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Effects of North American Shale Gas On the World Natural Gas Market

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Abstract

In this paper, we develop an "OPEC" type of model for the world natural gas market where buyers and sellers (dominant producers and competitive fringe) are connected by a trading network. The market power of a producer depends on its supply capacity, its elasticity of supply, the number of competitors it faces in each market and their supply elasticities. We apply this model to a natural gas trade network based on BP's Statistical Review of World Energy 2010 major trade flows. We then expand this network by allowing for North American natural gas exports. In our model, strategic interactions of *all* the producers and consumers in the world natural gas trade network determine the export volumes from North America and their impacts on North American natural gas prices. We find that North America exports natural gas when its supply curve is highly elastic and hence the domestic price impact of its exports is very small. Even so, the price impacts on the importing markets are substantial. We also find that shale gas development in North America decreases dominant producers' market power and hence decreases the incentive of any parties to form a natural gas cartel.

1 Introduction

Recent developments in hydraulic fracturing and horizontal drilling have changed the course of natural gas trade for the U.S. Until a decade ago, market players were investing in LNG import facilities in the U.S., based on the predictions that U.S. domestic supply was becoming scarce. Contrary to these predictions, recent technological developments have unlocked natural gas resources and enabled a rapid growth of natural gas production in the U.S. For instance, according to the Energy Information Administration (EIA), gross withdrawals from shale gas wells in the U.S. has increased from zero in 2000 to over 23 billion cubic feet per day (Bcfd) in 2011, representing over 29 percent of total gross production in the U.S. These abundant supplies and the consequent low prices in the U.S. relative to the European and Asia Pacific markets have led natural gas producers to look at the profit opportunities from exporting to these markets. This paper focuses on the possible impacts on domestic and international gas prices of U.S. natural gas exports.

As stated in Cigerli (2013), most world natural gas production is concentrated in a small number of producers. However, following the Natural Gas Policy Act in 1978, the U.S. has developed the most liberalized natural gas market with a large number of producers of whom each has easy access to a huge market. In particular, ownership of transportation capacity rights is unbundled from pipeline ownership. Unbundling of capacity rights from facility ownership makes it possible for any producer to access markets through a competitive bid. By contrast, in most other markets globally, pipeline capacity is not unbundled from facility ownership, meaning large incumbent monopolies can effectively present barriers to entry through control of the transportation infrastructure.[1] We therefore consider a mixed oligopoly competitive model[2] of the world natural gas market, where we allow for OPEC type[3] of competition where there are dominant producers facing a fringe of small competitors, albeit largely confined to North America. In reality, small firms are also part of the market in some overseas jurisdictions, especially Australia, but for simplicity we assume the competitive fringe is present only in North America.

We model the world natural gas market in a network structure where buyers and sellers are connected through a trading network. We base our model on Ilkilic (2010), who develops a bipartite network model for m markets and n firms in Cournot competition and analyzes how the structure of network that connects suppliers with producers affects the market outcome. In this paper, we relax Ilkilic's (2010) assumption that each producer is a Cournot player and has no capacity constraint. To better represent the North American natural gas market, this paper allows for perfect competition in that market. We show

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[1] See the section by Medlock in "2013 Policy Recommendations for the Obama Administration" by the James A. Baker III Institute for Public Policy, March 2013.

[2] The literature uses "mixed oligopoly" to refer to a market with public and private firms, where the public firms maximize social welfare and private firms maximize their profits. In this paper, we introduce a new term "mixed oligopoly competitive" to define a market which has a mix of competitive, monopolistic, monopsonistic and oligopolistic elements.

[3] Our model differs from the most common model of OPEC, which assumes there is a single dominant producer that is OPEC. Unlike in the oil market, in the world natural gas market a few dominant producers compete with each other.

that our game can be represented as a potential game and with a unique equilibrium.

The literature on North American natural gas exports is very recent. Therefore, there are few studies that we can compare with ours. In January 2012, the U.S. Energy Information Administration (EIA) published a study on the price impacts of U.S. LNG exports. Their analysis treated U.S. LNG exports as exogenous and did not consider potential interactions between the U.S. LNG exports and the world natural gas market. Similar to the EIA's report, a Deloitte Center for Energy Solutions' study titled "Made in America: The Economic Impact of LNG Exports from the United States" assumed a particular volume of LNG exports from the U.S. when assessing the domestic price impact. It also did not allow any interaction between domestic and international markets to influence the volume of trade.

Contrary to these studies, Medlock (2012) suggested that one should consider U.S. LNG exports in a global setting and model them in an international trade framework. According to Medlock (2012), key factors that determine the impact of U.S. LNG exports on domestic prices are the elasticity of domestic supply and demand, the elasticity of foreign supply and demand, the role of short-term capacity constraints, the cost of developing and utilizing export capacity and the exchange rate. Most of these factors were ignored in the previous studies. His analysis, using the Rice World Gas Trade Model (RWGTM), concluded that the natural gas spot price differentials between Asia and the U.S. and Europe and the U.S. are not sufficient to support long-term LNG exports from the U.S. Gulf Coast to these regions.

Shortly after Medlock (2012), in December 2012, the U.S. Department of Energy has published another study[4] titled "Macroeconomic Impacts of LNG Exports from the United States" which assesses the potential macroeconomic impacts of LNG exports. Compared to the previous studies, the DOE study considered the world natural gas market in a global setting but failed to model it realistically. Specifically, they assumed that the world natural gas market had a single dominant supplier, with the largest share of LNG exports. The dominant supplier was assumed to limit output, but had to contend with competitive fringe whose production adjusts to market prices. Their calculations of U.S. benefits from LNG exports assumed that the dominant supplier would not change its plan for expanding production to counter U.S. entry to market. Therefore, they concluded that there will be demand for U.S. LNG exports.

Like the EIA (2012) paper and unlike the RWGTM, we assume that the world natural gas market is imperfectly competitive. However, we allow all production, consumption, trade and pricing outcomes to be endogenous. In particular, to the best of our knowledge, this is the first explicit non-competitive model, where export volumes from North America and their price impacts are endogenous.[5]

We find that North American LNG exports occur when its elasticity of supply is very

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[4] This study was done by NERA Economic Consulting at the request of the U.S. Department of Energy, Office of Fossil Energy.

[5] The RWGTM has endogenous export volumes and prices, but it is competitive.

high and Asian demand remains strong.[6][7] The volume of natural gas that North America exports decrease as its competitors' elasticities of supply increase. We also find that a more elastic North American supply curve reduces natural gas producers' market power all around the world.

In Section 2, we introduce world natural gas market. In Section 3, we introduce our fringe and dominant producers' Cournot game and solve for its unique Cournot-Nash equilibrium. Section 2.4 is devoted to analyzing different policy scenarios. Section 5 concludes. In the appendix, we calibrate the model parameters by using natural gas production, consumption, trade, proved reserves and prices in 2009.

2 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.

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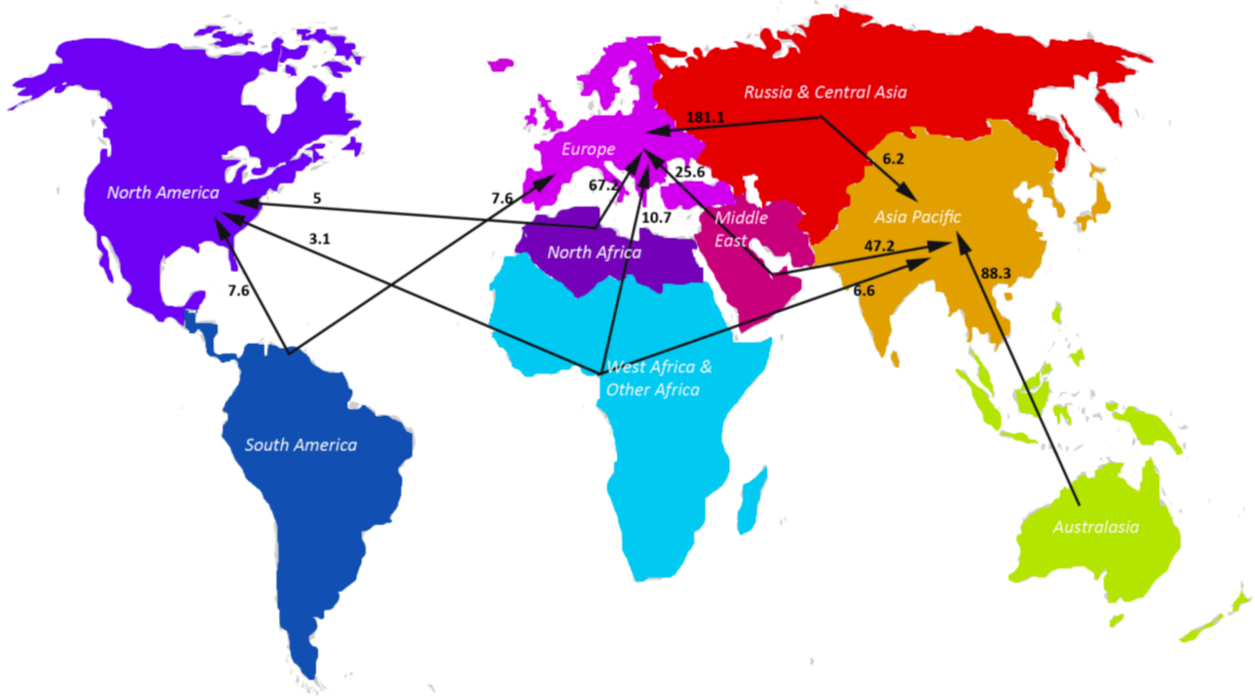
[6] More explicitly, we show that North America exports LNG when the North American supply curve is at least 75 percent flatter than its original supply curve in 2009 and Asia Pacific's demand is increased by at least 15 percent relative to 2009.

[7] An unrealistic feature of our model is that North America does not export and import at the same time. This is because we assume a single price for the North American market. However, in reality due to pipeline capacity constraints it can export LNG from the Gulf Coast and import to New England.

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[8] as Europe,[9] North America,[10] Asia Pacific,[11] South America,[12] West Africa,[13]

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[8] 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.

