[14] See Zhu (2008).

They compute a Cournot-Nash equilibrium that would also satisfy a market clearing condition. We look for a coupled constraint[15] Cournot-Nash equilibrium, which is a more appropriate solution concept for the natural gas network problem. This is because each producer's value from supplying a given market depends on its own actions and on the actions of competitors who are connected to the same market. In addition, a firm's actions in one market depend on its actions in other markets to which it is connected.

In summary, our model captures the strategic interactions among the small number of natural gas producers in the world natural gas network.[16] Contrary to previous authors, we assume that the strategic players are heterogeneous in terms of their access to markets, their costs of exporting natural gas, and their supply capacities.

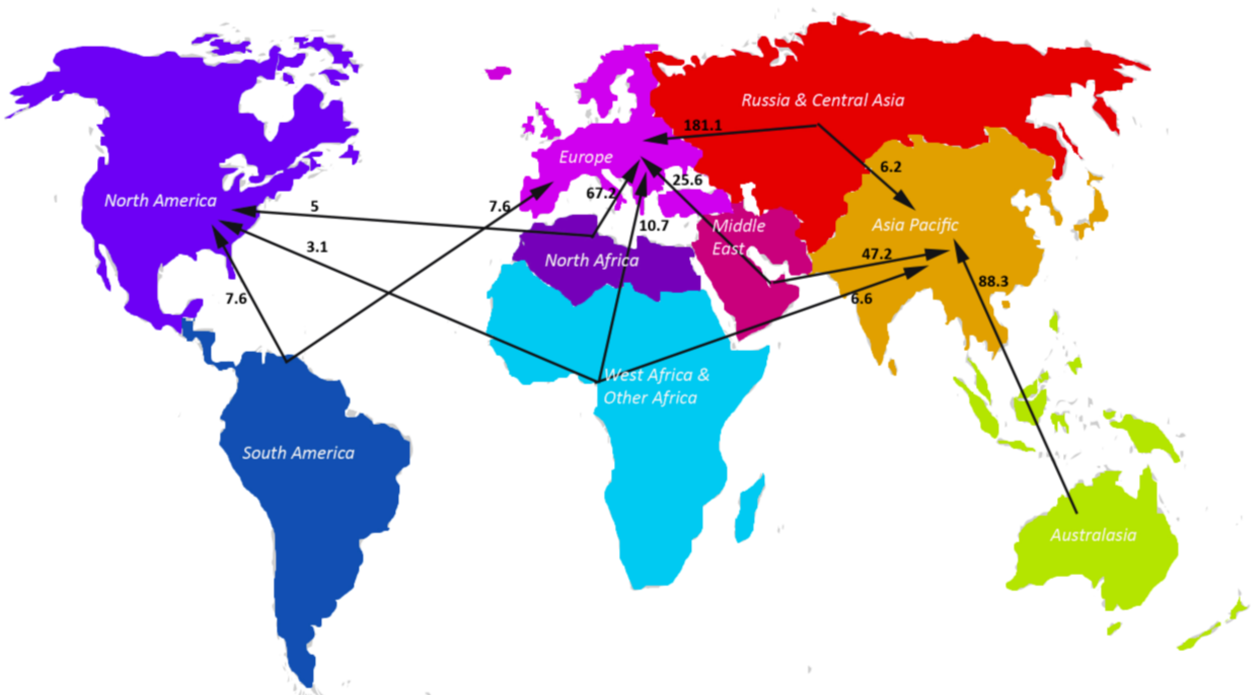
3 World natural gas market

Taking account of the strategic interaction between suppliers adds to the complexity of our model. To simplify, we therefore aggregate producers and consumers into a small number of regions and equilibrium trade flows as shown in the world map in Figure 1.

[15] A producer's supply to a market is constrained by its supply to several other markets.

[16] The world natural gas network is based on the BP's Statistical Review of World Energy 2010's major trade flows and is not a complete graph. This means that not every producer is connected to every market.

Figure 1: Aggregated representation of producers and consumers and natural gas trade movements in 2009 (in Bcm)



Since each producer is connected to its domestic market, the number of producers and consumers is identical and in our case equals nine. In addition, six of the nine producers are exporters, and three of the nine consumers are importers. Producers and consumers are ordered[17] as Europe,[18] North America,[19] Asia Pacific,[20] South America,[21]

[17]They are labeled according this order. Producers: Europe labeled as 1, North America labeled as 2, Asia Pacific labeled as 3, South America labeled as 4, West Africa labeled as 5, North Africa labeled as 6, Russia labeled as 7, Middle East labeled as 8, Australasia labeled as 9. Consumers are in the same order as producers and labeled the same.

[18]Europe includes Austria, Belarus, Belgium, Bosnia, Bulgaria, Croatia, Czech Republic, Estonia, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Macedonia, Moldova, Netherlands, Poland, Portugal, Romania, Serbia, Slovakia, Slovenia, Spain, Sweden, Switzerland, Turkey, United Kingdom and Ukraine.

[19]North America includes Mexico, U.S. and Canada.

[20]Asia Pacific includes Bangladesh, China, india, Japan, Myanmar, Pakistan, South Korea, Taiwan, Thailand and Vietnam.

[21]South America includes Argentina, Bolivia, Brazil, Colombia, Peru, Trinidad and Tobago, Venezuela.

West Africa,[22] North Africa,[23] Russia,[24] Middle East[25] and Australasia.[26]

According to the BP's Statistical Review of World Energy 2010, in 2009, North America's total natural gas consumption was 828 billion cubic meters (Bcm) and total production was 812.95 Bcm. In 2009, North America imported 42 percent of its natural gas from Trinidad and Tobago and 29 percent from Egypt.

In 2009, Europe's total natural gas consumption was 580.3 Bcm and total production was 288.1 Bcm. The production-to-consumption ratio for Europe was 0.49; thus, more than 50 percent of the natural gas consumed in Europe in 2009 was imported. Russia was the largest supplier of natural gas to Europe, with a 62 percent share of imports. The Middle East's share in European natural gas imports was 8.8 percent and North Africa's share was 23.3 percent.

In 2009, Asia Pacific's total natural gas consumption was 394.4 Bcm and its total production was 246.1 Bcm. The production-to-consumption ratio for the Asia Pacific was 0.62. Australasia supplied 59.5 percent of Asia Pacific's natural gas imports, making it Asia Pacific's largest supplier. The Middle East accounted for 31.8 percent of Asia Pacific's natural gas imports. Russia exported 6.2 Bcm of natural gas to the Asia Pacific in 2009, which was 3.7 percent of total imports. Before 2009, Russia had no natural gas exports to the Asia Pacific.

According to the BP's Statistical Review of World Energy in 2010, the U.S. Henry Hub natural gas price was 3.89 USD per million British thermal units (MMBtu). However, according to the OECD data on natural gas import costs, the U.S. LNG import cost was 4.52 USD per MMBtu. Due to our single price assumption for each region, the North American price in this model is 150 million USD per Bcm, which is approximately 4.18 USD per MMbtu.[27]

For the natural gas price in the Asia Pacific, we use LNG Japan price data reported by the BP's Statistical Review of World Energy in 2010, which is 9.06 USD per MMBtu. For natural gas price in the European market, we use the average of German import price, LNG and pipeline import prices for the European Union members provided by the OECD, which is 8.4 USD per MMbtu.

In our model, natural gas prices in the European and the Asia Pacific markets are close to each other and higher than the North American price. However, according to Figure 5 in Medlock (2012) the prices of natural gas at the U.S. Henry Hub, the UK National Balancing Point, the Platts Japan/Korea Marker were close before the Fukushima incident. We need to consider the historical natural gas price trends among these markets in our future research.

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[22] West Africa includes Angola, Equatorial Guniea, Mozambique and Nigeria.

[23] North Africa includes Algeria, Egypt and Libya.

[24] Russia includes Armenia, Azerbaijan, Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan and Russia.

[25] Middle East includes Iran, Israel, Kuwait, Lebanon, Oman, Saudi Arabia, Syria, Qatar, U.A.E., Yemen.

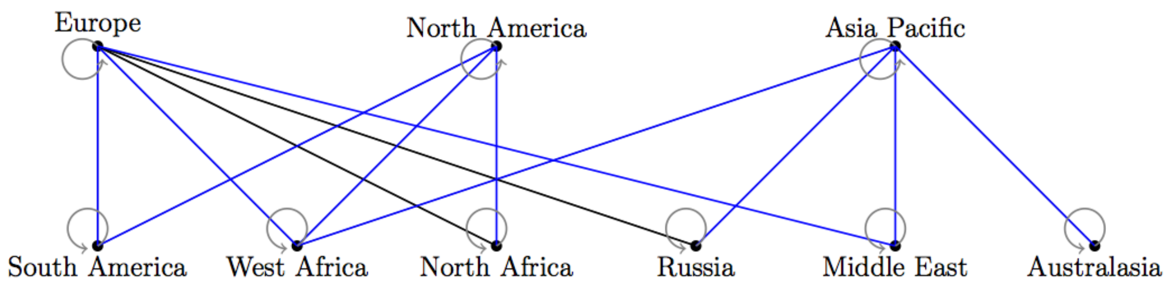
[26] Australasia includes Australia, Brunei, Indonesia, Malaysia, New Zealand, Philippines and Singapore.

[27] This price reflects the natural gas price in Canada, U.S. and Mexico.

