A Network Game Analysis of Strategic Interactions in the International Trade of Natural Gas

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Abstract: Natural gas is an important source of relatively low-emission and low-cost, non-nuclear, readily abundant energy, but the difficulty of storage and transportation add a geopolitically and geostrategically complex aspect to the international trade of this resource. Most of global natural gas trade is through natural gas pipelines, which is an infrastructure that is strictly specific to the transportation of natural gas, and thus the very structure of its network can dictate the strategic relationship among countries involved in its trade. This paper attempts to apply a network game model in which these pipeline networks are modeled as graphs and respective value functions, and to employ the Flexible Network Allocation Rule developed by Jackson (2005) as a solution concept to measure the relative power structure among these natural gas trading countries. The paper analyzes the case of trade between Russia, Ukraine, Belarus and Western Europe, and compares the results to existing analyses that employs a cooperative game model and the Shapley Value as the solution concept. The results provide both a player-based and link-based analysis of the value allocation.

Keywords: Natural Gas Transport, Network Game, Bargaining Power, Flexible Network, Allocation Rule

1 Introduction

Growth in Global Energy Consumption and the Importance of Natural Gas

Energy consumption in “emerged” economies such as China and India grow rapidly and other “emerging” countries follow in their footsteps. Compared to 1990 standards, global marketed energy consumption is projected to grow by over 200% by 2035, and the growth in Non-OECD Asia is forecasted at 600% (EIA 2010). Within this unprecedented growth, natural gas is gaining increased attention as a considerably “cleaner” source of energy in terms of carbon emission as compared to coal and oil, and the second largest source of energy for power generation (22% of primary energy source consumption in power generation). Given the energy security aftershocks of the Fukushima Nuclear Disaster in Japan and the shift in nuclear energy policy around the world, it would be appropriate to forecast that the importance of natural gas as an alternative source of energy will increase in the coming years.

Yet, not only is natural gas one of the most important sources of alternative energy, it is arguably one of the most geopolitical and geostrategic sources of energy due to the following two reasons: since it usually exists as a gas it is difficult to store, and its distribution is geographically uneven. In 2009, it was estimated that over 72% of global natural gas reserves were located in the Middle East and the former Soviet Union. In other words, natural gas trade required a small number of producers to constantly produce and transport natural gas across borders to consumers around the continent and around the globe.

Natural gas is transported either through extensive networks of natural gas pipelines or as liquefied natural gas (LNG), usually shipped on massive LNG tankers. Although advancement in liquefaction and gasification technology has led to fast growth in the LNG market, the predominant method of natural gas transportation is still through trans-boundary natural gas pipelines (Trade in the form of LNG accounts for roughly 30% of global natural gas trade).

One characteristic of pipelines that adds to the geopolitical complexity of natural gas trade is its high level of specificity as an infrastructure. The only type of good that natural gas pipelines can transport is obviously natural gas, and due to this specificity, classical economic issues such as the hold-up problem can occur between producers and transit countries, or producers and consumers. For example, if a natural gas producer invests in pipelines to export natural gas, the producer must collect the usually large investments through profits made in the natural gas trade. If there is only one consumer in the market, or if a strategic transit player has control over the flow of natural gas through its own territory, these countries can threaten the producer to stop the trade of natural gas, which would prevent the producer from collecting its initial costs. If the infrastructure was not specific to a single good (e.g. road), the producer can decide to trade a different type of good in order to collect the initial investment, but in the case of natural gas pipelines, such alternative trade strategies do not exist. Therefore, committing to an initial investment may weaken the investor's bargaining power and lead to the hold-up problem, in which potential investors will be hesitant to invest in the necessary infrastructure, and thus leading to underinvestment. Therefore, natural gas traders have taken various measures (*e.g.* transit fees and gas price discounts to transit countries, long-term binding contracts, international consortiums and joint investment in pipelines) in order to protect their bargaining position, evade conflict and make profit from this geopolitically complex trade.

Existing Literature

Existing work on the subject of natural gas trade include that of Jaffe and Hayes (2006), which provides an extensive overview of natural gas trade around the world, the geopolitical and strategic interaction among countries involved in natural gas trade. Shiobara (2007) introduces various analytic perspectives on the subject, such as the issue of natural monopolies that emerges from pipelines, bypassing of particular countries, the planning of pipeline routes, transit fees and account settlement, externalities generated by technological innovation, and legal restrictions that try to control the strategic aspect of natural gas trade.