[9] 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.

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

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

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

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

North Africa,[14] Russia,[15] Middle East[16] and Australasia.[17]

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.[18]

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

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

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

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

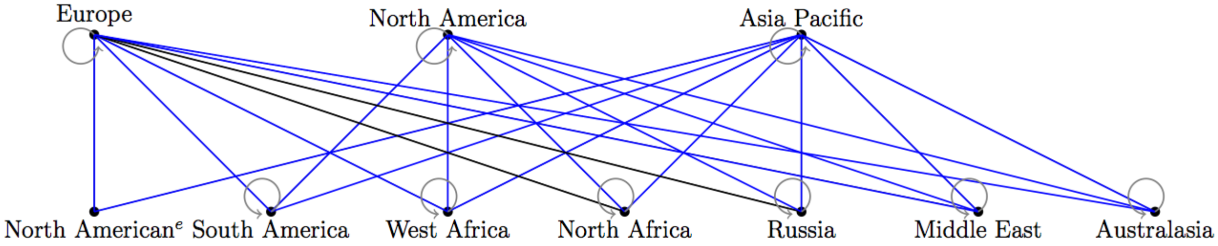
[18] This price reflects the natural gas price in Canada, U.S. and Mexico.

2.1 Schematic representation of the world natural gas market

In this paper, we add more links to the world natural gas trade network that we introduced in the previous section, and but we also assume that the network graph is fixed. More specifically, we allow for buyers and sellers to be connected if the seller has a liquefaction facility and the buyer has a regasification facility. For instance in 2009, there was no natural gas trade between Trinidad and Tobago and Japan[19] but we allow for a link that connects South America to the Asia Pacific. We do not assume any exogenous trade volumes and instead let our model solve for equilibrium trade volumes. As a result, in the equilibrium there might be links that carry zero flows but they are strategically redundant.[20]

Below is the schematic representation of the world natural gas network used in this paper.[21] We denote the North American exporter[22] by North American^e.

Figure 2: Schematic representation



3 Model

3.1 Notation[23]

There are m markets[24] $d_1, ..., d_m$ and n firms[25] $f_1, ..., f_n$. They are embedded in a network that links markets with firms, and firms can supply only to the markets to which they are

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[19] In our aggregated regions, Trinidad and Tobago belongs to South America and Japan belongs to the Asia Pacific.

[20] Theorem 2 of Ilkilic (2010) tells us that the links which carry no flows in the equilibrium are strategically redundant; they play no role in determining the equilibrium. For the firms of such links, the marginal profits of supplying via them are not positive. They are indifferent between having such a link or not.

[21] 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.

[22] It purchases natural gas at domestic prices and exports to the Asia Pacific and Europe.

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

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

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

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.

3.2 Fringe and dominant producers' 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 market d_i and Ω_g be the vector of quantities supplied in graph g. Let $r(g)$ be the size of Ω_g and assume we list the supply q_{ij} above the supply q_{kl} when $j < l$ or $j = l$ and $i < k$.

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

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

where α_i and β_i are positive constants and h_i is natural gas consumption in market d_i:

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

For example, the total consumption in North America in our trade network is $h_2 = q_{22} + q_{24} + q_{25} + q_{26} + q_{27} + q_{28} + q_{29} - q_{12} - q_{32}$ leading to linear inverse demand $p_2 = \alpha_2 - \beta_2(q_{22} + q_{24} + q_{25} + q_{26} + q_{27} + q_{28} + q_{29} - q_{12} - q_{32})$.

We assume that each natural gas producer has quadratic costs of production in the short run up to its production capacity, $\bar{S}_j$:

$$TC_j(\Omega_g) = \frac{\gamma_j}{2}\left[\sum_{d_i \in N_g(f_j)} q_{ij}\right]^2 \quad \text{where} \quad \sum_{d_i \in N_g(f_j)} q_{ij} \leq \bar{S}_j, \tag{4}$$

We also assume that the cost of exporting natural gas is linear. For firm f_j the short-run total cost of export therefore is

$$T_j(\Omega_g) = \sum_{d_i \in N_g(f_j) \setminus d_j} \tau_{ij} q_{ij}, \tag{5}$$

where τ_{ij} is the marginal cost of exporting natural gas to market i.[26] If the natural

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

gas is carried via LNG, τ_{ij} includes[27] 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.

3.3 North American fringe producers

We assume that the domestic producers in North America form a competitive fringe. Each member of the fringe is too small to influence the market price, and takes the equilibrium price to be given independently of its own actions.

Let the aggregate cost function of competitive fringe firms in North America be

$$TC(\Omega_g) = \frac{\gamma_2}{2} Q_2^2 \tag{6}$$

where Q_2 is the total supply of fringe producers in North America, which is the sum of North American domestic demand and its exports to Europe and the Asia Pacific.[28]

In equilibrium, fringe producers supply at $p_2 = \gamma_2 Q_2 \implies Q_2^\star = \frac{p_2}{\gamma_2} \implies q_{22} = \frac{p_2}{\gamma_2} - q_{12} - q_{32}$.

A dominant producer's demand curve in each market is not the same as the market demand curve. Their demand curve is the difference between market demand and the supply from fringe firms.

The inverse demand function that dominant firms[29] face in North America is

$$p_2 = \alpha_2 - \beta_2 \left(\overbrace{\frac{p_2}{\gamma_2} - q_{12} - q_{32}}^{\text{Fringe's supply}} + \overbrace{q_{24} + q_{25} + q_{26} + q_{27} + q_{28} + q_{29}}^{\text{Dominant firms' supply}} \right). \tag{7a}$$

Re-arranging (7) we obtain:

$$p_2 \left(1 + \frac{\beta_2}{\gamma_2} \right) = \alpha_2 - \beta_2 (q_{24} + q_{25} + q_{26} + q_{27} + q_{28} + q_{29} - q_{12} - q_{32}), \tag{7b}$$

which can then be solved for p_2:

$$p_2 = \underbrace{\left(\frac{\gamma_2}{\gamma_2 + \beta_2} \right) \alpha_2}_{=\tilde{\alpha}_2} - \underbrace{\left(\frac{\gamma_2}{\gamma_2 + \beta_2} \right) \beta_2}_{=\tilde{\beta}_2} (q_{24} + q_{25} + q_{26} + q_{27} + q_{28} + q_{29} - q_{12} - q_{32}). \tag{7c}$$

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

[28] That is,

$$Q_2 = \overbrace{q_{22}}^{\text{Domestic Demand}} + \overbrace{q_{12} + q_{32}}^{\text{Export Supply}}.$$

[29] The dominant firms that are connected to North America are South America, West Africa, North Africa, Russia, the Middle East and Australasia.

Since we assume that there is a single price for each region, North America does not export and import at the same time. Therefore, total exports to North America, $q_{24} + q_{25} + q_{26} + q_{27} + q_{28} + q_{29}$, and the total exports from North America, $q_{12} + q_{32}$, are not positive in the equilibrium of a same scenario.[30]

3.4 North America as an exporter

The North American exporter, when it exists, is a monopsony buyer who purchases natural gas from the domestic fringe producers at the price, represented in (7c) and ships to Europe and/or the Asia Pacific. The North American exporter then maximizes its profit by choosing q_{12} and q_{32}.

$$\begin{aligned}\max_{q_{12},\, q_{32} \geq 0} \{ & (\alpha_1 - \beta_1 h_1)\, q_{12} + (\alpha_3 - \beta_3 h_3)\, q_{32} - \tau_{12} q_{12} - \tau_{32} q_{32} \\ & - (\tilde{\alpha}_2 - \tilde{\beta}_2 (q_{24} + q_{25} + q_{26} + q_{27} + q_{28} + q_{29} - q_{12} - q_{32}))\,(q_{12} + q_{32})\} \end{aligned} \tag{8}$$

where $h_1 = q_{11} + q_{12} + q_{14} + q_{15} + q_{16} + q_{17} + q_{18} + q_{19}$ and $h_3 = q_{32} + q_{33} + q_{34} + q_{35} + q_{36} + q_{37} + q_{38} + q_{39}$.

The first order conditions are

$$\begin{aligned} q_{12} :\ & \alpha_1 - \beta_1 (q_{11} + q_{14} + q_{15} + q_{16} + q_{17} + q_{18} + q_{19}) - 2\beta_1 q_{12} - \tau_{12} - \tilde{\alpha}_2 \\ & + \tilde{\beta}_2 (q_{24} + q_{25} + q_{26} + q_{27} + q_{28} + q_{29}) - 2\tilde{\beta}_2 (q_{12} + q_{32}) = 0 \end{aligned}$$

$$\begin{aligned} q_{32} :\ & \alpha_3 - \beta_3 (q_{33} + q_{34} + q_{35} + q_{36} + q_{37} + q_{38} + q_{39}) - 2\beta_3 q_{32} - \tau_{32} - \tilde{\alpha}_2 \\ & + \tilde{\beta}_2 (q_{24} + q_{25} + q_{26} + q_{27} + q_{28} + q_{29}) - 2\tilde{\beta}_2 (q_{12} + q_{32}) = 0 \end{aligned}$$

Equilibrium exports to Europe are

$$\begin{aligned} q_{12}^{\star} = & \frac{\alpha_1 - \tilde{\alpha}_2 - \beta_1 (q_{11} + q_{14} + q_{15} + q_{16} + q_{17} + q_{18} + q_{19}) + \tilde{\beta}_2 (q_{24} + q_{25} + q_{26} + q_{27} + q_{28} + q_{29})}{2\beta_1 + 2\tilde{\beta}_2} \\ & - \frac{2\tilde{\beta}_2 q_{32} + \tau_{12}}{2\beta_1 + 2\tilde{\beta}_2} \end{aligned} \tag{9}$$

while equilibrium exports to the Asia Pacific are

$$\begin{aligned} q_{32}^{\star} = & \frac{\alpha_3 - \tilde{\alpha}_2 - \beta_3 (q_{33} + q_{34} + q_{35} + q_{36} + q_{37} + q_{38} + q_{39}) + \tilde{\beta}_2 (q_{24} + q_{25} + q_{26} + q_{27} + q_{28} + q_{29})}{2\beta_3 + 2\tilde{\beta}_2} \\ & - \frac{2\tilde{\beta}_2 q_{12} + \tau_{32}}{2\beta_3 + 2\tilde{\beta}_2} \end{aligned} \tag{10}$$

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[30] To have a unique equilibrium, a bipartition of the network graph is required. If there was more than one price for North America, such as one price in New England and one price in Houston, then we would have to disaggregate North America into two regions: New England as an importing region and Houston as an exporting region. For now, we assume North America as a one region; either an exporting or an importing region.