3.1 Schematic representation of the world natural gas trade

The world natural gas network formed using these statistics[28] is shown below.

Figure 2: Schematic representation



4 Model

4.1 Notation

There[29] are m markets[30] $d_1, ..., d_m$ and n firms[31] $f_1, ..., f_n$. They are embedded in a network that links markets with firms, and firms can supply only to the markets to which they are connected. This network will be represented as a set, $g = \langle D \cup F, L \rangle$, of *nodes* formed by markets $D = d_1, ..., d_m$, and firms $F = f_1, ..., f_n$ and a set of *links* L, each link joining a market with a firm. A link from d_i to f_j will be denoted as (i, j). We say that a market d_i is *linked* to a firm f_j if f_j supplies natural gas to market d_i, using the link joining the two. We will use $(i, j) \in g$ meaning that d_i and f_j are connected in g.

A graph is *connected* if there exists a path connecting any two nodes of the graph while ignoring direction of physical flows. This concept is important because in a connected graph any change affecting one node will impact all other nodes.

$N_g(d_i)$ will denote the set of firms linked with d_i in $g = \langle D \cup F, L \rangle$. More formally:

$$N_g(d_i) = \{f_j \in F \text{ such that } (i, j) \in g\} \tag{1}$$

and similarly $N_g(f_j)$ stands for the set of markets linked with f_j.

[28] The blue lines indicate that the natural gas is transported via LNG and the black lines indicate that the natural gas is transported via pipeline. Half of the natural gas exports from North Africa to Europe are carried via LNG and half of them are carried via pipeline. Each producer is connected to its domestic market, which is indicated by gray circle.

[29] We use the conventions set forth in Ilkilic (2010).

[30] We use terms "market", "consumer" and "buyer" interchangeably.

[31] We use terms "firm", "producer" and "seller" interchangeably.

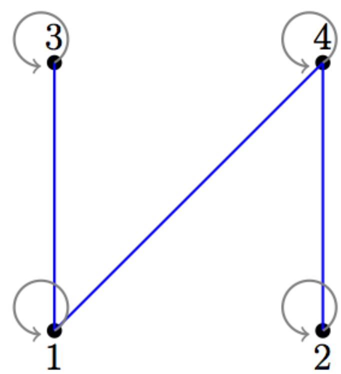
4.2 Cournot game

Given a graph g, each firm f_j maximizes its profit by supplying non-negative quantities to the markets in $N_g(f_j)$. Thus, the set of strategic players is the set of firms F. Let $q_{ij} \geq 0$ be the quantity supplied by firm f_j to the market d_i and Q_g be the vector of quantities supplied in graph g. Let $r(g)$ be the size of Q_g, and assume we list the supply q_{ij} above the supply q_{kl} when $j < l$ or when $j = l$ and $i < k$.

A simplified example might help the reader understand the general formulation. Consider a network with four producers,[32] four markets,[33] and seven links connecting them. Out of these four markets, two are importers, market 3 and market 4. Out of these four producers, two are exporters, producer 1 and producer 2.[34]

Natural gas carried from producer 1 to market 1 is denoted as q_{11}, from producer 1 to market 3 is denoted as q_{31}, from producer 1 to market 4 is denoted as q_{41}, from producer 2 to market 2 is denoted as q_{22}, from producer 2 to market 4 is denoted as q_{42}, from producer 3 to market 3 is denoted as q_{33} and from producer 4 to market 4 is denoted as q_{44}.

Figure 3: A simplified example



We write the vector of quantities supplied in this graph as:

$$Q_g = \begin{bmatrix} q_{11} & q_{31} & q_{41} & q_{22} & q_{42} & q_{33} & q_{44} \end{bmatrix}$$

We assume that markets have linear inverse demand functions. Given a market d_i and a flow vector Q_g the price, p_i, at d_i is

$$p_i(Q_g) = \alpha_i - \beta_i h_i, \tag{2}$$

where α_i and β_i are positive constants and h_i is natural gas consumption in market d_i. More specifically h_i is

[32] They are labeled as 1, 2, 3 and 4.
[33] They are labeled as 1, 2, 3 and 4.
[34] The network graph is shown in Figure 1.3.

$$h_i = \sum_{f_j \in N_g(d_i)} q_{ij}. \tag{3}$$

For example, the total consumption in market 4 in the simple network is $h_4 = q_{41} + q_{42} + q_{44}$, leading to linear inverse demand $p_4 = \alpha_4 - \beta_4(q_{41} + q_{42} + q_{44})$.

We assume that the natural gas producer has zero costs of production in the short run up to its production capacity, $\bar{S}_j$.[35] We also assume that the cost of exporting natural gas is linear. In the case of LNG, the export cost depends on the exporting country's liquefaction cost, the importing country's regasification cost and the distance traveled. In the case of pipeline transport, it depends on tariffs paid to transit countries and the length of the pipeline. For firm f_j the short-run total cost of supply therefore is

$$T_j(Q_g) = \sum_{d_i \in N_g(f_j) \backslash d_j} \tau_{ij} q_{ij} \tag{4}$$

where τ_{ij} is the marginal cost of exporting natural gas to market i.[36] If the natural gas is carried via LNG, τ_{ij} includes[37] the port-to-port cost of shipment, and the costs of liquefaction and regasification. If the natural gas is carried via pipeline, τ_{ij} includes tariffs paid to transit countries, the cost of fuel lost during transportation, and the cost of operations and maintenance of the pipeline.

Firm j's total supply is denoted as s_j:

$$s_j = \sum_{d_i \in N_g(f_j)} q_{ij} \tag{5}$$

where $s_j \leq \bar{S}_j$. Given a graph Q_g and a supply capacity of $\bar{S}_j$, firm j maximizes profit by choosing q_{ij}:[38]

$$\max_{q_{ij}} \pi_j = \max_{q_{ij}} \left\{ \sum_{d_i \in N_g(f_j)} \alpha_i q_{ij} - \sum_{d_i \in N_g(f_j)} \beta_i q_{ij}^2 - \sum_{d_i \in N_g(f_j)} \beta_i q_{ij} \sum_{f_k \in N_g(d_i) \backslash f_j} q_{ik} - \sum_{d_i \in N_g(f_j) \backslash d_j} \tau_{ij} q_{ij} \right\} \tag{6}$$

[35]We assume that the supply capacity is fixed in the short-term because no new wells are drilled. Our main focus in this study is to capture short-run strategic interactions among the producers. In another paper of ours, titled "Strategic capacity investments in an imperfectly competitive world natural gas market", we change the model to a two-stage game. In the first stage, a producer chooses the level of investment for its supply. In the second stage, it decides how much to supply to each market to which it is connected.

[36]We assume that cost of exporting natural gas is proportional to the export volume.

[37]These costs are per unit of natural gas, that is one Bcm in this paper.

[38]For the graph Q_g in the simple example, producer 1 maximizes

$$\max_{q_{11}, q_{31}, q_{41}} (\alpha_1 - \beta_1 q_{11}) q_{11} + (\alpha_3 - \beta_3(q_{31} + q_{33})) q_{31} + (\alpha_4 - \beta_4(q_{41} + q_{42} + q_{44})) q_{41} - \tau_{31} q_{31} - \tau_{41} q_{41}$$

subject to

$$\sum_{d_i \in N_g(f_j)} q_{ij} \leq \bar{S}_j \tag{7a}$$

$$q_{ij} \geq 0 \quad \text{for all} \;\; (i,j) \in g \tag{7b}$$

We write the Kuhn-Tucker Lagrangian of firm j's maximization problem as

$$\begin{aligned}\mathcal{L} = & \sum_{d_i \in N_g(f_j)} \alpha_i q_{ij} - \sum_{d_i \in N_g(f_j)} \beta_i q_{ij} h_i - \sum_{d_i \in N_g(f_j) \setminus d_j} \tau_{ij} q_{ij} + \lambda_j \left(\bar{S}_j - \sum_{d_i \in N_g(f_j)} q_{ij} \right) \\ & + \sum_{d_i \in N_g(f_j)} \mu_{ij} q_{ij}. \end{aligned} \tag{8}$$

Then there exists $\lambda_j^\star$ and $\mu_{ij}^\star$ such that $q_{ij}^\star$, $\lambda_j^\star$ and $\mu_{ij}^\star$ satisfy the following Kuhn-Tucker optimality conditions:

$$\frac{\partial \mathcal{L}}{\partial q_{ij}} = \alpha_i - \tau_{ij} - \beta_i \left(\sum_{f_k \in N_g(d_i) \setminus f_j} q_{ik} + 2 q_{ij}^\star \right) - \lambda_j + \mu_j + \iota_{ij} = 0 \tag{9a}$$

$$\frac{\partial \mathcal{L}}{\partial \lambda_j} = \bar{S}_j - \sum_{d_i \in N_g(f_j)} q_{ij} \geq 0 \tag{9b}$$

$$\frac{\partial \mathcal{L}}{\partial \mu_{ij}} = q_{ij} \geq 0 \tag{9c}$$

$$\lambda_j \frac{\partial \mathcal{L}}{\partial \lambda_j} = \lambda_j \left(\bar{S}_j - \sum_{d_i \in N_g(f_j)} q_{ij} \right) = 0 \tag{9d}$$

$$\mu_{ij} \frac{\partial \mathcal{L}}{\partial \mu_{ij}} = \mu_{ij} q_{ij} = 0. \tag{9e}$$

We get the[39] Cournot-Nash equilibrium flow of $q_{ij}^\star$:

$$q_{ij}^\star = \begin{cases} \dfrac{\alpha_i - \tau_{ij} - \lambda_j - \beta_i \left(\sum_{f_k \in N_g(d_i) \setminus f_j} q_{ik} \right)}{2\beta_i} & \text{if } \frac{\partial \pi_j}{\partial q_{ij}}\Big|_{Q_g} \geq 0 \\ 0 & \text{if } \frac{\partial \pi_j}{\partial q_{ij}}\Big|_{Q_g} < 0 \end{cases} \tag{10}$$

[39]Ilkilic (2010) shows that the unconstrained Cournot game in a bipartite graph has a unique Nash equilibrium.