This paper attempts to focus on the strategic interactions induced by the network structure of pipelines, and takes a formal approach by applying Game Theory. Existing literature from a Game Theoretic perspective include that of Ikonnikova (2006) and Hubert and Ikonnikova (2009), which employ cooperative game models to analyze the strategic interaction between Russia and transit countries such as Ukraine and Belarus.

This paper attempts to employ a similar but distinct *network game* approach based on the work by Jackson (2005) to this subject in hope of accomplishing the following:

(1) Where existing works were able to assign value only to players (i.e. countries), the network game approach will allow modeling based on the value accrued from links (i.e. pipelines), which seems more appropriate for pipelines

(2) Where existing works could not incorporate both producers (e.g. Russia) and consumers (e.g. Germany, Italy) in the model, the approach taken assigns value to the entire network of producers and consumers.

(3) Where existing works could not incorporate externalities (i.e. what happens outside of the coalition in question) and partition function form games, which are capable of addressing this issue, have computational limitations,, the approach taken in this research can assign separate values for each possible network structure in a computable manner.

2 Model

The theoretical model employed in this paper has its basis in the network games literature, with special emphasis on allocation rules that might serve as a way to measure the relative power of players (i.e. countries) involved in the trade of natural gas. As abovementioned in the introduction, this paper applies the network game model and employs the link-based flexible network allocation rule proposed by Jackson (2005) as the solution concept by which we estimate the relative power of players, and the relative value allocated to each of the links involved in the pipeline network.

In order to compare results with existing literature, the calibration follows that designed by Hubert (2009), with some modifications. In this paper, an example will be taken for one exporting player, *Russia*, two transit/import players, *Ukraine* and *Belarus*, and one importing player, *Western Europe*.

Networks

Let $N = \{1, \ldots, n\}$ denote a set of players. A network g is defined as a set of unordered pairs of players $\{i, j\}$ where $\{i, j\} \in g$ indicates that i and j are linked under the network g. For notational simplicity, let ij represent link $\{i, j\}$. The set of all unordered pairs within N is denoted by g^N, and the set of all networks on N is denoted by $G = \{g | g \subseteq g^N\}$.

Links can be either added or deleted from the network. We denote the network that results from adding a new link ij by $g + ij$, and the network that results from deleting a link ij by $g - ij$.

Value Function and Utility Function

A value function for network g is a function $v: G \to \mathbb{R}$, and the set of all possible value functions is denoted V. As noted in Jackson (2005), a value function specifies the total value generated by a given network structure, and is a richer object than a characteristic function of a cooperative game or that induced in a communication game because it allows the value that accrues to depend on the network structure and not only on the coalition of players involved. For example, in a game that involves three players $N = \{1,2,3\}$, a network game in value function form can assign different values to a network $g_1 = \{12,23,13\}$ in which a link exists between all three players, and a network $g_2 = \{12,23\}$ in which a link does not exist between players 1 and 3, but all three players are indeed involved. A cooperative game in the characteristic function form game would have assigned the same value.

This difference is critical when analyzing the strategic relationship of countries involved in natural gas trade. A model based on characteristic function form would not be able to distinguish between a pipeline network in which the *Nord Stream* pipeline directly connects *Russia* with *Western Europe*, and a network in which *Russia* and *Western Europe* are connected only through the old and problematic pipelines that pass through *Ukraine* and *Belarus*. Hubert (2009) successfully modeled various pipeline network scenarios as a cooperative game in characteristic function form by assuming that players are restricted to the role as a transit country (i.e. they are not consumers of natural gas). Hubert (2009) then defined these players' joining the coalition as either as an addition of a link to the already-existing pipeline structure or an alteration (e.g. upgrade of a pipeline) of the already-existing pipeline network structure.

Jackson (2005) also mentions that the value function may involve both costs and benefits, and thus can be interpreted flexibly. Taking advantage of this flexibility, in this paper, we define utility functions $u: G(N) \to R$ for each link ij in the network, and define the value function of a network as the sum of these utility functions.

$$v(g) = \sum_{ij} u_{ij}(g) \quad \textbf{(1)}$$

A network game is a pair (N, v), of a set of players and a value function.

Given a value function v, the monotonic cover $\hat{v}$ is defined by

$$\hat{v} = \max_{g' \in g} v(g') \quad \textbf{(2)}$$

Link-Based Flexible Network Allocation Rule

According to Jackson (2005), an allocation rule is the way in which the value generated by a network is allocated among the players, either through decisions or perhaps even by some outside intervention. An allocation rule is a function $Y: G \times V \to \mathbb{R}^n$ such that $\sum_i Y_i(g, v) = v(g)$ for all v and g.