As we see in (9) and (10) LNG exports from North America depend on the elasticities of domestic supply and demand, the elasticities of foreign supply and demand,[31] and the role of short-run capacity constraints.[32]

3.5 Dominant producers

In the world natural gas trade network, there are *eight* dominant producers[33] who have monopoly power in their domestic markets but compete with each other in the foreign market. Each dominant producer's objective is to maximize its profits subject to its supply constraint.

Example: West Africa's producer, labelled as 5, aims to:

$$\begin{aligned}\max_{q_{15},q_{25},q_{35},q_{55}} \{&(\alpha_1-\beta_1(q_{11}+q_{12}+q_{14}+q_{15}+q_{16}+q_{17}+q_{18}+q_{19}))q_{15}\\ &+(\tilde{\alpha}_2-\tilde{\beta}_2(q_{24}+q_{25}+q_{26}+q_{27}+q_{28}+q_{29}-q_{12}-q_{32}))q_{25}\\ &+(\alpha_3-\beta_3(q_{32}+q_{33}+q_{34}+q_{35}+q_{37}+q_{38}+q_{39}))q_{35}\\ &+(\alpha_5-\beta_5 q_{55})q_{55}-\frac{\gamma_5}{2}(q_{15}+q_{25}+q_{35}+q_{55})^2-\tau_{15}q_{15}-\tau_{25}q_{25}-\tau_{35}q_{35}\}\end{aligned} \tag{11}$$

subject to

$$q_{15}+q_{25}+q_{35}+q_{55}\leq \bar{S}_5 \quad \text{and} \quad q_{15},q_{25},q_{35},q_{55}\geq 0. \tag{12}$$

We get the first order conditions as:

$$\begin{aligned}q_{15}:\quad &\alpha_1-2\beta_1 q_{15}-\beta_1(q_{11}+q_{12}+q_{14}+q_{16}+q_{17}+q_{18})-\gamma_5(q_{15}+q_{25}+q_{35}+q_{55})\\ &-\tau_{15}-\lambda_5-\mu_{15}=0\end{aligned}$$

$$\begin{aligned}q_{25}:\quad &\tilde{\alpha}_2-2\tilde{\beta}_2 q_{25}-\tilde{\beta}_2(q_{24}+q_{26}+q_{26}+q_{27}+q_{28}+q_{29}-q_{12}-q_{32})\\ &-\gamma_5(q_{15}+q_{25}+q_{35}+q_{55})-\tau_{25}-\lambda_5-\mu_{25}=0\end{aligned}$$

$$\begin{aligned}q_{35}:\quad &\alpha_3-2\beta_3 q_{35}-\beta_3(q_{32}+q_{33}+q_{36}+q_{37}+q_{38}+q_{39})-\gamma_5(q_{15}+q_{25}+q_{35}+q_{55})\\ &-\tau_{35}-\lambda_5-\mu_{35}=0\end{aligned}$$

$$q_{55}:\quad \alpha_5-2\beta_5 q_{55}-\gamma_5(q_{15}+q_{25}+q_{35}+q_{55})-\lambda_5-\mu_{55}=0$$

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[31] For instance, equilibrium supply of Europe to its domestic market, that is q_{11} depends on its elasticity of supply.

[32] Each dominant producer has a supply constraint in the short-run.

[33] Unlike the rest of the producers, North America is a fringe producer. However, the North American exporter is a dominant supplier who competes with the dominant producers in the foreign markets.

where λ_5 is the Lagrange multiplier of the capacity constraint in (12), which can be interpreted as the shadow price of expanding capacity.

The stylized representation of the current world natural gas model that described above is a non-cooperative game with coupled payoff functions and coupled constraints.[34] Applying the Lagrangian multiplier theory to our model is not computationally convenient. This is because 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 introduced by Monderer and Shapley (1994).

Definition 1: Consider the Cournot game that we describe above with linear inverse demand functions, quadratic cost of productions and linear costs of exporting. Assume that there is one non-producing exporter, denoted as f_e, buying from one competitive domestic market, denoted as d_e. The exporter, f_e, supplies other importing markets which are imperfectly competitive. We denote the consumers in the exporter's domestic market as d_e. Then, we define a function

$$\begin{aligned}
P^{\star}(Q_g) = & \sum_{d_i \in N_g(f_j) \backslash d_e} \alpha_i \left(\sum_{f_j \in N_g(d_i)} q_{ij} \right) - \sum_{d_i \in N_g(f_j) \backslash d_e} \beta_i \left(\sum_{f_j \in N_g(d_i)} q_{ij}^2 \right) \\
& - \sum_{d_i \in N_g(f_j) \backslash d_e} \beta_i \left(\sum_{1 \le j < k \le n} q_{ij} q_{ik} \right) - \sum_{d_i \in N_g(f_j) \backslash d_j} \sum_{f_j \in N_g(d_i)} \tau_{ij} q_{ij} \\
& - \frac{\beta_e \gamma_e}{\gamma_e + \beta_e} \left(\sum_{1 \le j < k \le n} q_{ej} q_{ek} \right) + \frac{\alpha_e \gamma_e}{\gamma_e + \beta_e} \left(\sum_{f_j \in N_g(d_e) \backslash f_e} q_{ej} \right) \\
& - \frac{\beta_e \gamma_e}{\gamma_e + \beta_e} \left(\sum_{f_j \in N_g(d_e) \backslash f_e} q_{ej}^2 \right) + \frac{\beta_e \gamma_e}{\gamma_e + \beta_e} \left(\sum_{f_j \in N_g(d_e) \backslash f_e} q_{ej} \right) \left(\sum_{d_i \in N_g(f_e) \backslash d_e} q_{ie} \right) \\
& - \frac{\beta_e \gamma_e}{\gamma_e + \beta_e} \left(\sum_{d_i \in N_g(f_e) \backslash d_e} q_{ie} \right)^2 - \frac{\alpha_e \gamma_e}{\gamma_e + \beta_e} \sum_{d_i \in N_g(f_e) \backslash d_e} q_{ie} \\
& - \sum_{f_j \in N_g(d_i) \backslash f_e} \frac{\gamma_j}{2} \left(\sum_{d_i \in N_g(f_j)} q_{ij} \right)^2
\end{aligned} \tag{13}$$

subject to

$$\bar{S}_j \ge \sum_{d_i \in N_g(f_j)} q_{ij} \quad \text{for all } \; j \in F \tag{14}$$

---

[34] The coupling arises because producers have a limited production capacity, which in turn limits their ability to supply markets to which they are connected.

and

$$q_{ij} \geq 0 \quad \text{for all } \ (i,j) \in g \tag{15}$$

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}, $P^{\star}(Q_g)$[35] satisfies[36]

$$\pi_j(q_{ij}, q_{-ij}) - \pi_j(x_{ij}, q_{-ij}) = P^{\star}(q_{ij}, q_{-ij}) - P^{\star}(x_{ij}, q_{-ij}) \tag{16}$$

and

$$\pi_e(q_{ie}, q_{-ij}) - \pi_e(x_{ie}, q_{-ij}) = P^{\star}(q_{ie}, q_{-ij}) - P^{\star}(x_{ie}, q_{-ij}) \tag{17}$$

A function $P^{\star}$ satisfying (16) and (17) is called a potential function which requires

$$\frac{\partial \pi_j}{\partial q_{ij}} = \frac{\partial P^{\star}}{\partial q_{ij}} \quad \text{for all } \ (i,j) \in g \tag{18}$$

$$\frac{\partial \pi_e}{\partial q_{ie}} = \frac{\partial P^{\star}}{\partial q_{ie}} \quad \text{for all } \ (i,e) \in g \tag{19}$$

---

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

[36] π_j is the optimization problem of dominant firm j in the noncooperative game with constraints. More specifically, dominant firm j, f_j, maximizes

$$\begin{aligned}
\pi_j(q_{ij}) = & \sum_{d_i \in N_g(f_j) \backslash d_e} \alpha_i q_{ij} - \sum_{d_i \in N_g(f_j) \backslash d_e} \beta_i q_{ij}^2 - \sum_{d_i \in N_g(f_j) \backslash d_e} \beta_i q_{ij} \left(\sum_{f_k \in N_g(d_i) \backslash f_j} q_{ik} \right) - \frac{\gamma_j}{2} \left(\sum_{f_j \in N_g(d_i)} q_{ij} \right)^2 \\
& - \sum_{f_j \in N_g(d_i)} \tau_{ij} q_{ij} + \sum_{d_e \in N_g(f_j)} \frac{\alpha_e \gamma_e}{\gamma_e + \beta_e} q_{ej} - \sum_{d_e \in N_g(f_j)} \frac{\beta_e \gamma_e}{\gamma_e + \beta_e} q_{ej}^2 - \sum_{1 \leq j < k \leq n} \frac{\beta_e \gamma_e}{\gamma_e + \beta_e} q_{ej} q_{ek} \\
& + \sum_{d_i \in N_g(f_e) \backslash d_e} \frac{\beta_e \gamma_e}{\gamma_e + \beta_e} q_{ej} q_{ie}
\end{aligned}$$

and the exporter e, f_e, maximizes

$$\begin{aligned}
\pi_e(q_{ie}) = & \sum_{d_i \in N_g(f_e) \backslash d_e} \alpha_i q_{ie} - \sum_{d_i \in N_g(f_e) \backslash d_e} \beta_i q_{ie}^2 - \sum_{d_i \in N_g(f_e) \backslash d_e} \beta_i q_{ie} \left(\sum_{f_k \in N_g(d_i) \backslash f_e} q_{ik} \right) \\
& - \sum_{d_i \in N_g(f_e) \backslash d_e} \frac{\alpha_e \gamma_e}{\gamma_e + \beta_e} q_{ie} - \frac{\beta_e \gamma_e}{\gamma_e + \beta_e} \left(\sum_{d_i \in N_g(f_e) \backslash d_e} q_{ie} \right)^2 + \frac{\beta_e \gamma_e}{\gamma_e + \beta_e} \left(\sum_{f_j \in N_g(d_e) \backslash f_e} q_{ej} \right) \left(\sum_{d_i \in N_g(f_e) \backslash d_e} q_{ie} \right) \\
& - \sum_{d_i \in N_g(f_e) \backslash d_e} \tau_{ie} q_{ie}
\end{aligned}$$

subject to their supply capacity constraint (of dominant producer) and non-negativity constraints.