The stylized representation of the current world natural gas market described above is a non-cooperative game with coupled payoff functions and coupled constraints.[40] Although the Lagrangian multiplier theory is widely used to solve nonlinear mathematical programming problems with constraints,[41] it is not computationally convenient to apply it to our model. In particular, we have a large number of first-order conditions with inequality constraints (one for each producer) that need to be solved simultaneously. Instead, we use the potential game method. This involves re-casting our model as a single constrained optimization problem as if it were being solved by a centralized approach where there is a single agent who searches for the optimal solution given the constraints.[42]

Definition 1: Consider the Cournot game that we describe above with linear inverse demand function[43] and linear cost function. Define a function

$$P^{\star}(Q_g) = \sum_{d_i \in N_g(f_j)} \alpha_i \left(\sum_{f_j \in N_g(d_i)} q_{ij} \right) - \sum_{d_i \in N_g(f_j)} \beta_i \left(\sum_{f_j \in N_g(d_i)} q_{ij}^2 \right) - \sum_{d_i \in N_g(f_j)} \beta_i \left(\sum_{1 \le j < k \le n} q_{ij} q_{ik} \right) - \sum_{f_j \in N_g(d_i)} \sum_{d_i \in N_g(f_j) \backslash d_j} \tau_{ij} q_{ij} \tag{11}$$

subject to

$$\bar{S}_j \geq \sum_{d_i \in N_g(f_j)} q_{ij} \quad \text{for all} \;\; j \in F \tag{12}$$

and

$$q_{ij} \geq 0 \quad \text{for all} \;\; (i,j) \in g. \tag{13}$$

It can be verified that for every link from firm j to market i, that is q_{ij}, and for every link that is not from firm j to market i, that is q_{-ij}, $P^{\star}(Q_g)$[44] satisfies

$$\pi_j(q_{ij}, q_{-ij}) - \pi_j(x_{ij}, q_{-ij}) = P^{\star}(q_{ij}, q_{-ij}) - P^{\star}(x_{ij}, q_{-ij}) \tag{14}$$

A function $P^{\star}$ satisfying (14) is called a potential function which requires

[40] The coupling arises because producers have limited capacity of production to allocate to markets to which they are connected.

[41] Among others see Bertsekas (1998), Boyd and Vandeberghe (2004) and Bazaraa, Sherali and Shetty (1993).

[42] We note that this is a mathematical device only. We do not assume that there is a single world authority planning all natural gas trades. In particular, the optimization embeds the efficiency costs of oligopoly. Presumably, if there were a single centralized planner, that agent would choose an efficient outcome.

[43] Monderer and Shapley (1994) define a potential function for a Cournot game with linear inverse demand function. We adapt their functional form to our network Cournot game.

[44] Here Q_g is the vector of quantities in graph g.

$$\frac{\partial \pi_j}{\partial q_{ij}} = \frac{\partial P^\star}{\partial q_{ij}} \quad \text{for all} \ \ (i,j) \in g \tag{15}$$

Theorem 1: The solution to the potential game[45] defined in (11) subject to constraints defined in (12) and (13) is unique:

$$\max_{q_{ij}} P^\star(Q_g) \quad \text{for all} \ \ (i,j) \in g \tag{16}$$

subject to (12) and (13).
Proof: See Section (A.1).
Theorem 2: The Nash equilibrium of the potential game with constraints defined in (16) and the Nash equilibrium of the noncooperative Cournot game with constraints defined in (6) are the same.
Proof of Theorem 2: Let Q'_g be the optimal solution to (16). Since Q'_g minimizes $\mathcal{L}_{P^\star}$, Q'_g minimizes $\mathcal{L}_j$ for each player j. Therefore, Q'_g is a Nash equilibrium to the constrained noncooperative game.[46]

5 Calibration

In order to quantitatively evaluate different policy scenarios, we first need to calibrate the theoretical model. To calibrate the model parameters, we use the production, consumption, price and trade flow data in 2009. The price data is obtained from International Energy Agency's (IEA) website and other country websites. The data on production, consumption, and trade flows are obtained from BP's Statistical Review of World Energy 2010.
For calibration, we use the first order conditions of our model.
Example: South America's producer, labeled as 4, aims to [47]

$$\max_{q_{14},q_{24},q_{44}} \Pi_4(Q_g) = \max_{q_{14},q_{24},q_{44}} \{p_1 q_{14} + p_2 q_{24} + p_4 q_{44} - \tau_{14} q_{14} - \tau_{24} q_{24}\} \tag{17}$$

subject to

$$q_{14} + q_{24} + q_{44} \leq \bar{S}_4 \quad \text{and} \quad q_{14}, q_{24}, q_{44} \geq 0. \tag{18}$$

By considering the links that carry positive flows[48] in equilibrium, we get the first order conditions as:

[45] We know that the optimization problem defined in (11) is a potential game because it satisfies (14).
[46] Monderer and Shapley (1996) say that if a game that possesses an ordinal potential (the network game introduced in this paper is an exact potential game, which is a subset of ordinal potential game) is called an ordinal potential game. Clearly, the pure strategy equilibrium set of the Cournot game coincides with the pure-strategy equilibrium set of the game in which every firm's profit is given by ordinal potential.
[47] As an identifying assumption, we set that the cost of transporting natural gas to the domestic market as zero.
[48] According to Ilkilic (2010) links that carry zero flows in equilibrium have no role in determining the equilibrium.

q_{14}:

$$\alpha_1 - 2\beta_1 q_{14} - \beta_1(q_{11} + q_{15} + q_{16} + q_{17} + q_{18}) - \tau_{14} - \lambda_4 - \mu_{14} = 0 \quad (19)$$

q_{24}:

$$\alpha_2 - 2\beta_2 q_{24} - \beta_2(q_{22} + q_{25} + q_{26}) - \tau_{24} - \lambda_4 - \mu_{24} = 0 \quad (20)$$

q_{44}:

$$\alpha_4 - 2\beta_4 q_{44} - \lambda_4 - \mu_{44} = 0. \quad (21)$$

We assume an interior solution for the capacity constraint,[49] $q^\star_{14} + q^\star_{24} + q^\star_{44} < \bar{S}_4$, this requires $\lambda_4 = 0$.

We apply the same equilibrium condition to each producer from 1 to 9, and get twenty one equations.[50] The equilibrium price[51] in each market is denoted as $\hat{p}_i$.[52]

Insert Table (1) here.

We have 30 unknowns[53] and 30 equations to solve for these parameters. We substitute natural gas production, consumption, trade flow and price data in 2009 into these equations and calculate the parameters.

Insert Table (2) here.

Our network parameters are consistent with the world natural gas market experience in 2009. For instance, although the distance between Russia and the Asia Pacific is the shortest, the marginal cost of exporting natural gas from Russia and the Asia Pacific is the highest. This is due to Russia's limited natural gas production and liquefaction capacities on Sakhalin Island. On the other hand, the marginal cost of exporting natural gas from Russia to Europe is the lowest. This result is consistent with the Rice World Gas Trade Model's[54] (RWGTM) pipeline cost estimate of the Yamal pipeline.[55]

As depicted in Figure 4, North America has the most elastic demand curve among the importers. This could be because North America has more alternatives to natural gas than Europe and Asia Pacific.

[49] We make this assumption only when calibrating the parameters. This assumption is realistic especially in 2009, where due to the global recession, producers had excess supply capacities. When analyzing alternative scenarios we do not impose this assumption.

[50] For the rest of the equations see Appendix (A.2).

[51] We use linear inverse demand, which is defined in (2).

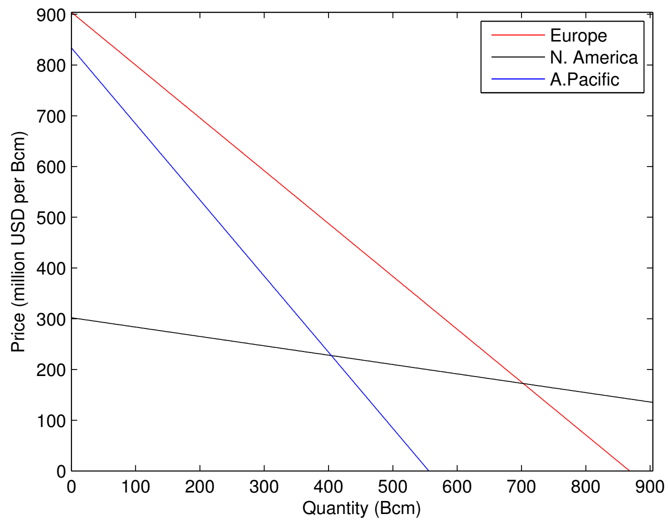
[52] Natural gas import prices are usually different for each importer and this price differs from the domestic producer's price. However, our model assumes that there is a single price of natural gas in each region, which is determined by the total supply of producers connected to that region.