In the network game literature, Myerson (1977) was the first to define what is now known as the Myerson Value, which is a variation of the Shapley value for communication games. Jackson (2005) criticizes the Myerson value for the following two reasons:

(1) as being insensitive to the possibility of alternative networks
(2) the notion of equal bargaining power
(3) the notion of component balance

Jackson (2005) alternatively provides two new allocation rules that are based on eliminating the notion of equal bargaining power, and replacing the notion of component balance.

The concept that Jackson (2005) introduces is the concept of *flexible* networks. An allocation rule Y is a *flexible rule* if $Y_i(g,v) = Y_i(g^N, \hat{v})$ for all v and efficient g relative to v. A network $g \in G$ is efficient relative to value function v if $v(g) \geq v(g')$ for all $g' \in G$. Thus, efficient networks are value-maximizing networks.

Jackson (2005) defines two variations of his flexible network allocation rule according to whether one assesses value on a player-by-player basis or on a link-by-link basis. Since players can presumably choose to withhold certain links and not others, the link-by-link allocation, or the *link-based flexible network allocation rule*, is considered a richer concept. Because this paper is interested in the value of links (i.e. pipelines) and the players that control these links, we employ the link-based approach.

An allocation rule Y is link-based if there exists $\psi: V \times G \to R^{n(n-1)/2}$ such that $\sum_{ij \in g^N} \psi_{ij}(g,v) = v(g)$

and

$$Y_i(g,v) = \sum_{j \neq i} \frac{\psi_{ij}(g,v)}{2}$$

Finally, the *link-based flexile allocation rule* is defined as

$$Y_i^{LBFN}(g,v) = \frac{v(g)}{\hat{v}(g^N)} \sum_{j \neq i} \left[\sum_{g \in g^N - ij} \frac{1}{2} (\hat{v}(g+ij) - \hat{v}(g)) \left(\frac{\#g!([n(n-1)/2] - \#g - 1)!}{[n(n-1)/2]!} \right) \right]. \qquad \textbf{(3)}$$

where $\#g$ denotes the number of links in g.

As in the definition of the Shapley Value for conventional cooperative games, the LBFN allocation measures the contribution of links to the overall value of the network by calculating the value accrued from adding each link, and then averaging over all permutations in which the network may be formed. The difference between the LBFN allocation rule and the Myerson value is that the Myerson value assigns value to players rather than links, and that the LBFN allocation rule depends only on the monotonic cover of the value function, implying that the allocation is "being decided upon when the network is formed or can still be changed: at a time where there is still some flexibility in the network" (Jackson 2005).

4 Calibration

As abovementioned in the introduction, one of the purposes of this paper is to apply the link-based flexible allocation rule to the case of natural gas trade in Europe, and to compare the results with existing works in order to gain insight into the appropriateness of the model. Further, we try to draw additional implications about the strategic relationship between nations involved in natural gas trade.

In order to fulfill our first motivation, which is to compare results with the Shapley value for cooperative games calculated in the existing literature (namely, Hubert , 2009), we base our calibration on that proposed by Hubert (2009) with modifications where necessary.

First, we define the set of players as $N = \{R, U, B, We\}$, using the capital initials of the countries *Russia, Ukraine, Belarus* and *Western Europe*. *Western Europe* is mainly composed of *Germany* and *Italy*, which are by far the largest importers of Russian natural gas. Combining the two countries as one strategic player *Western Europe* can be justified because membership in the European Union forbids any strategic move within the European Union that may be a hindrance to free trade and the rule of law (e.g. *Germany* refusing a contracted transit of natural gas to *Italy*).

Next, we define the status quo. In the status quo, there exist pipelines between Russia and Ukraine as well as Russia and Belarus that have existed since the Soviet Union days, and extends through these two transit countries to Western Europe. Hence, the natural gas pipeline network in the status quo is $L = \{RU, RB, UWe, BWe\}$. Using the names of pipelines from Hubert (2009), $l_{RU} + l_{UWe}$ would be *South*, and $l_{RB} + l_{BWe}$ would be *Yamal*. The capability of this model to define pipelines strictly as a link between two countries allows for additional flexibility, and thus we can define the *Nord Stream* pipeline as a direct link l_{RWe} between Russia and Western Europe.