Theorem 1: The solution to the potential game defined in (13) subject to constraints defined in (14) and (15) is unique.

$$\max_{q_{ij}} P^{\star}(Q_g) \quad \text{for all} \ (i,j) \in g \tag{20}$$

subject to (14) and (15).
Proof: See Section (A.1).

4 Scenario analysis

In this section we analyze various scenarios[37] in the world natural gas market by changing the model's parameters[38] exogenously. With each of these changes we optimize a pair of new potential functions subject to new set of constraints.[39] Then, we compare our results with our reference case, that is world natural gas trade in 2009.

4.1 Scenario I: Change in North America's elasticity of domestic supply

Our motivation in this paper is to understand the impact of shale gas developments on the world natural gas market. The elasticity of domestic supply is a critical determinant of the domestic price changes resulting from increased exports. We therefore change the slope of North American supply curve while holding all else constant.

In our first experiment, we decreased the slope of North American supply curve by 40 percent. The price in North America decreases from 150 million USD per Bcm to 99.91 million USD per Bcm, and the consumption in North America increases from 828 Bcm to 902.61 Bcm, and its natural gas imports are zero. Dominant producers which exported to North America in 2009, namely South America, West Africa and North Africa, shift their supply to Europe, the Asia Pacific and their domestic markets. For instance, South America increases its supply to Europe from 7.6 Bcm to 9.2 Bcm, while North Africa increases its supply to Europe from 67.2 Bcm to 67.75 Bcm. As a result, there will be more competition in the European and Asia Pacific markets for Russia, the Middle East and Australasia. In response, they decrease their their supply to Europe and the Asia Pacific. For example, Russia's supply to Europe decreases by 0.56 Bcm and its supply to the Asia Pacific decreases by 0.04 Bcm.

A 40 percent decrease in the slope of North American supply curve is not sufficient for the North American exporter to export natural gas to Europe and/or the Asia Pacific. If we allow for a perfectly elastic North American supply curve, however, then North America exports 19.71 Bcm of natural gas to Europe and 17.48 Bcm of natural gas to the Asia

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[37] Equilibrium trade flows under each scenario are provided in Table (2), Table (3) and Table (4).

[38] For calibration of these parameters see the appendix (A.2).

[39] We use the sequential quadratic programming algorithm in MATLAB's optimization toolbox to solve for the constrained optimum.

Pacific. With these exports, there will be more competition for all dominant producers in the European or Asia Pacific markets. To prevent a further decline in equilibrium prices, the dominant producers decrease supply to both markets. For instance, Russia decreases its equilibrium supply to Europe from 181.1 Bcm to 177.59 Bcm and to the Asia Pacific from 6.2 Bcm to 3.13 Bcm. Under this scenario, equilibrium total supply to Europe increases from 580.3 Bcm to 584.6 Bcm, which decreases the equilibrium price from 300 million USD per Bcm to 296.98 million USD per Bcm. Similarly, equilibrium total supply to the Asia Pacific increases from 394.4 Bcm to 398 Bcm, which decreases the equilibrium price from 320 million USD per Bcm to 316.56 million USD per Bcm. The decline in equilibrium prices decrease the profits of dominant producers. For instance, the profit of the Asia Pacific declines by 1.4 billion USD. Similarly, the profit of Russia declines by 1 billion USD.

All else constant, North America starts exporting when the slope of its supply curve is 90 percent less than that of 2009. With a 90 percent lower slope, North America exports 0.7 Bcm to Europe and 0.83 Bcm to the Asia Pacific.

On the other hand, North America stops importing natural gas if we decrease the slope of North American supply curve by more than just 4 percent. With the 4 percent decline in the slope of its supply curve, it imports 0.47 Bcm of natural gas from South America. There is thus a big wedge in supply curve slopes where North American natural gas is a non-traded good, neither exported not imported.

4.1.1 Further analysis on Scenario I

In this section, first we shift North American supply curve[40] upward and keep its slope constant, and then decrease its slope.

If we increase the intercept of North American supply curve from zero to 19, then equilibrium exports to North America increase from 15.69 Bcm to 48.61 Bcm. An upward shift in the North American supply curve increases the marginal profits of all producers that are connected to it. This shift increases the equilibrium price in North America from by 10 million USD per Bcm.

Next, we assume a flat North American supply curve with a slope of 19. With this change, North America again becomes an exporter. It exports 0.6 Bcm to Europe and 0.75 Bcm to the Asia Pacific and all dominant producers shift their resources to Europe and the Asia Pacific. For instance, South America increases its supply to Europe from 7.6 Bcm to 9.17 Bcm while decreasing its supply to North America from 7.6 Bcm to zero.

4.2 Scenario II: An increase in Asia Pacific's natural gas demand

According to EIA projections, natural gas demand in Asia will grow from 341 Bcm to 497 Bcm from 2008 to 2015. We incorporate these projections into our model by increasing the choke price in the Asia Pacific by 15 percent. This shifts the demand curve out in a

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[40] In our model, the North American supply curve is $p_2 = \gamma_2 Q_{22}$ however in this section we assume it to be $p_2 = \kappa_2 + \gamma_2 Q_{22}$ where we test for different values of κ_2 and/or γ_2.

parallel fashion. We analyze the impact of this demand increase with a 40 percent, and a 75 percent decrease in the slope of North American supply curve, and with a flat North American supply curve.

If we allow for a natural gas demand increase in the Asia Pacific without changing the slope of North American supply curve, then total natural gas exports to North America decrease to 6.1 Bcm.[41] This occurs because all of the producers that are connected to the Asia Pacific respond to the demand increase by shifting supply from Europe, North America and their domestic markets to the Asia Pacific. For instance, West Africa increases its supply to the Asia Pacific from 6.6 Bcm to 21.23 Bcm by decreasing its supply to Europe from 10.7 Bcm to zero, and to North America from 3.1 Bcm to zero, and to its domestic market from 10.07 Bcm to 9.24 Bcm. The decline in total supply to the European market from West Africa, Russia and the Middle East will result in less competition in Europe for South America and North Africa. In response, South America and North Africa shift their resources from North America and their domestic markets to Europe.

Under this scenario, equilibrium total supply to Europe decreases by 7.1 Bcm, which increases the equilibrium price by 4.97 million USD per Bcm. Similarly, equilibrium total supply to North America decreases by 2.05 Bcm, which increases the equilibrium price by 1.39 million USD per Bcm. On the other hand, equilibrium supply to the Asia Pacific increases by 77.73 Bcm and the equilibrium price increases by 30.49 million USD per Bcm due to the upward shift in the Asia Pacific demand curve.

If, on top of the Asian demand increases, we decrease the slope of the North American supply curve by 40 percent, then total exports to North America decrease to zero. Under this scenario, North America does not export or import any natural gas.

If we decrease the slope of the North American supply curve by 75 percent, then North America exports 3.75 Bcm of natural gas to the Asia Pacific. The equilibrium prices in North America decrease from 150 million USD per Bcm to 45.48 million USD per Bcm. However, if we decrease the slope of North American supply curve by 75 percent but do not allow for exports, the equilibrium price decreases to 45.32 million USD per Bcm. Therefore, the impact of 3.75 Bcm of natural gas exports on North American domestic natural gas prices is 0.16 million USD per Bcm.

Next, we assume that North America has a flat supply curve. With a flat supply curve, North America exports 22.45 Bcm of natural gas to Europe and 39.97 Bcm of natural gas to the Asia Pacific. In the new equilibrium, total supply to the Asia Pacific increases by 91.41 Bcm, but the equilibrium price in the Asia Pacific also increases.[42] Profits of dominant producers decrease as the North American supply curve becomes more elastic.

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[41] The link from South America carries 4.51 Bcm and the link from North Africa carries 1.59 Bcm of natural gas.

[42] It increases by 17.65 million USD per Bcm. This is due to the upward shift in the Asia Pacific demand curve.

4.2.1 Further analysis on Scenario II

In this section, first we increase the intercept of North American supply curve and keep its slope constant, and then decrease its slope.[43]

If we increase the intercept of North American supply curve to 5, then the equilibrium exports to North America decrease by 2.77 Bcm.[44] This results in an increase of 4.38 million USD per Bcm in North American prices. However, a 15 percent increase in the Asia Pacific choke price increase North American prices by only 1.39 million USD per Bcm.

Next, we assume a flat North American supply curve with an intercept of 50.[45] Then, North America becomes an exporter, and it exports 0.28 Bcm to the Asia Pacific. A flat North American supply curve with an intercept of 50 makes all producers shift supply from North America to Europe and the Asia Pacific. For instance, South America increases supply to Europe from 7.6 Bcm to 14.24 Bcm.