[53] These unknowns are α_i, β_i where $i = 1, ..., 9$ and τ_{ij} where there are twelve (i, j) pairs in the world natural gas network graph.

[54] The Rice World Gas Trade Model is a tool for examining the effects of economic and political influences on the global natural gas market within a framework grounded in geologic data and economic theory.

[55] According to the RWGTM, the marginal cost of carrying natural gas (tariffs plus the fuel cost plus the operating and maintenance of the pipeline) from Yamal to Germany (through Belarus and Poland) is 74.9 million USD per Bcm.

Figure 4: Demand Curve of Europe, North America and the Asia Pacific, based on our calibration.



6 Scenario analysis

In this section we analyze various scenarios[56] in the world natural gas market by changing the model's parameters and/or capacity constraints exogenously. With each of these changes we optimize a new potential function subject to a new set of constraints. We use the sequential quadratic programming algorithm to solve for the constrained optimum.[57]

6.1 Scenario I: Increased competition between Russia and the Middle East

According to BP's Statistical Review of World Energy 1997, about 84 percent of European natural gas imports came from Russia. Even though there has been a significant decline[58] in LNG transport costs since then, by 2009 Russia was still the biggest external supplier of European natural gas, with a share of 78 percent.[59] However, Russia's dominance in the European market is threatened by developments in Qatar,[60] and the concomitant

[56]Equilibrium trade flows under each scenario are provided in Table (3).

[57]More specifically, we use fmincon from MATLAB's optimization toolbox, which finds the minimum of a constrained nonlinear multivariable function. To obtain the maximum, we minimize (-1) times the potential function.

[58]For more details see The Global Liquefied Natural Gas Market: Status and Outlook, 2003.

[59]These claims are based on calculations using BP's Statistical Review of World Energy 2010's natural gas trade data.

[60]According to Dargin (2007), Qatar became the world's leading LNG exporter in 2006.

doubling in LNG import capability in Europe since 2000.[61] From 2000 to 2009, Middle East exports to Europe increased from 0.84 Bcm to 25.6 Bcm. Nevertheless, Russia's dominance of the European natural gas market persists.

To reduce Europe's dependence on Russian natural gas, an alternative pipeline route, Nabucco, was proposed a decade ago. The goal was to connect European consumers to natural gas resources in the Caspian Sea area. Unlike the Nabucco pipeline project as originally proposed, we assume that a Nabucco pipeline would connect the Middle East and Europe.[62]

We incorporate this scenario in our model by using the RWGTM's cost estimation[63] for Nabucco. The Nabucco route is assumed to go from Iraq to Istanbul, Istanbul to Bulgaria, then Bulgaria to Austria. We get the marginal cost of exporting to Europe by taking the weighted average of marginal costs of exporting natural gas to Europe via Nabucco and via LNG.[64]

We assume that 20 percent[65] of natural gas from the Middle East to Europe is carried via Nabucco and 80 percent is carried via LNG. With 20 percent via pipeline, the marginal cost of exporting one Bcm of natural gas from the Middle East to Europe decreases to 235.97 million USD. With this reduction, the Middle East increases its supply to Europe from 25.6 Bcm to 48.32 Bcm; decreases its supply to the Asia Pacific from 47.20 Bcm to 41.4 Bcm; and decreases its domestic market supply from 345.54 Bcm to 328.67 Bcm. The Middle East's share in Europe's natural gas imports increases from 3.09 percent to 5.83 percent. Europe's share in the Middle East's total production increases from 6.11 percent to 11.5 percent. When Nabucco is built, there will be more competition in the European market for all producers that are connected to it: Europe, South America, West Africa, North Africa, and Russia. They will decrease their supply to Europe to avoid further decline in the equilibrium natural gas price in Europe.

Contrary to the effects in Europe, the decline in supply from the Middle East will result in less competition in the Asia Pacific. As a result, West Africa, Russia, and Australasia will increase their supplies to the Asia Pacific. In the equilibrium, Russia's supply to the Asia Pacific increases from 6.2 Bcm to 7.9 Bcm; West Africa's supply to the Asia Pacific increases from 6.59 Bcm to 8.31 Bcm; and Australasia's supply to the Asia

[61] See Medlock, Jaffe and Hartley (2011).

[62] In our model, countries around the Caspian Sea are considered to be part of the Russia super-region. Since the original Nabucco pipeline was proposed, analysts have questioned whether reserves in the Caspian region are not large enough to cover the capital cost of building a pipeline to Europe. On the other hand, developments in Iraq in particular have raised the possibility that the Middle East could become a large supplier of natural gas to Europe via pipeline.

[63] We consider tariffs paid to transit countries plus the operating and maintenance costs. We ignore the capital cost as it is another decision problem which is beyond the motivation of this paper.

[64] The cost of exporting natural gas via LNG is calibrated in the previous section.

[65] We also look at different scenarios such as: 30 percent is carried via pipeline and 70 percent is carried via LNG, and 50 percent is carried via pipeline and 50 percent is carried via LNG. The sign of changes in these scenarios are the same as in the case where 20 percent is carried via pipeline and 80 percent is carried via LNG, but the magnitudes are different. For instance, Middle East's supply to Europe is bigger when 50 percent of its exports are carried via pipeline.

Pacific increases from 88.29 Bcm to 88.94 Bcm. The increase in supply from Russia and West Africa is greater than the increase from Australasia because the former two regions reap larger marginal profits than does Australasia from supplying the Asia Pacific region.

Under this scenario, equilibrium total supply to Europe goes from 580.3 Bcm to 584.9 Bcm, which decreases the equilibrium price in Europe from 300 million USD per Bcm to 296 million USD per Bcm. On the other hand, equilibrium total supply to the Asia Pacific declines from 394.39 Bcm to 392.96 Bcm, which increases the equilibrium price in the Asia Pacific from 320 million USD per Bcm to 322 million USD per Bcm. Neither the equilibrium price nor the equilibrium consumption changes in North America, since there is no change in the equilibrium supply to it.

Under this scenario, profits of the Asia Pacific, Middle East, and Australasia producers increase. Profits of North American producers stay the same and the profits of the remaining producers decrease. Both the Asia Pacific and Australasia have higher profits due to the increase in equilibrium price in the Asia Pacific. Europe, South America, West Africa, North Africa, and Russia have lower profits since their market shares, as well as the equilibrium price in Europe, decline.

In a variant of the Nabucco case we simply increase Middle East supply capacity by 10 percent while leaving transport costs to Europe unchanged. In the new equilibrium, the Middle East increases its supply to Europe without decreasing supply to the Asia Pacific or its domestic market.

6.2 Scenario II: Decreased competition between Russia and the Middle East

This scenario assumes that Russia and the Middle East collude to maximize their joint profits. Via such collusion they increase their market power in both markets they share and, hence, their joint profits increase.

Given the natural gas network we had in 2009, suppose Russia and the Middle East[66] merge to maximize their joint profit, which is:

$$\begin{aligned}\Pi_{78}(Q_g) =& \alpha_1(q_{17}+q_{18}) - \beta_1(q_{11}+q_{14}+q_{15}+q_{16}+q_{17}+q_{18})(q_{17}+q_{18}) + \alpha_3(q_{37}+q_{38}) \\ & - \beta_3(q_{33}+q_{35}+q_{37}+q_{38}+q_{39})(q_{37}+q_{38}) - \tau_{17}q_{17} - \tau_{18}q_{18} - \tau_{37}q_{37} - \tau_{38}q_{38}\end{aligned} \tag{22}$$

subject to

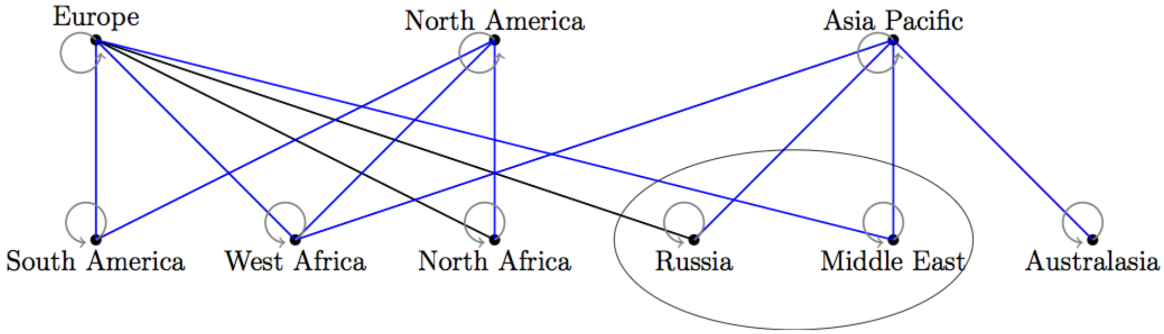
$$q_{17}+q_{37}+q_{77} \leq \bar{S}_7\ , \quad q_{18}+q_{38}+q_{88} \leq \bar{S}_8 \quad \text{and} \quad q_{17},\, q_{37},\, q_{77},\, q_{18},\, q_{38},\, q_{88} \geq 0. \tag{23}$$

The graph of this new network is:

We optimize the new potential function subject to supply constraints. After the merger, Russia and the Middle East reduce their combined output and their equilibrium supplies to each of the markets that they share, Europe and the Asia Pacific. The

[66]We label Russia and the Middle East after the merger as 78.

Figure 5: Schematic representation after Russia and the Middle East merger



new equilibrium outcome is that the links from Russia to the Asia Pacific and from the Middle East to Europe carry zero flows, meaning that Russia specializes in the European market and the Middle East specializes in the Asia Pacific. This occurs because Russia has a lower marginal cost of exporting natural gas to Europe, while the Middle East has a lower marginal cost of exporting natural gas to the Asia Pacific.

The equilibrium supply of Russia and the Middle East to Europe decreases to 187.75 Bcm. The pre-merger supply from Russia to Europe was 181.1 Bcm and from the Middle East to Europe was 25.6 Bcm. Similarly, the equilibrium supply of Russia and the Middle East to the Asia Pacific is 49.84 Bcm after the merger. The pre-merger supply from Russia to the Asia Pacific was 6.2 Bcm and from the Middle East to the Asia Pacific was 47.19 Bcm. As a result of the collusion, prices rise in both Europe and the Asia Pacific. In the new equilibrium, total supply to Europe decreases from 580.3 Bcm to 573.54 Bcm, which increases the equilibrium price from 300 million USD per Bcm to 307.03 million USD per Bcm. In the new equilibrium, total supply to the Asia Pacific decreases from 394.39 Bcm to 391.74 Bcm, which increases the equilibrium price in the Asia Pacific from 320 million USD per Bcm to 323.2 million USD per Bcm.

As these equilibrium outcomes indicate, the attempt to exploit consumers in Europe and the Asia Pacific via collusion is thwarted to some extent by other suppliers. South America, West Africa, and North Africa all increase their supply to Europe by decreasing their supply to North America and to their domestic markets. For instance, West Africa decreases its equilibrium supply to North America from 3.1 Bcm to zero and decreases its equilibrium supply to the Asia Pacific from 6.6 Bcm to 6.51 Bcm. Similarly, North Africa decreases its supply to North America from 5 Bcm to 1.46 Bcm in order to increase its supply to Europe. After the collusive merger, the marginal profit of supplying to North America declines for all producers that are connected to it.

The equilibrium prices after the merger increase in each market except Russia and the Middle East[67] due to a decline in equilibrium supply. For instance, the equilibrium supply to North America declines from 828.7 Bcm to 818.86 Bcm, and the equilibrium price increases from 150 million USD per Bcm to 151.816 million USD per Bcm.

[67]In the latter two markets they remain at the pre-merger level.

The joint profit of Russia and the Middle East after the merger increases by 2.18 billion USD. Although this provides an incentive for Russia and the Middle East to merge, it is a weak one. Furthermore, the stability of such a collusion is hard to maintain since both parties would retain an incentive to "cheat" by reneging on a commitment to refrain from selling to their partner's exclusive market area.

As a further modification to the Russia and Middle East collusion, we increase North America's supply capacity by 5 percent and increase the marginal cost of exporting natural gas to it by 2 percent.[68] These changes make, the merger of Russia and the Middle East even less profitable (compared to no shale with collusion scenario). Due to the decline in import demand of North America, all exporters that are connected to it move their resources to other markets, that is, Europe, the Asia Pacific, and their domestic markets. Hence, Russia and Middle East's market power is reduced.

6.3 Scenario III: An increase in Asia Pacific's natural gas demand

According to the IEA's 2010 World Energy Outlook, China's demand for natural gas has recently grown faster than demand in any other region. In fact, it is projected to grow at an average of almost 6 percent per year 2008-2035. The IEA report projects that from 2008 to 2015, Asia's demand will grow from 341 Bcm to 497 Bcm a year.

In addition to demand growth from China and India, Japan's demand for natural gas has increased after the Fukushima nuclear disaster. According to the IEA's 2011 World Energy Outlook, the Fukushima disaster could lead to a 15 percent fall in world nuclear power generation by 2035, when power demand may be 3.1 percent higher. This will raise gas-fired power generation along with other types of generation. The incremental demand for LNG in Japan's power sector in 2011 was expected to be 11 Bcm, according to the IEA report.

The demand increase expected in the 2011 report is incorporated in our model by increasing the choke price in the Asia Pacific by 5 percent. With a 5 percent increase in the choke price, natural gas demand in the Asia Pacific increases by 32.02 Bcm, which corresponds to an 8.12 percent increase in demand at the 2009 price in the Asia Pacific. All of the producers that are connected to the Asia Pacific respond to the demand increase by shifting supply from other markets to the Asia Pacific.

West Africa increases its supply to the Asia Pacific from 6.59 Bcm to 12.25 Bcm, decreases its supply to Europe from 10.7 Bcm to 8.34 Bcm and stops supplying North America in equilibrium. This is because the marginal profit of supplying to the Asia Pacific is greater than the marginal profit of supplying to Europe, North America, and to West Africa's domestic market.

Similarly, an upward shift in Asia Pacific's demand curve increases Russia's supply to the Asia Pacific from 6.2 Bcm to 13.65 Bcm and decreases Russia's supply to its domestic market from 485.43 Bcm to 478.13 Bcm. Russia thus meets most of its additional supply

[68] These changes are a simple way of representing the depressing effects on North American imports of increased shale gas production.

to the Asia Pacific from supplies to its domestic market. The share of Russia's supply to the Asia Pacific over its total production increases from 0.9 percent to 2 percent, whereas the share of its domestic market decreases from 72.2 percent to 71.1 percent.

With a 5 percent increase in Asia Pacific's choke price, the Middle East's supply to the Asia Pacific increases from 47.19 Bcm to 53.78 Bcm. This is achieved via a 5.34 Bcm cut in supply to its domestic market and a 1.19 Bcm reduction in its supply to Europe. The Asia Pacific's total consumption of natural gas from the Middle East increases by 0.9 percent.

As a result of an increase in Asia Pacific's demand, West Africa, Russia, and the Middle East decrease their supply to Europe, which makes the European market more attractive for South America and North Africa. In response, they decrease their supply to North America and their domestic markets.

The total consumption in each region except the Asia Pacific declines. The equilibrium price in these regions increases due to decline in equilibrium supply. Although the equilibrium supply to the Asia Pacific increases, the equilibrium price also increases due to the shift in demand for natural gas. Profits of each producer increase due to the increase in natural gas prices.

6.4 Scenario IV: Increase in importers' natural gas demand

We assume that the choke price in Europe, North America and the Asia Pacific increases by 2 percent. With this change, natural gas demand at 2009 prices increases by 3.02 percent in Europe, by 4.24 percent in North America, and by 3.3 percent in the Asia Pacific. We analyze world natural gas demand increase in two cases: with shale gas and without shale gas.

6.4.1 Without shale gas:

Following the increase in the choke price in importing countries, the marginal profit of exporting increases for each producer. Thus, they reduce their equilibrium supply to their domestic markets and increase their supply to abroad.

In the 2009 world natural gas trade network, West Africa is the only producer connected to all three importing markets. Under this scenario, West Africa increases its supply to Europe and the Asia Pacific and decreases its supply to North America, even though the demand in all three markets increases.

On the other hand, the rest of the producers increase their exports by decreasing their supply to their domestic markets. For instance, South America increases its equilibrium supply to Europe from 7.6 Bcm to 8.82 Bcm, increases its equilibrium supply to North America from 7.6 Bcm to 9.21 Bcm, and decreases its equilibrium supply to its domestic market from 134.7 Bcm to 131.86 Bcm.

Similarly, North Africa increases its equilibrium supply to Europe from 67.2 Bcm to 68.28 Bcm, and increases its equilibrium supply to North America from 4.99 Bcm to 5.85 Bcm.

Under this scenario, total supplies to Europe, North America, and the Asia Pacific increase. Due to the increase in demand, the equilibrium price in Europe, North America, and the Asia Pacific increases.[69]

The profit of each producer increases as the equilibrium prices in their domestic markets and abroad increase.

6.4.2 With shale gas:

We assume that, simultaneous with the demand increase, North America's supply capacity increases by 5 percent and the marginal cost of exporting natural gas to North America increases by 2 percent. These exogenous changes mimic the decrease in the import demand of North America resulting from the exploitation of shale gas.

Due to the decrease in North American import demand the producers connected to North America move their exports to Europe and the Asia Pacific. The market share of Russia, the Middle East, and Australasia decrease in Europe and the Asia Pacific compared to the no shale gas scenario. For instance, if there is no shale gas, Russia supplies 185.58 Bcm to Europe but with shale gas, it supplies 184.05 Bcm. Similarly, the Middle East's supply to Europe declines from 28.92 Bcm to 27.67 Bcm. The impact of shale gas development in North America is greater in Europe than in the Asia Pacific since Europe and North America share more producers than the Asia Pacific and North America.

Equilibrium prices in Europe, North America, and the Asia Pacific are lower than the ones under the no shale gas production scenario. However, they are higher than the prices in 2009 due to the concomitant increase in natural gas demand. With shale gas development, North America's total consumption increases from 830.3 Bcm to 840.92 Bcm and imports decrease from 17.3 Bcm to 7.3 Bcm. North America's profit increases after the shale gas development while the rest of the producers make losses compared to a demand increase with no shale gas scenario.