4.3 Scenario III: Decreased competition between Russia and the Middle East

In this scenario, we assume that Russia and the Middle East collude to maximize their joint profits. Our motivation is to understand the impact of shale gas developments in North America and resulting exports from it under such collusion. After the merger, the joint objective of Russia and the Middle East[46] is

$$\begin{aligned}\Pi_{78} = {} & \alpha_1(q_{17}+q_{18}) - \beta_1(q_{11}+q_{12}+q_{14}+q_{15}+q_{16}+q_{17}+q_{18}+q_{19})(q_{17}+q_{18}) \\ & + \alpha_3(q_{37}+q_{38}) - \beta_3(q_{33}+q_{32}+q_{34}+q_{35}+q_{36}+q_{37}+q_{38}+q_{39})(q_{37}+q_{38}) \\ & + \tilde{\alpha}_2(q_{27}+q_{28}) - \tilde{\beta}_2(q_{24}+q_{25}+q_{26}+q_{27}+q_{28}+q_{29}-q_{12}-q_{32})(q_{27}+q_{28}) \\ & - \tau_{17}q_{17} - \tau_{18}q_{18} - \tau_{27}q_{27} - \tau_{28}q_{28} - \tau_{37}q_{37} - \tau_{38}q_{38} \qquad (21)\end{aligned}$$

subject to

$$q_{17}+q_{27}+q_{37}+q_{77} \leq \bar{S}_7\,, \quad q_{18}+q_{28}+q_{38}+q_{88} \leq \bar{S}_8$$

and

$$q_{17},\, q_{27},\, q_{37},\, q_{77},\, q_{18},\, q_{28},\, q_{38},\, q_{88} \geq 0$$

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[43] Note that the choke price in the Asia Pacific is also increased by 15 percent in all these cases.

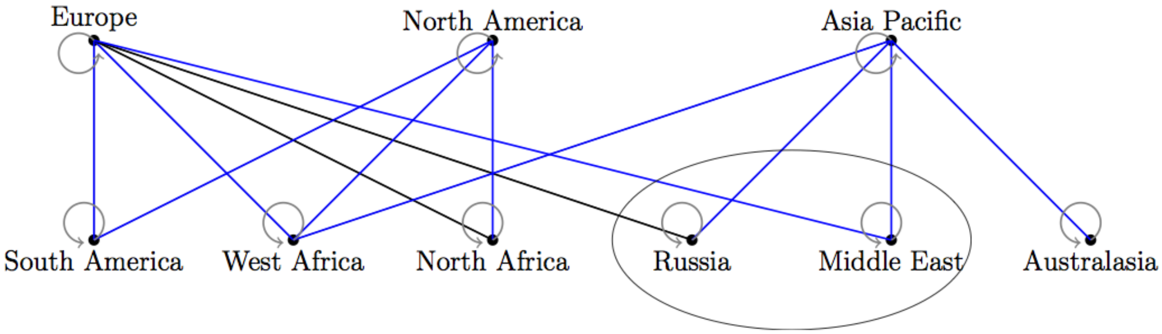
[44] Among the dominant producers, only South America increases its exports to North America.

[45] For any intercept that is higher than 50, North America does not export even though its supply curve is flat.

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

The graph of this new network is:

Figure 3: Schematic representation after Russia and the Middle East merger



We optimize the new potential function subject to supply constraints. The 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 from Russia and the Middle East to Europe decreases to 187.8 Bcm whereas the pre-merger total supply of Russia and the Middle East to Europe was 206.69 Bcm. Similarly, the equilibrium supply to the Asia Pacific from the Middle East is 50.18 Bcm after the merger, whereas the pre-merger total supply of Russia and the Middle East together was 53.39 Bcm. In response, 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 supply to North America from 3.1 Bcm to zero and decreases supply to the Asia Pacific from 6.59 Bcm to 6.41 Bcm, but increases supply to Europe from 10.07 Bcm to 14.1 Bcm. Australasia also increases supply to the Asia Pacific by 1 Bcm. The equilibrium price in each region increases due to the decline in equilibrium supply. For instance, the equilibrium price in Europe increases by 4.88 million USD per Bcm due to a 6.9 Bcm decline in total supply. The joint profit of Russia and the Middle East increases by 1.5 billion USD.

If we allow in addition for a flat North American supply curve, then North America becomes a net exporter and exports 23.3 Bcm of natural gas to Europe and 18.1 Bcm of natural gas to the Asia Pacific. Under this scenario, the equilibrium supply of Russia and the Middle East to Europe decreases to 181.2 Bcm and to the Asia Pacific decreases to 44.84 Bcm. With a flat North American supply curve, equilibrium total supply to each region increases, which decreases the equilibrium prices.

The joint profit of Russia and the Middle East increases by 1.5 billion USD compared to no merger scenario. However, with a flat North American supply curve the joint profit of merged pair is 0.08 billion USD less than the reference case[47] (no shale and no collusion)

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[47] This is because of the lower natural gas prices (compared to no exports from North America) in the

but 0.06 billion USD more than scenario where there is flat North American supply curve and no collusion.

4.3.1 Further analysis on Scenario III

In this section, first we shift the North American supply curve upward and keep its slope constant, and then decrease its slope.

If the intercept of North American supply curve increases to 5, then the equilibrium exports to North America increase by 2.85 Bcm, [48] and the equilibrium price in North America increases by 1.35 million USD per Bcm compared to the case where Russia and the Middle East merge. With this change, equilibrium prices in Europe and the Asia Pacific increase as well.

Next, we assume a flat North American supply curve with an intercept of 20.[49] Under this scenario, North America becomes a net exporter and it exports 0.28 Bcm to the Asia Pacific. In response to a flat North American supply curve with an intercept of 20, all dominant producers shift their supply from North America to Europe and the Asia Pacific. For instance, South America increases supply to Europe from 7.6 Bcm to 13.75 Bcm. In the new equilibrium, prices in Europe decrease by 1.24 million USD per Bcm and decrease in the Asia Pacific by 0.75 million USD per Bcm (compared to the scenario with a merger only).

5 Conclusions

This paper presented a network model of the world natural gas market which consists of consumers, competitive fringe producers, dominant producers and links connecting them. To better mimic the world natural gas market, we represented it under a mixed oligopoly competitive assumption where the North American market is perfectly competitive while the rest of the world consists of oligopolistic and monopolistic markets. We showed that such a noncooperative game has a unique Cournot-Nash equilibrium. We calibrated the model parameters by using production, consumption, price, proved reserves and trade flow data in 2009. This allowed us to quantify the strategic interactions among natural gas producers.

Our scenario analysis focused on the impacts of natural gas exports from North America on domestic and foreign natural gas prices. We find that equilibrium natural gas exports from North America depend on the elasticities of domestic and foreign supplies, the elasticities of domestic and foreign demands, the number of dominant producers that

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Asia Pacific and Europe as a result of exports from North America.

[48] The equilibrium export from South America to North America increases by 1.35 Bcm, from West Africa to North America it increases by 0.32 Bcm and from North Africa to North America it increases by 1.18 Bcm.

[49] For any intercept that is higher than 20, North America does not export even when its supply curve is flat. However, it imports when the intercept is 150. More specifically, it imports 3.69 Bcm from South America and 0.69 Bcm from North Africa.

the North American exporter faces in each market and these dominant producers' short run supply capacities. Based on our numerical results, North America exports natural gas when its supply curve is highly elastic and the domestic price impact of its export is very small. Even so, the price impacts on the markets it is exporting to are substantial. We also find that shale gas development in North America decreases dominant producers' market power elsewhere in the world and hence decreases the incentive to form a cartel.

A Appendix

A.1 Proof of Theorem 1

Since there is a single price for natural gas in each market, the market with competitive fringe does not export and import. Therefore, there will be some links that become offline when some others are online and vice versa. Therefore, the potential function defined in (13) represents a network graph with links that work in the opposite direction.

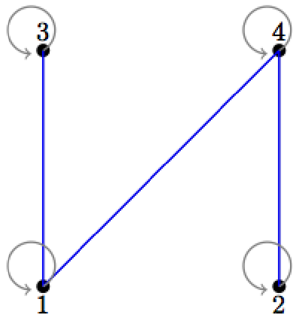
Let $Z(Q^\star_g) = \{z \in \mathbb{N}_+ : z = \rho(i,j) \text{ for some } (i,j) \text{ such that } q^\star_{ij} = 0\}$.[50] Let $|Z(Q^\star_g)| = t^\star$, then $Q^\star_{g-Z(Q^\star_g)}$ is vector of size $r(g) - t^\star$ obtained from $Q^\star_g$ by deleting the zero entries (where $r(g)$ is the size of $Q^\star_g$). It is the vector of equilibrium quantities for links over which there is strictly positive flow from a firm to a market.

Let $Q^\star_g$ be the equilibrium of the Cournot game at network g. We denote by $g - Z(Q^\star_g$ the network obtained from g by deleting the links which have zero flows at $Q^\star_g$.

Theorem 2 in Ilkilic (2012): Given two networks g and g'. Let $Q^\star_g$ and $Q^\star_{g'}$ be the equilibrium of Cournot game in g and g', respectively. If $g - Z(Q^\star_g) = g' - Z(Q^\star_{g'})$, then $Q^\star_{g-Z(Q^\star_g)} = Q^\star_{g'-Z(Q^\star_{g'})}$.

For instance, let the network graph g be:

Graph g:



and the flow vector of graph g is $Q_g = \begin{bmatrix} q_{11} & q_{31} & q_{41} & q_{22} & q_{42} & q_{33} & q_{44} \end{bmatrix}$. Suppose that in the equilibrium link from firm 2 to market 4 carries zero flows. Therefore, the equilibrium flow vector is $Q^\star_g = \begin{bmatrix} q^\star_{11} & q^\star_{31} & q^\star_{41} & q^\star_{22} & q^\star_{33} & q^\star_{44} \end{bmatrix}$.

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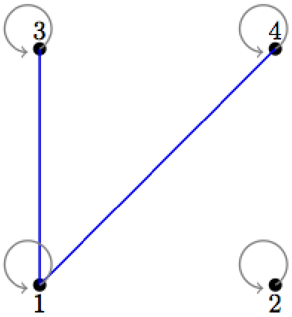
[50] Note that the notation of labeling links is introduced in the proof of Theorem 1 in (**??**).

According to Theorem 2 in Ilkilic (2010) solving the equilibrium of network graph g' and g are the same, where g' is

Graph g':



Now, we go back to our optimization problem defined in (13).