6.5 Scenario V: Russia to China pipeline

In this scenario we assume that Western Siberia and China are connected through a pipeline. To incorporate this scenario into our model we use the Rice World Gas Trade Model's cost estimations for pipeline routes from Surgut to Urengoy, from West Siberia to China, from West China to Xian, and from Xian to Shanghai. We assume that 30 percent of natural gas from Russia to Asia Pacific is carried via pipeline and 70 percent is carried via LNG. We get the marginal costs of exporting natural gas to the Asia Pacific by taking the weighted average of marginal costs of exporting natural gas to the Asia Pacific via pipeline and via LNG.

[69] The equilibrium price in Europe increases from 300 million USD per Bcm to 306.73 million USD per Bcm, in North America it increases from 150 million USD per Bcm to 155.76 million USD per Bcm and in the Asia Pacific it increases from 320 million USD per Bcm to 326.38 million USD per Bcm.

If 30 percent of natural gas is carried via pipeline, then the marginal cost of exporting one Bcm of natural gas from Russia to the Asia Pacific decreases to 237.22 USD. With this reduction, Russia increases its supply to the Asia Pacific from 6.19 Bcm to 47.83 Bcm, decreases its supply to Europe from 181.1 Bcm to 173.86 Bcm, and decreases its domestic market supply from 485.43 Bcm to 451.09 Bcm. Russia's share in the Asia Pacific's imports increases from 3.7 percent to 32.25 percent. This increases the competition in the Asia Pacific for the Asia Pacific, West Africa, the Middle East, and Australasia. For that reason, they decrease their supply to the Asia Pacific. For instance, in the new equilibrium Australasia's supply to the Asia Pacific decreases from 88.29 Bcm to 79.54 Bcm and West Africa does not supply the Asia Pacific.

Under this scenario, the Middle East's equilibrium supply to the Asia Pacific decreases from 47.19 Bcm to 38.44 Bcm and its supply to Europe increases from 25.6 Bcm to 27.2 Bcm.

The decrease in natural gas supply from Russia to Europe decreases the competition in the European market. As a result, the marginal profit of supplying to Europe increases for South America, West Africa, North Africa, and the Middle East. For instance, South America's supply to Europe increases from 7.6 Bcm to 8.82 Bcm, West Africa's supply to Europe increases from 10.7 Bcm to 12.3 Bcm, and North Africa's supply to Europe increases from 67.2 Bcm to 68.42 Bcm. South America and North Africa decrease their supply to North America and to their domestic markets in order to supply more to Europe.

Under this scenario, equilibrium total supply to Europe decreases from 580.3 Bcm to 578.7 Bcm, which increases the equilibrium price in Europe from 300 million USD per Bcm to 301.66 million USD per Bcm. However, the equilibrium total supply to the Asia Pacific increases from 394.4 Bcm to 403.15 Bcm, and this decreases the equilibrium price in the Asia Pacific from 320 million USD per Bcm to 308.61 million USD per Bcm. The equilibrium price in North America increases by 0.19 million USD per Bcm as the total supply to North America decreases by 1.06 Bcm. Russia's natural gas prices in its domestic market increase due to the increased exports. They produce a decline in domestic market consumption.

Russia's profits increase from 65.76 billion USD to 67.89 billion USD, North America's profits increase from 121.95 billion USD to 122.11 billion USD, and the rest of the producers' profits decrease. The Asia Pacific has the biggest profit loss among remaining producers[70] because both its market share in the Asia Pacific and the equilibrium natural gas price in its domestic market decline.

6.6 Scenario VI: Russia to China pipeline and Nabucco

In this section, we consider the case where Russia has a pipeline connection to the Asia Pacific and the Middle East has a pipeline connection to Europe. We compare these results with the results in 6.1.[71]

[70] Its profits decrease by 7.5 billion USD.

[71] That is the scenario where we considered increased competition between Russia and Middle East in the European market via a pipeline connection from the Middle East to Europe.

Under this scenario, Russia increases supply to the Asia Pacific to 49.35 Bcm, which is 1.51 Bcm higher than the scenario where there is only a Russia-China pipeline[72] and 41.43 Bcm higher than the case where there is only Nabucco. Russia's equilibrium supply to Europe is 169.93 Bcm; however, its equilibrium supply to Europe is 177.31 Bcm under the scenario where there is only Nabucco. The Middle East increases its supply to Europe to 51.54 Bcm, which is 3.22 Bcm higher than the scenario where there is only Nabucco and 24.35 Bcm higher than the scenario where there is only a Russian pipeline.

Under this scenario, Europe's, South America's, and North Africa's supplies to Europe are higher than the scenario where there is only Nabucco. in equilibrium, West Africa does not supply to the Asia Pacific.

Under this scenario, Russia's profits are higher than its profits in 2009 and its profits when there is Nabucco only. It is in Russia's best interest to have a Russia-China pipeline when there is Nabucco.

7 Conclusions

This paper presented a network model of the world natural gas market that consists of consumers, producers (which are represented as strategic Cournot players), and links connecting them. We calibrated the model parameters using natural gas consumption, production, trade, and price data in 2009. The model allowed us to quantify the strategic interactions among natural gas producers.

We find that if a natural gas producer has access[73] to a market then its market power at that market depends on its production capacity and its costs of exporting natural gas. For instance, Russia's market power in the Asia Pacific is low because of its high costs of exporting natural gas from Sakhalin island to Japan.

We also find that any exogenous change affecting one market impacts all other markets. The size of the impact on any one market also declines as the number of links connecting markets increases.

Although the establishment of a single (or a reference) price for natural gas is difficult to achieve due to the high cost of transport and long-term contracts over 20-25 years with prices indexed to oil, our model confirms that with the developments in LNG technology and growing diversity in supply sources and new demand sinks, natural gas has been evolving into a global commodity with some convergence in regional prices.

[72] The decrease in the Middle East's cost of exporting natural gas to Europe will increase Middle East's exports to Europe making the European market more competitive for Russia.

[73] If it does not have access then its market power is zero.

A Appendix

A.1 Proof of Theorem 1

The proof follows Zhu (2008) which introduces the game as minimization problem. *Corollary 2.8* in Zhu (2008) says that every strictly convex potential game admits a unique equilibrium. We therefore show that $(-1)\times$ our potential function, $(-1)\times P^{\star}(Q_g) = f(Q_g)$ is strictly convex in each q_{ij} for all $(i,j) \in N_g$.

Now $f : \mathcal{R}^{r(g)} \to \mathcal{R}$ where $r(g)$ is the size of Q_g, which is the number of links in the network graph of Q_g. It is well-known that f is strictly convex if and only if its Hessian is positive definite.

Notation for defining the Hessian of f: We use Ilkilic's (2010) notation for labeling links in a bipartite graph. We define firm j's supply to the domestic market as q_{jj}.

Let $\rho : L \leftarrow \mathbb{N}_+$ be a lexicographic order on L respecting ι[74] such that ρ relabels the (i,j) pairs from 1 to $r(g)$ by skipping those links which are not in g. The function ρ satisfies the following conditions:

1. $\exists (i,j) \in L$ such that $\rho(i,j) = 1$,
2. $(i,j) \neq (k,l) \implies \rho(i,j) \neq \rho(k,l)$,
3. $j \leq l \implies \rho(i,j) \leq \rho(k,l)$ for all (i,j), $(k,l) \in L$,
4. $i \leq k \implies \rho(i,j) \leq \rho(k,j)$ for all (i,j), $(k,l) \in L$,
5. If $\exists (i,j)$ s.t. $\rho(i,j) = z \geq 1$ then $\exists (k,l) \in L$ s.t. $\rho(k,l) = z - 1$.

Given a network g and for $t = \xi(i,j)$, the Hessian matrix of the potential function, $H = [g_{tz}]_{r(g)\times r(g)}$ is

$$g_{tz} = \begin{cases} 2\beta_i, & \text{if } t = z = \xi(i,j) \text{ for some } m_i \in M\,,\, f_j \in F \\ \beta_i, & \text{if } t \neq z\,,\, t = \xi(i,j)\,,\, z = \xi(i,k) \text{ for some } m_i \in M\,,\, f_j\,,f_k \in F \\ 0, & \text{otherwise.} \end{cases}$$

Next, we show that for any matrix H we can find a matrix R with independent columns such that $H = R^T R$, which is equivalent to checking that H is positive definite.

Create a diagonal matrix, $\dot{H}$, of size $r(g) \times r(g)$ with diagonal elements equal to square root of $\frac{1}{2}\times$ the corresponding diagonal element of H for those rows that have non-zero non-diagonal elements and diagonal elements equal to $2\times$ the corresponding diagonal element of H for those rows that have only zero non-diagonal elements.

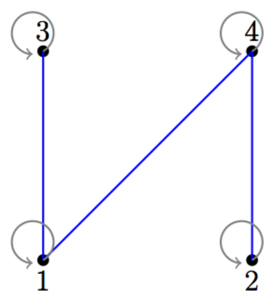
[74] We will order all possible links such that the links of a firm f_j are assigned a lower number than any firm f_i for $i > j$, and the links of a firm are ordered according to the indices of the markets they are connected. The label of a possible link (i,j) will be denoted by $\iota(i,j)$.

Then, create a matrix, $\tilde{H}$, of size equal to (number of non-zero non-diagonal elements in the upper triangular of H divided by 2)$\times r(g)$[75]. Row l of $\tilde{H}$ is filled by:

$$g_{lk} = \begin{cases} \sqrt{\beta_i}, & \text{for all columns } k = 1, 2, ..., r(g) \text{ where} \rho^{-1}(k) = q_{ij} \text{ if they share market } m_i \\ 0, & \text{otherwise.} \end{cases}$$

Apply this to all rows l in $\tilde{H}$. The final step involves combining the matrices $\dot{H}$ and $\tilde{H}$ by their rows to obtain a matrix R with a size of (number of non-zero non-diagonal elements in the upper triangular of H divided by 2)$+\ r(g) \times r(g)$. One can easily show that $H = R^T R$ which completes the proof. Finally, the constraints in this problem are linear, which satisfies the requirement in *Theorem 2.3* in Zhu (2008) that they have to be convex.

Example: Here is the Hessian, H and the matrix, R in the simple example network provided in the paper.



We write the vector of quantities supplied in this graph as:

$$Q_g = \left[\begin{array}{ccccccc} q_{11} & q_{31} & q_{41} & q_{22} & q_{42} & q_{33} & q_{44} \end{array} \right]$$

$$H = \begin{bmatrix} 2\beta_1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 2\beta_3 & 0 & 0 & 0 & \beta_3 & 0 \\ 0 & 0 & 2\beta_4 & 0 & \beta_4 & 0 & \beta_4 \\ 0 & 0 & 0 & 2\beta_2 & 0 & 0 & 0 \\ 0 & 0 & \beta_4 & 0 & 2\beta_4 & 0 & \beta_4 \\ 0 & \beta_3 & 0 & 0 & 0 & 2\beta_3 & 0 \\ 0 & 0 & \beta_4 & 0 & \beta_4 & 0 & 2\beta_4 \end{bmatrix}$$

and

[75] Ignore the rows of H that have zero non-diagonal elements.

$$\dot{H} = \begin{bmatrix} \sqrt{2\beta_1} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \sqrt{\beta_3} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \sqrt{\beta_4} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \sqrt{2\beta_2} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \sqrt{\beta_4} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & \sqrt{\beta_3} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & \sqrt{\beta_4} \end{bmatrix}$$

$$\tilde{H} = \begin{bmatrix} 0 & \sqrt{\beta_3} & 0 & 0 & 0 & \sqrt{\beta_3} & 0 \\ 0 & 0 & \sqrt{\beta_4} & 0 & \sqrt{\beta_4} & 0 & \sqrt{\beta_4} \end{bmatrix}$$

We combine the matrices $\dot{H}$ and $\tilde{H}$ by their rows to obtain:

$$R = \begin{bmatrix} \sqrt{2\beta_1} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & \sqrt{\beta_3} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & \sqrt{\beta_4} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \sqrt{2\beta_2} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \sqrt{\beta_4} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & \sqrt{\beta_3} & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & \sqrt{\beta_4} \\ 0 & \sqrt{\beta_3} & 0 & 0 & 0 & \sqrt{\beta_3} & 0 \\ 0 & 0 & \sqrt{\beta_4} & 0 & \sqrt{\beta_4} & 0 & \sqrt{\beta_4} \end{bmatrix}$$

A.2 First order conditions for calibration

The first order conditions that are used in calibration:
Europe:

$$\alpha_1 - 2\beta_1 q_{11} - \beta_1(q_{14} + q_{15} + q_{16} + q_{17} + q_{18}) - \lambda_1 - \mu_{11} = 0$$

North America:

$$\alpha_2 - 2\beta_2 q_{22} - \beta_2(q_{24} + q_{25} + q_{26}) - \lambda_2 - \mu_{22} = 0$$

Asia Pacific:

$$\alpha_3 - 2\beta_3 q_{33} - \beta_3(q_{35} + q_{37} + q_{38} + q_{39}) - \lambda_3 - \mu_{33} = 0$$

West Africa:

$$\alpha_1 - 2\beta_1 q_{15} - \beta_1(q_{11} + q_{14} + q_{16} + q_{17} + q_{18}) - \tau_{15} - \lambda_5 - \mu_{15} = 0$$

$$\alpha_2 - 2\beta_2 q_{25} - \beta_2(q_{22} + q_{24} + q_{26}) - \tau_{25} - \lambda_5 - \mu_{25} = 0$$

$$\alpha_3 - 2\beta_3 q_{35} - \beta_3(q_{33} + q_{37} + q_{38} + q_{39}) - \tau_{35} - \lambda_5 - \mu_{35} = 0$$

$$\alpha_5 - 2\beta_5 q_{55} - \lambda_5 - \mu_{55} = 0$$

North Africa:

$$\alpha_1 - 2\beta_1 q_{16} - \beta_1(q_{11} + q_{14} + q_{15} + q_{17} + q_{18}) - \tau_{16} - \lambda_6 - \mu_{16} = 0$$

$$\alpha_2 - 2\beta_2 q_{26} - \beta_2(q_{22} + q_{24} + q_{25}) - \tau_{26} - \lambda_6 - \mu_{26} = 0$$

$$\alpha_6 - 2\beta_6 q_{66} - \lambda_6 - \mu_{66} = 0$$

Russia:

$$\alpha_1 - 2\beta_1 q_{17} - \beta_1(q_{11} + q_{14} + q_{15} + q_{16} + q_{18}) - \tau_{17} - \lambda_7 - \mu_{17} = 0$$

$$\alpha_3 - 2\beta_3 q_{37} - \beta_3(q_{33} + q_{35} + q_{38} + q_{39}) - \tau_{37} - \lambda_7 - \mu_{37} = 0$$

$$\alpha_7 - 2\beta_7 q_{77} - \lambda_7 - \mu_{77} = 0$$

Middle East:

$$\alpha_1 - 2\beta_1 q_{18} - \beta_1(q_{11} + q_{14} + q_{15} + q_{16} + q_{18}) - \tau_{18} - \lambda_8 - \mu_{18} = 0$$

$$\alpha_3 - 2\beta_3 q_{38} - \beta_3(q_{33} + q_{35} + q_{37} + q_{39}) - \tau_{38} - \lambda_8 - \mu_{38} = 0$$

$$\alpha_8 - 2\beta_8 q_{88} - \lambda_8 - \mu_{88} = 0$$

Australasia:

$$\alpha_3 - 2\beta_3 q_{39} - \beta_3(q_{33} + q_{35} + q_{37} + q_{38}) - \tau_{39} - \lambda_9 - \mu_{39} = 0$$

$$\alpha_9 - 2\beta_9 q_{99} - \lambda_9 - \mu_{99} = 0$$

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Table 1: Price in each market

Price in Europe:	$\hat{p}_1 = \alpha_1 - \beta_1(q_{11} + q_{14} + q_{15} + q_{16} + q_{17} + q_{18})$
Price in North America:	$\hat{p}_2 = \alpha_2 - \beta_2(q_{22} + q_{24} + q_{25} + q_{26})$
Price in Asia Pacific:	$\hat{p}_3 = \alpha_3 - \beta_3(q_{33} + q_{35} + q_{37} + q_{38} + q_{39})$
Price in South America:	$\hat{p}_4 = \alpha_4 - \beta_4 q_{44}$
Price in West Africa:	$\hat{p}_5 = \alpha_5 - \beta_5 q_{55}$
Price in North Africa:	$\hat{p}_6 = \alpha_6 - \beta_6 q_{66}$
Price in Russia:	$\hat{p}_7 = \alpha_7 - \beta_7 q_{77}$
Price in Middle East:	$\hat{p}_8 = \alpha_8 - \beta_8 q_{88}$
Price in Australasia:	$\hat{p}_9 = \alpha_9 - \beta_9 q_{99}$

Table 2: Network parameters

	Parameter	Value
Choke price in Europe:	α_1	904.27
Choke price in North America:	α_2	302.9
Choke price in Asia Pacific:	α_3	832.83
Choke price in South America:	α_4	260.02
Choke price in West Africa:	α_5	220.01
Choke price in North Africa:	α_6	199.97
Choke price in Russia:	α_7	130.03
Choke price in Middle East:	α_8	200.01
Choke price in Australasia:	α_9	239.99
Slope of European inverse demand curve:	β_1	1.041
Slope of North America's inverse demand curve:	β_2	0.184
Slope of Asia Pacific's inverse demand curve:	β_3	1.3003
Slope of South America's inverse demand curve:	β_4	0.965
Slope of West Africa's inverse demand curve:	β_5	10.912
Slope of North Africa's inverse demand curve:	β_6	1.445
Slope of Russian inverse demand curve:	β_7	0.134
Slope of Middle East's inverse demand curve:	β_8	0.2894
Slope of Australasian inverse demand curve:	β_9	1.083
Marginal cost of exporting from South America to Europe:	τ_{14}	292.08
Marginal cost of exporting from South America to North America:	τ_{24}	148.59
Marginal cost of exporting from West Africa to Europe:	τ_{15}	288.85
Marginal cost of exporting from West Africa to North America:	τ_{25}	149.43
Marginal cost of exporting from West Africa to Asia Pacific:	τ_{35}	311.41
Marginal cost of exporting from North Africa to Europe:	τ_{16}	230.02
Marginal cost of exporting from North Africa to North America:	τ_{26}	149.07
Marginal cost of exporting from Russia to Europe:	τ_{17}	111.41
Marginal cost of exporting from Russia to Asia Pacific:	τ_{37}	311.93
Marginal cost of exporting from Middle East to Europe:	τ_{18}	273.34
Marginal cost of exporting from Middle East to Asia Pacific:	τ_{38}	258.62
Marginal cost of exporting from Australasia to Asia Pacific:	τ_{39}	205.18