- If $q^{\star}_{ie} > 0$ for any $i \in M \setminus \{d_e\}$ means that the exporter f_e is exporting, $\implies q^{\star}_{ej} = 0$ for all $j \in F \setminus \{f_e\}$. As a result (13) becomes

$$\begin{aligned} P^{\star}(\tilde{Q}_g) = & \sum_{d_i \in N_g(f_j) \setminus d_e} \alpha_i \left(\sum_{f_j \in N_g(d_i)} q_{ij} \right) - \sum_{d_i \in N_g(f_j) \setminus d_e} \beta_i \left(\sum_{f_j \in N_g(d_i)} q_{ij}^2 \right) \\ & - \sum_{d_i \in N_g(f_j) \setminus d_e} \beta_i \left(\sum_{1 \le j < k \le n} q_{ij} q_{ik} \right) - \sum_{d_i \in N_g(f_j) \setminus d_j} \sum_{f_j \in N_g(d_i)} \tau_{ij} q_{ij} \\ & - \frac{\beta_e \gamma_e}{\gamma_e + \beta_e} \left(\sum_{d_i \in N_g(f_e) \setminus d_e} q_{ie} \right)^2 - \frac{\alpha_e \gamma_e}{\gamma_e + \beta_e} \sum_{d_i \in N_g(f_e) \setminus d_e} q_{ie} \\ & - \sum_{f_j \in N_g(d_i) \setminus f_e} \frac{\gamma_j}{2} \left(\sum_{d_i \in N_g(f_j)} q_{ij} \right)^2 \end{aligned} \tag{22}$$

  Following the proof of Theorem 1 in Cigerli (2013), one can show that (22) is strictly concave (or $(-1) \times$ (22) is strictly convex)[51] and the constraints are linear.

- If $q^{\star}_{ej} > 0$ for any $j \in F \setminus \{f_e\}$ means that the market d_e is importing, $\implies q^{\star}_{ie} = 0$

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[51] *Corollary 2.8* in Zhu (2008) shows that every strictly convex potential game with convex constraints admits a unique equilibrium.

for all $i \in M \setminus \{d_e\}$. Then (13) becomes

$$\begin{aligned}
P^{\star}(Q_g) = & \sum_{d_i \in N_g(f_j) \setminus d_e} \alpha_i \left(\sum_{f_j \in N_g(d_i) \setminus f_e} q_{ij} \right) - \sum_{d_i \in N_g(f_j) \setminus d_e} \beta_i \left(\sum_{f_j \in N_g(d_i) \setminus f_e} q_{ij}^2 \right) \\
& - \sum_{d_i \in N_g(f_j) \setminus d_e} \beta_i \left(\sum_{1 \leq j < k \leq n} q_{ij} q_{ik} \right) - \sum_{d_i \in N_g(f_j) \setminus d_j} \sum_{f_j \in N_g(d_i) \setminus f_e} \tau_{ij} q_{ij} \\
& - \frac{\beta_e \gamma_e}{\gamma_e + \beta_e} \left(\sum_{1 \leq j < k \leq n} q_{ej} q_{ek} \right) + \frac{\alpha_e \gamma_e}{\gamma_e + \beta_e} \left(\sum_{f_j \in N_g(d_e) \setminus f_e} q_{ej} \right) \\
& - \frac{\beta_e \gamma_e}{\gamma_e + \beta_e} \left(\sum_{f_j \in N_g(d_e) \setminus f_e} q_{ej}^2 \right) - \sum_{f_j \in N_g(d_i) \setminus f_e} \frac{\gamma_j}{2} \left(\sum_{d_i \in N_g(f_j)} q_{ij} \right)^2 \qquad (23)
\end{aligned}$$

Following the proof of Theorem 1 in Cigerli (2013), one can show that (23) is strictly concave and the constraints are linear.

A.2 Calibration

We calibrate the model parameters by using production, consumption, price, proved reserves and trade flow data in 2009. We obtain data from BP's Statistical Review of World Energy 2010, EIA and various country websites. In this section, we provide the list of equations that we use in calibration.

The first order conditions of the objective functions of dominant producers' and fringe producers:
Europe:

$$q_{11}: \ \alpha_1 - 2\beta_1 q_{11} - \beta_1(q_{12} + q_{14} + q_{15} + q_{16} + q_{17} + q_{18} + q_{19}) - \gamma_1 q_{11} - \mu_{11} - \lambda_1 = 0$$

North American fringe producers:

$$q_{22}: \ p_2 - \gamma_2 q_{22} = 0$$

North American exporter:

$$\begin{aligned}
q_{12}: \ & \alpha_1 - 2\beta_1 q_{12} - \beta_1(q_{11} + q_{14} + q_{15} + q_{16} + q_{17} + q_{18} + q_{19}) - \tau_{12} - 2\tilde{\beta}_2(q_{12} + q_{32}) - \tilde{\alpha}_2 \\
& + \tilde{\beta}_2(q_{24} + q_{25} + q_{26} + q_{27} + q_{28} + q_{29}) = 0
\end{aligned}$$

$$\begin{aligned}
q_{32}: \ & \alpha_3 - 2\beta_3 q_{32} - \beta_3(q_{33} + q_{34} + q_{35} + q_{36} + q_{37} + q_{38} + q_{39}) - \tau_{32} - 2\tilde{\beta}_2(q_{12} + q_{32}) - \tilde{\alpha}_2 \\
& + \tilde{\beta}_2(q_{24} + q_{25} + q_{26} + q_{27} + q_{28} + q_{29}) = 0
\end{aligned}$$

Asia Pacific:

$$q_{33}: \quad \alpha_3 - 2\beta_3 q_{33} - \beta_3(q_{32} + q_{34} + q_{35} + q_{36} + q_{37} + q_{38} + q_{39}) - \gamma_3 q_{33} - \mu_{33} - \lambda_3 = 0$$

South America:

$$q_{14}: \quad \alpha_1 - 2\beta_1 q_{14} - \beta_1(q_{11} + q_{12} + q_{15} + q_{16} + q_{17} + q_{18} + q_{19}) - \gamma_4(q_{14} + q_{24} + q_{34} + q_{44}) - \tau_{14} - \mu_{14} - \lambda_4 = 0$$

$$q_{24}: \quad \tilde{\alpha}_2 - 2\tilde{\beta}_2 q_{24} - \tilde{\beta}_2(q_{25} + q_{26} + q_{26} + q_{27} + q_{28} + q_{29} - q_{12} - q_{32}) - \gamma_4(q_{14} + q_{24} + q_{34} + q_{44}) - \tau_{24} - \mu_{24} - \lambda_4 = 0$$

$$q_{34}: \quad \alpha_3 - 2\beta_3 q_{34} - \beta_3(q_{32} + q_{33} + q_{35} + q_{36} + q_{37} + q_{38} + q_{39}) - \gamma_4(q_{14} + q_{24} + q_{34} + q_{44}) - \tau_{34} - \mu_{34} - \lambda_4 = 0$$

$$q_{44}: \quad \alpha_4 - 2\beta_4 q_{44} - \gamma_4(q_{14} + q_{24} + q_{34} + q_{44}) - \mu_{44} - \lambda_4 = 0$$

West Africa:

$$q_{15}: \quad \alpha_1 - 2\beta_1 q_{15} - \beta_1(q_{11} + q_{12} + q_{14} + q_{16} + q_{17} + q_{18}) - \gamma_5(q_{15} + q_{25} + q_{35} + q_{55}) - \tau_{15} - \mu_{15} - \lambda_5 = 0$$

$$q_{25}: \quad \tilde{\alpha}_2 - 2\tilde{\beta}_2 q_{25} - \tilde{\beta}_2(q_{24} + q_{26} + q_{27} + q_{28} + q_{29} - q_{12} - q_{32}) - \gamma_5(q_{15} + q_{25} + q_{35} + q_{55}) - \tau_{25} - \mu_{25} - \lambda_5 = 0$$

$$q_{35}: \quad \alpha_3 - 2\beta_3 q_{35} - \beta_3(q_{32} + q_{33} + q_{36} + q_{37} + q_{38} + q_{39}) - \gamma_5(q_{15} + q_{25} + q_{35} + q_{55}) - \tau_{35} - \mu_{35} - \lambda_5 = 0$$

$$q_{55}: \quad \alpha_5 - 2\beta_5 q_{55} - \gamma_5(q_{15} + q_{25} + q_{35} + q_{55}) - \mu_{55} - \lambda_5 = 0$$

North Africa:

$$q_{16}: \quad \alpha_1 - 2\beta_1 q_{16} - \beta_1(q_{11} + q_{12} + q_{14} + q_{15} + q_{17} + q_{18} + q_{19}) - \gamma_6(q_{16} + q_{26} + q_{36} + q_{66}) - \tau_{16} - \mu_{16} - \lambda_6 = 0$$

$$q_{26}: \quad \tilde{\alpha}_2 - 2\tilde{\beta}_2 q_{26} - \tilde{\beta}_2(q_{24} + q_{25} + q_{27} + q_{28} + q_{29} - q_{12} - q_{32}) - \gamma_6(q_{16} + q_{26} + q_{36} + q_{66}) - \tau_{26} - \mu_{26} - \lambda_6 = 0$$

$$q_{36}: \quad \alpha_3 - 2\beta_3 q_{36} - \beta_3(q_{32} + q_{33} + q_{34} + q_{35} + q_{37} + q_{38} + q_{39}) - \gamma_6(q_{16} + q_{26} + q_{36} + q_{66}) - \tau_{36} - \mu_{36} - \lambda_6 = 0$$

$$q_{66}: \quad \alpha_6 - 2\beta_6 q_{66} - \gamma_6(q_{16} + q_{26} + q_{36} + q_{66}) - \mu_{66} - \lambda_6 = 0$$

Russia:

$$q_{17}: \quad \alpha_1 - 2\beta_1 q_{17} - \beta_1(q_{11} + q_{12} + q_{14} + q_{15} + q_{16} + q_{18} + q_{19}) - \gamma_7(q_{17} + q_{27} + q_{37} + q_{77}) - \tau_{17} - - \mu_{17} - \lambda_7 = 0$$

$$q_{27}: \quad \tilde{\alpha}_2 - 2\tilde{\beta}_2 q_{27} - \tilde{\beta}_2(q_{24} + q_{25} + q_{26} + q_{28} + q_{29} - q_{12} - q_{32}) - \gamma_7(q_{17} + q_{27} + q_{37} + q_{77}) - \tau_{27} - \mu_{27} - \lambda_7 = 0$$

$$q_{37}: \quad \alpha_3 - 2\beta_3 q_{37} - \beta_3(q_{32} + q_{33} + q_{34} + q_{35} + q_{36} + q_{38} + q_{39}) - \gamma_7(q_{17} + q_{27} + q_{37} + q_{77}) - \tau_{37} - \mu_{37} - \lambda_7 = 0$$

$$q_{77}: \quad \alpha_7 - 2\beta_7 q_{77} - \gamma_7(q_{17} + q_{27} + q_{37} + q_{77}) - \mu_{77} - \lambda_7 = 0$$