Table 3: Equilibrium trade flows (in Bcm)

Route	2009	Scenario I	Scenario II	Scenario III	Scenario IV.a	Scenario IV.b	Scenario V	Scenario VI
From Europe to Europe	288.1	284.31	288.10	288.10	288.10	288.10	288.10	285.15
From North America to North America	813	813.00	813.00	813.00	813.00	833.61	813.00	813.00
From Asia Pacific to Asia Pacific	246.1	246.10	246.10	246.10	246.10	246.10	237.34	238.36
From South America to Europe	7.6	3.81	12.04	8.54	8.82	10.81	8.82	4.64
From South America to North America	7.6	7.63	4.41	7.11	9.22	5.06	6.58	7.64
From South America to South America	134.7	134.70	133.45	134.25	131.87	134.02	134.50	134.70
From West Africa to Europe	10.7	6.91	14.05	8.35	11.49	12.16	12.30	7.74
From West Africa to North America	3.1	3.09	0.00	0.00	2.23	0.00	4.15	3.08
From West Africa to Asia Pacific	6.6	8.32	6.51	12.25	6.95	8.38	0.00	0.00
From West Africa to West Africa	10.08	10.08	9.92	9.88	9.81	9.94	10.08	10.08
From North Africa to Europe	67.2	63.41	71.59	68.12	68.29	70.40	68.42	64.24
From North Africa to North America	5.0	5.00	1.46	4.38	5.85	2.26	3.92	5.00
From North Africa to North Africa	69.2	69.20	68.35	68.89	67.26	68.74	69.06	69.20
From Russia to Europe	181.1	177.31	187.76	181.00	185.58	184.06	173.87	169.94
From Russia to Asia Pacific	6.2	7.92	0.00	13.66	9.51	9.18	47.83	49.35
From Russia to Russia	485.5	485.44	485.04	478.14	477.70	479.56	451.10	453.52
From Middle East to Europe	25.6	48.32	0.00	24.41	28.93	27.68	27.20	51.55
From Middle East to Asia Pacific	47.2	41.41	49.85	53.79	49.59	49.48	38.44	33.87
From Middle East to Middle East	345.6	328.67	345.54	340.20	339.88	341.24	345.54	332.98
From Australasia to Asia Pacific	88.3	88.94	89.29	91.66	90.14	89.87	79.54	80.56
From Australasia to Australasia	110.8	110.16	109.81	107.44	108.96	109.23	110.80	110.80

Table 4: Percentage change in equilibrium trade flows compared to 2009

Route	Scenario I	Scenario II	Scenario III	Scenario IV.a	Scenario IV.b	Scenario V	Scenario VI
From Europe to Europe	-1.31	0.00	0.00	0.00	0.00	0.00	-1.03
From North America to North America	0.00	0.00	0.00	0.00	2.54	0.00	0.00
From Asia Pacific to Asia Pacific	0.00	0.00	0.00	0.00	0.00	-3.56	-3.15
From South America to Europe	-49.86	58.46	12.35	16.00	42.28	16.08	-38.91
From South America to North America	0.40	-42.03	-6.41	21.29	-33.39	-13.42	0.48
From South America to South America	0.00	-0.93	-0.34	-2.10	-0.50	-0.15	0.00
From West Africa to Europe	-35.38	31.30	-22.01	7.34	13.64	14.93	-27.63
From West Africa to North America	-0.33	-100.00	-100.00	-27.99	-100.00	33.92	-0.64
From West Africa to Asia Pacific	26.00	-1.30	85.64	5.36	27.02	-100.00	-100.00
From West Africa to West Africa	0.00	-1.62	-1.96	-2.69	-1.42	0.00	0.00
From North Africa to Europe	-5.63	6.53	1.38	1.62	4.75	1.81	-4.40
From North Africa to North America	-0.01	-70.71	-12.25	17.12	-54.70	-21.58	-0.02
From North Africa to North Africa	0.00	-1.23	-0.44	-2.80	-0.66	-0.20	0.00
From Russia to Europe	-2.09	3.68	-0.05	2.48	1.63	-3.99	-6.17
From Russia to Asia Pacific	27.69	-100.00	120.33	53.48	48.11	671.56	696.02
From Russia to Russia	-0.01	-0.09	-1.52	-1.61	-1.22	-7.09	-6.59
From Middle East to Europe	88.76	-100.00	-4.64	12.99	8.12	6.24	101.36
From Middle East to Asia Pacific	-12.27	5.61	13.95	5.06	4.83	-18.56	-28.24
From Middle East to Middle East	-4.90	-0.02	-1.56	-1.65	-1.26	-0.02	-3.65
From Australasia to Asia Pacific	0.73	1.12	3.81	2.08	1.78	-9.92	-8.77
From Australasia to Australasia	-0.58	-0.90	-3.04	-1.66	-1.42	0.00	0.00

Table 5: Producers' percentage market share in each importing region

Europe	2009	Scenario I	Scenario II	Scenario III	Scenario IV.a	Scenario IV.b	Scenario V	Scenario VI
Share of Europe	49.6	48.7	50.2	49.8	48.7	48.6	49.8	48.9
Share of South America	1.3	0.7	2.1	1.5	1.5	1.8	1.5	0.8
Share of West Africa	1.8	1.2	2.4	1.4	1.9	2.0	2.1	1.3
Share of North Africa	11.6	10.9	12.5	11.8	11.6	11.9	11.8	11.0
Share of Russia	31.2	30.4	32.7	31.3	31.4	31.0	30.0	29.1
Share of Middle East	4.4	8.3	0.0	4.2	4.9	4.7	4.7	8.8
North America	**2009**	**Scenario I**	**Scenario II**	**Scenario III**	**Scenario IV.a**	**Scenario IV.b**	**Scenario V**	**Scenario VI**
Share of North America	98.1	98.1	99.3	98.6	97.9	99.1	98.2	98.1
Share of South America	0.9	0.9	0.5	0.9	1.1	0.6	0.8	0.9
Share of West Africa	0.4	0.4	0.0	0.0	0.3	0.0	0.5	0.4
Share of North Africa	0.6	0.6	0.2	0.5	0.7	0.3	0.5	0.6
Asia Pacific	**2009**	**Scenario I**	**Scenario II**	**Scenario III**	**Scenario IV.a**	**Scenario IV.b**	**Scenario V**	**Scenario VI**
Share of Asia Pacific	62.4	62.7	62.8	59.0	61.2	61.1	58.9	59.3
Share of West Africa	1.7	2.1	1.7	2.9	1.7	2.1	0.0	0.0
Share of Russia	1.6	2.0	0.0	3.3	2.4	2.3	11.9	12.3
Share of Middle East	12.0	10.5	12.7	12.9	12.3	12.3	9.5	8.4
Share of Australasia	22.4	22.6	22.8	22.0	22.4	22.3	19.7	20.0

Table 6: Percentage share of each market in exporters' total production

South America	2009	Scenario I	Scenario II	Scenario III	Scenario IV.a	Scenario IV.b	Scenario V	Scenario VI
Europe	5.1	2.6	8.0	5.7	5.9	7.2	5.9	3.2
North America	5.1	5.2	2.9	4.7	6.1	3.4	4.4	5.2
South America	89.9	92.2	89.0	89.6	88.0	89.4	89.7	91.6
West Africa	2009	Scenario I	Scenario II	Scenario III	Scenario IV.a	Scenario IV.b	Scenario V	Scenario VI
Europe	35.1	24.3	46.1	27.4	37.7	39.9	46.4	37.0
North America	10.2	10.9	0.0	0.0	7.3	0.0	15.6	14.7
Asia Pacific	21.7	29.3	21.4	40.2	22.8	27.5	0.0	0.0
West Africa	33.1	35.5	32.5	32.4	32.2	32.6	38.0	48.2
North Africa	2009	Scenario I	Scenario II	Scenario III	Scenario IV.a	Scenario IV.b	Scenario V	Scenario VI
Europe	47.5	46.1	50.6	48.2	48.3	49.8	48.4	46.4
North America	3.5	3.6	1.0	3.1	4.1	1.6	2.8	3.6
North Africa	48.9	50.3	48.3	48.7	47.6	48.6	48.8	50.0
Russia	2009	Scenario I	Scenario II	Scenario III	Scenario IV.a	Scenario IV.b	Scenario V	Scenario VI
Europe	26.9	26.4	27.9	26.9	27.6	27.4	25.8	25.3
Asia Pacific	0.9	1.2	0.0	2.0	1.4	1.4	7.1	7.3
Russia	72.2	72.4	72.1	71.1	71.0	71.3	67.0	67.4
Middle East	2009	Scenario I	Scenario II	Scenario III	Scenario IV.a	Scenario IV.b	Scenario V	Scenario VI
Europe	6.1	11.5	0.0	5.8	6.9	6.6	6.6	12.3
Asia Pacific	11.3	9.9	12.6	12.9	11.9	11.8	9.3	8.1
Middle East	82.6	78.6	87.4	81.3	81.2	81.6	84.0	79.6
Australasia	2009	Scenario I	Scenario II	Scenario III	Scenario IV.a	Scenario IV.b	Scenario V	Scenario VI
Asia Pacific	44.3	44.7	44.8	46.0	45.3	45.1	41.8	42.1
Australasia	55.7	55.3	55.2	54.0	54.7	54.9	58.2	57.9