Middle East:

$$q_{18}: \quad \alpha_1 - 2\beta_1 q_{18} - \beta_1(q_{11} + q_{12} + q_{14} + q_{15} + q_{16} + q_{17} + q_{19}) - \gamma_8(q_{18} + q_{28} + q_{38} + q_{88}) - \tau_{18} - \mu_{18} - \lambda_8 = 0$$

$$q_{28}: \quad \tilde{\alpha}_2 - 2\tilde{\beta}_2 q_{28} - \tilde{\beta}_2(q_{24} + q_{25} + q_{26} + q_{27} + q_{29} - q_{12} - q_{32}) - \gamma_8(q_{18} + q_{28} + q_{38} + q_{88}) - \tau_{28} - \mu_{28} - \lambda_8 = 0$$

$$q_{38}: \quad \alpha_3 - 2\beta_3 q_{38} - \beta_3(q_{32} + q_{33} + q_{34} + q_{35} + q_{36} + q_{37} + q_{39}) - \gamma_8(q_{18} + q_{28} + q_{38} + q_{88}) - \tau_{38} - \mu_{38} - \lambda_8 = 0$$

$$q_{88}: \quad \alpha_8 - 2\beta_8 q_{88} - \gamma_8(q_{18} + q_{28} + q_{38} + q_{88}) - \mu_{88} - \lambda_8 = 0$$

Australasia:

$$q_{19}:\ \ \alpha_1 - 2\beta_1 q_{19} - \beta_1(q_{11}+q_{12}+q_{14}+q_{15}+q_{16}+q_{17}+q_{18}) - \gamma_9(q_{19}+q_{29}+q_{39}+q_{99}) - \tau_{19} - \mu_{19} - \lambda_9 = 0$$

$$q_{29}:\ \ \tilde{\alpha}_2 - 2\tilde{\beta}_2 q_{29} - \tilde{\beta}_2(q_{24}+q_{25}+q_{26}+q_{27}+q_{28}-q_{12}-q_{32}) - \gamma_9(q_{19}+q_{29}+q_{39}+q_{99}) - \tau_{29} - \mu_{29} - \lambda_9 = 0$$

$$q_{39}:\ \ \alpha_3 - 2\beta_3 q_{39} - \beta_3(q_{32}+q_{33}+q_{34}+q_{35}+q_{36}+q_{37}+q_{38}) - \gamma_9(q_{19}+q_{29}+q_{39}+q_{99}) - \tau_{39} - \mu_{39} - \lambda_9 = 0$$

$$q_{99}:\ \ \alpha_9 - 2\beta_9 q_{99} - \gamma_9(q_{19}+q_{29}+q_{39}+q_{99}) - \mu_{99} - \lambda_9 = 0$$

Price in Europe:

$$p_1 = \alpha_1 - \beta_1(q_{11}+q_{12}+q_{14}+q_{15}+q_{16}+q_{17}+q_{18}+q_{19})$$

Price in North America:

$$p_2 = \tilde{\alpha}_2 - \tilde{\beta}_2(q_{24}+q_{25}+q_{26}+q_{27}+q_{28}+q_{29}-q_{12}-q_{32})$$

Price in Asia Pacific:

$$p_3 = \alpha_3 - \beta_3(q_{32}+q_{33}+q_{34}+q_{35}+q_{36}+q_{37}+q_{38}+q_{39})$$

Price in South America:

$$p_4 = \alpha_4 - \beta_4 q_{44}$$

Price in West Africa:

$$p_5 = \alpha_5 - \beta_5 q_{55}$$

Price in North Africa:

$$p_6 = \alpha_6 - \beta_6 q_{66}$$

Price in Russia:

$$p_7 = \alpha_7 - \beta_7 q_{77}$$

Price in Middle East:

$$p_8 = \alpha_8 - \beta_8 q_{88}$$

Price in Australasia:

$$p_9 = \alpha_9 - \beta_9 q_{99}$$

In 2009, links from North America to Europe, q_{12}, from North America to the Asia Pacific, q_{32}, from South America to the Asia Pacific, q_{34}, from North Africa to the Asia Pacific, q_{36}, from Russia to North America, q_{27}, from the Middle East to North America, q_{28}, from Australasia to Europe, q_{19}, and from Australasia to the Asia Pacific, q_{29}, carried zero flows. Therefore, we do not have any observation to calibrate parameters in the first order conditions of these links. To get the marginal costs of these links, τ_{ij}'s, we used the marginal costs of the links that have (approximately) the same LNG distance.[52] For

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[52] Marginal costs of these links are $\tau_{12} = 280$, $\tau_{32} = 300$, $\tau_{34} = 340$, $\tau_{36} = 320$, $\tau_{27} = 340$, $\tau_{28} = 320$, $\tau_{19} = 320$, $\tau_{29} = 340$.

instance, we use the calibrated value of τ_{15}, from West Africa to Europe to approximate for the marginal cost of exporting natural gas from North America to Europe.

We get the equilibrium fringe supply in North America as $q_{22} = \frac{p_2}{\gamma_2}$. According to BP's Statistical Review of World Energy 2010, North America supplied 813 Bcm of natural gas to its domestic market at a price of 150 million USD per bcm. By substituting these values into North America's first order condition we get $\gamma_2 = 0.1845$. Next, we define γ_2 as a proportion of proved reserves. In effect, we assume that higher proved reserves[53] indicate lower costs of production. We assume that this proportion holds for each producer hence we define each producer's γ which is the slope of their supply curves in terms of γ_2, the slope of North America's supply curve.

To identify the model parameters uniquely, we assume that North America and Europe have the same choke price. A justification for the assumption is that, North America and Europe have similar technologies for using natural gas.

A.3 Scenario I.a: Change in North America's elasticity of domestic supply

In this section,[54] we analyze the impacts of shale gas developments in North America in the world natural gas market. Unlike the LNG cost parameters that we used in our scenario analysis in (4.1), we use the LNG cost parameters in Medlock (2012) and NERA (2012).[55] According to the Table 1 of Medlock (2012), liquefaction cost of 1 mcf (thousand cubic feet) of natural gas in the U.S. is 2.92 USD and the transport cost to United Kingdom is 1.07 USD per mcf and to Japan is 2.15 USD per mcf. For regasification costs, we use the numbers in Figure 58 of NERA (2012). For this analysis, we set the marginal cost of exporting natural gas from North America to Europe to 170 million USD per Bcm and to the Asia Pacific to 210 million USD per Bcm.

In our first experiment, we decreased the slope of North American supply curve by 15 percent. The price in North America decreases from 150 million USD per Bcm to 140.08 million USD per Bcm, and the consumption in North America increases from 828 Bcm to 843.35 Bcm, and its natural gas imports are zero.

Dominant producers which exported to North America in 2009, namely South America, West Africa and North Africa, shift their supply to Europe, the Asia Pacific and their domestic markets. For instance, South America increases its supply to Europe from 7.6 Bcm to 9.2 Bcm, while North Africa increases its supply to Europe from 67.2 Bcm to 67.75 Bcm. As a result, there will be more competition in the European and Asia Pacific markets for Russia, the Middle East and Australasia. In response, they decrease their their supply to Europe and the Asia Pacific. For example, Russia's supply to Europe

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[53] We obtain data from BP's Statistical Review of World Energy 2010.

[54] Equilibrium trade flows under this scenario are provided in Table (5).

[55] In 2009, the links from North America to Europe, q_{12}, from North America to the Asia Pacific, q_{32} carried zero flows. Therefore, we do not have any observation to calibrate parameters in the first order conditions of these links. As an experiment, we also use the LNG cost parameters in other studies.

decreases by 0.56 Bcm and its supply to the Asia Pacific decreases by 0.04 Bcm.

A 15 percent decrease in the slope of North American supply curve is not sufficient for the North American exporter to export natural gas to Europe and/or the Asia Pacific. If we decrease the slope of North American supply curve by 20 percent, then North America exports 2.08 Bcm of natural gas to Europe. With these exports, there will be more competition for all dominant producers in the European market. To prevent a further decline in equilibrium prices, the dominant producers decrease supply to Europe. Under this scenario, equilibrium total supply to Europe increases from 580.3 Bcm to 581 Bcm, which decreases the equilibrium price from 300 million USD per Bcm to 299.25 million USD per Bcm.

All else constant, North America starts exporting when the slope of its supply curve is 20 percent less than that of 2009.

On the other hand, North America stops importing natural gas if we decrease the slope of North American supply curve by more than just 4 percent. With the 4 percent decline in the slope of its supply curve, it imports 0.5 Bcm of natural gas from South America.

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Table 1: Network parameters

	Parameter	Value
Intercept of European inverse demand curve:	α_1	711.55
Intercept of North American inverse demand curve:	α_2	711.55
Intercept of residual inverse demand in North America:	$\tilde{\alpha}_2$	152.27
Intercept of Asia Pacific's inverse demand curve:	α_3	691.6
Intercept of South America's inverse demand curve:	α_4	223.2
Intercept of West Africa's inverse demand curve:	α_5	211.4
Intercept of North Africa's inverse demand curve:	α_6	168.5
Intercept of Russian inverse demand curve:	α_7	105.02
Intercept of Middle East's inverse demand curve:	α_8	189.92
Intercept of Australasian inverse demand curve:	α_9	200.47
Slope of European inverse demand curve:	β_1	0.71
Slope of North American inverse demand curve:	β_2	0.67
Slope of residual inverse demand in North America:	$\tilde{\beta}_2$	0.145
Slope of Asia Pacific's inverse demand curve:	β_3	0.94
Slope of South America's inverse demand curve:	β_4	0.69
Slope of West Africa's inverse demand curve:	β_5	10.06
Slope of North Africa's inverse demand curve:	β_6	0.98
Slope of Russian inverse demand curve:	β_7	0.082
Slope of Middle East's inverse demand curve:	β_8	0.26
Slope of Australasian inverse demand curve:	β_9	0.72
Slope of European cost curve:	γ_1	0.332
Slope of North American cost curve:	γ_2	0.184
Slope of Asia Pacific's cost curve:	γ_3	0.358
Slope of South America's cost curve:	γ_4	0.245
Slope of West Africa's cost curve:	γ_5	0.281
Slope of North Africa's cost curve:	γ_6	0.223
Slope of Russian cost curve:	γ_7	0.037
Slope of Middle East's cost curve:	γ_8	0.024
Slope of Australasian cost curve:	γ_9	0.198
Marginal cost of exporting from South America to Europe:	τ_{14}	257.29
Marginal cost of exporting from South America to North America:	τ_{24}	111.58
Marginal cost of exporting from West Africa to Europe:	τ_{15}	283.84
Marginal cost of exporting from West Africa to North America:	τ_{25}	140.98
Marginal cost of exporting from West Africa to Asia Pacific:	τ_{35}	305.2
Marginal cost of exporting from North Africa to Europe:	τ_{16}	220.84
Marginal cost of exporting from North Africa to North America:	τ_{26}	117.77
Marginal cost of exporting from Russia to Europe:	τ_{17}	146.17
Marginal cost of exporting from Russia to Asia Pacific:	τ_{37}	288.74
Marginal cost of exporting from Middle East to Europe:	τ_{18}	271.77
Marginal cost of exporting from Middle East to Asia Pacific:	τ_{38}	265.44
Marginal cost of exporting from Australasia to Asia Pacific:	τ_{39}	197.26

Table 2: Equilibrium trade flows (in Bcm) in Scenario I

Route	2009	Decrease γ_2 by 40%	Flat North American supply curve	Decrease γ_2 by 4%	Decrease γ_2 by 90%
From Europe to Europe	288.10	287.63	285.20	287.63	287.53
From North America to Europe	0.00	0.00	19.71	0.00	0.70
From North America to Asia Pacific	0.00	0.00	17.58	0.00	0.83
From Asia Pacific To Asia Pacific	246.09	245.98	243.45	245.98	245.86
From South America to Europe	7.60	9.26	6.51	9.16	9.15
From South America to North America	7.60	0.00	0.00	0.47	0.00
From South America to Asia Pacific	0.00	0.00	0.00	0.00	0.00
From South America to South America	134.70	135.91	136.33	135.85	135.92
From West Africa to Europe	10.70	10.91	8.99	10.92	10.84
From West Africa to North America	3.09	0.00	0.00	0.00	0.00
From West Africa to Asia Pacific	6.60	7.15	4.89	7.14	7.03
From West Africa to West Africa	10.08	10.11	10.17	10.11	10.11
From North Africa to Europe	67.20	67.76	64.98	67.77	67.65
From North Africa to North America	5.00	0.00	0.00	0.00	0.00
From North Africa to Asia Pacific	0.00	0.00	0.00	0.00	0.00
From North Africa to North Africa	69.20	69.65	69.93	69.64	69.66
From Russia to Europe	181.10	180.54	177.60	180.55	180.45
From Russia to North America	0.00	0.00	0.00	0.00	0.00
From Russia to Asia Pacific	6.20	6.16	3.14	6.16	6.03
From Russia to Russia	485.49	486.10	488.78	486.08	486.31
From Middle East to Europe	25.59	24.91	21.57	24.92	24.78
From Middle East to North America	0.00	0.00	0.00	0.00	0.00
From Middle East to Asia Pacific	47.19	47.06	43.74	47.06	46.90
From Middle East to Middle East	345.58	345.61	345.91	345.61	354.62
From Australasia to Europe	0.00	0.00	0.00	0.00	0.00
From Australasia to North America	0.00	0.00	0.00	0.00	0.00
From Australasia to Asia Pacific	88.30	88.18	85.24	88.18	88.04
From Australasia to Australasia	110.80	110.82	111.17	110.81	110.83

Table 3: Equilibrium trade flows (in Bcm) in Scenario II

Route	2009	Decrease γ_2 by 40%	Decrease γ_2 by 75 % w/ exports	Decrease γ_2 by 75% w/o exports	Flat North American supply curve
From Europe to Europe	288.10	288.10	288.10	288.10	287.07
From North America to Europe	0.00	0.00	0.00	0.00	22.45
From North America to Asia Pacific	0.00	0.00	3.75	0.00	39.96
From Asia Pacific To Asia Pacific	246.09	246.10	246.10	246.10	246.10
From South America to Europe	7.60	14.26	14.12	14.26	8.62
From South America to North America	7.60	0.00	0.00	0.00	0.00
From South America to Asia Pacific	0.00	0.00	0.00	0.00	0.00
From South America to South America	134.70	135.16	135.18	135.16	136.01
From West Africa to Europe	10.70	0.00	0.00	0.00	1.27
From West Africa to North America	3.09	0.00	0.00	0.00	0.00
From West Africa to Asia Pacific	6.60	21.22	21.17	21.22	19.41
From West Africa to West Africa	10.08	9.26	9.31	9.26	9.80
From North Africa to Europe	67.20	72.40	72.36	72.40	67.12
From North Africa to North America	5.00	0.00	0.00	0.00	0.00
From North Africa to Asia Pacific	0.00	0.00	0.00	0.00	0.00
From North Africa to North Africa	69.20	69.00	69.04	69.00	69.72
From Russia to Europe	181.10	180.61	180.67	180.61	176.74
From Russia to North America	0.00	0.00	0.00	0.00	0.00
From Russia to Asia Pacific	6.20	33.72	32.66	33.72	22.82
From Russia to Russia	485.49	458.47	459.47	458.47	473.24
From Middle East to Europe	25.59	19.17	19.45	19.17	18.55
From Middle East to North America	0.00	0.00	0.00	0.00	0.00
From Middle East to Asia Pacific	47.19	70.25	69.35	70.25	61.79
From Middle East to Middle East	345.58	328.98	329.60	328.98	338.06
From Australasia to Europe	0.00	0.00	0.00	0.00	0.00
From Australasia to North America	0.00	0.00	0.00	0.00	0.00
From Australasia to Asia Pacific	88.30	100.98	100.49	100.98	95.68
From Australasia to Australasia	110.80	98.12	98.61	98.12	103.42

Table 4: Equilibrium trade flows (in Bcm) in Scenario III

Route	2009	Russia and Middle East merger, without shale	Russia and Middle East merger, with shale
From Europe to Europe	288.10	288.10	287.67
From North America to Europe	0.00	0.00	23.33
From North America to Asia Pacific	0.00	0.00	18.19
From Asia Pacific To Asia Pacific	246.09	246.10	243.89
From South America to Europe	7.60	11.92	9.31
From South America to North America	7.60	4.58	0.00
From South America to Asia Pacific	0.00	0.00	0.00
From South America to South America	134.70	133.39	135.91
From West Africa to Europe	10.70	14.10	11.63
From West Africa to North America	3.09	0.00	0.00
From West Africa to Asia Pacific	6.60	6.42	4.75
From West Africa to West Africa	10.08	9.96	10.14
From North Africa to Europe	67.20	71.46	67.81
From North Africa to North America	5.00	1.68	0.00
From North Africa to Asia Pacific	0.00	0.00	0.00
From North Africa to North Africa	69.20	68.26	69.65
From Russia to Europe	181.10	187.85	181.20
From Russia to North America	0.00	0.00	0.00
From Russia to Asia Pacific	6.20	0.00	0.00
From Russia to Russia	485.49	484.95	488.69
From Middle East to Europe	25.59	0.00	0.00
From Middle East to North America	0.00	0.00	0.00
From Middle East to Asia Pacific	47.19	50.18	44.84
From Middle East to Middle East	345.58	346.58	346.81
From Australasia to Europe	0.00	0.00	0.00
From Australasia to North America	0.00	0.00	0.00
From Australasia to Asia Pacific	88.30	89.26	85.75
From Australasia to Australasia	110.80	109.84	111.11

Table 5: Equilibrium trade flows (in Bcm) in Scenario I.a

Route	2009	Decrease γ_2 by 20 %	Decrease γ_2 by 15 %	Decrease γ_2 by 4 %
From Europe to Europe	288.10	287.38	287.63	287.64
From North America to Europe	0.00	2.08	0.00	0.00
From North America to Asia Pacific	0.00	0.00	0.00	0.00
From Asia Pacific To Asia Pacific	246.09	245.97	245.98	245.98
From South America to Europe	7.60	8.98	9.26	9.16
From South America to North America	7.60	0.00	0.00	0.50
From South America to Asia Pacific	0.00	0.00	0.00	0.00
From South America to South America	134.70	135.96	135.91	135.85
From West Africa to Europe	10.70	10.64	10.91	10.93
From West Africa to North America	3.10	0.00	0.00	0.00
From West Africa to Asia Pacific	6.60	7.19	7.15	7.14
From West Africa to West Africa	10.08	10.12	10.11	10.11
From North Africa to Europe	67.20	67.48	67.76	67.78
From North Africa to North America	5.00	0.00	0.00	0.00
From North Africa to Asia Pacific	0.00	0.00	0.00	0.00
From North Africa to North Africa	69.20	69.68	69.65	69.65
From Russia to Europe	181.10	180.24	180.54	180.55
From Russia to North America	0.00	0.00	0.00	0.00
From Russia to Asia Pacific	6.20	6.19	6.16	6.16
From Russia to Russia	485.49	486.37	486.10	486.09
From Middle East to Europe	25.59	24.56	24.91	24.93
From Middle East to North America	0.00	0.00	0.00	0.00
From Middle East to Asia Pacific	47.19	47.05	47.06	47.07
From Middle East to Middle East	345.58	345.63	345.61	345.61
From Australasia to Europe	0.00	0.00	0.00	0.00
From Australasia to North America	0.00	0.00	0.00	0.00
From Australasia to Asia Pacific	88.30	88.17	88.18	88.18
From Australasia to Australasia	110.80	110.82	110.82	110.82