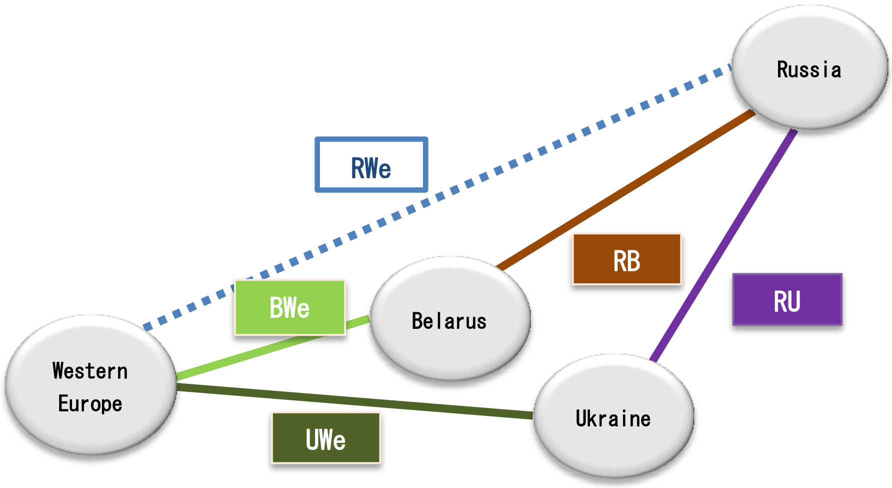

Figure 1. The Pipeline Network Structure

The existing links and the proposed link l_{RWe} are as shown above in Figure 1. As mentioned in Section 3, we will assign a utility function to each of these links, and the sum of the utility functions will be the value function of the graph. Given link ij, the utility function of the link is defined as

$$u_{ij}(\mathrm{g}) = (p - T_{ij})x_{ij} \qquad \textbf{(1)}$$

p is the price of natural gas, T_{ij} is the link-specific transportation cost per unit of gas, and x_{ij} is the quantity of natural gas exported through link ij. Hubert (2009) uses an inverse demand function for the price of Russian natural gas, but since natural gas prices are highly political and arbitrary, we will not assume that the price of natural gas will be determined according to the quantity traded in the pipeline network. In other words, we will consider price to be a dependent variable of the power structure between countries involved in natural gas trade rather than an independent variable that determines the power structure. Taking somewhat of an arbitrary average price of natural gas traded in Europe in the past several years, we will assume that the baseline for natural gas price is \$250/tcm.

The link-specific transportation cost per unit of gas T_{ij} is defined according to the calibration by Hubert (2009), but the capital cost will be treated separately.

$$T_{ij}(\mathrm{g}) = \frac{(m_{ij} + \beta_{ij} \times MC_0)(e^{\beta_{ij} \times \mu_{ij}})}{\beta_{ij}} \qquad \textbf{(2)}$$

Here, m_{ij}(\$/tcm/100km) is the management and maintenance cost, which is assumed to be proportional to the distance and quantity of natural gas transported. μ_{ij}(100km) is the length of the pipeline, β_{ij}(%/100km) is the amount of gas used to power compressor stations located along the pipeline, and $MC_0$is the marginal cost of production.

The pipeline network scenarios treated in this paper are as explained below. In the two "upgrade" scenarios, the additional capacity can be used to supply any of the consumers located along the path. For example, if *South* is upgraded by 15 bcm/year, this additional 15 bcm/year can be exported entirely to Western Europe, entirely to Ukraine, or to both consumers in any proportion. Here, we take the two extreme cases (i.e. either Western Europe or Ukraine imports the entire added capacity) because these are the scenarios that most clearly illustrate the shift in the allocation, and all hybrid cases lie in between the extreme cases.

1. Status Quo
- The status quo in which the current *South* and *Yamal* pipelines exist.

2. *South* upgrade (Western Europe buys all)
- Upgraded by 15 bcm/year, and Western Europe buys the entire amount through $l_{RU} + l_{UWe}$.

3. *South* upgrade (Ukraine buys all)
- The *South* pipeline is upgraded by 15 bcm/year, and Ukraine buys the entire amount through l_{RU}.

4. *Yamal* upgrade (Western Europe buys all)
- Upgraded by 60 bcm/year, and Western Europe buys the entire amount through $l_{RB+}l_{BWe}$.

5. *Yamal upgrade* (Belarus buys all)
- The *Yamal* pipeline is upgraded by 60 bcm/year, and Belarus buys the entire amount through l_{RB}

6. *Nord Stream*
- Between Greifswald, Germany and Vyborg, Russia. Maintenance costs higher due to the offshore nature.

Figure 2. Pipeline Network Scenarios

For each of the scenarios defined in Figure 2, we assign specific pipeline specifications as shown below. The values for maintenance fee and the amount of gas used to power compressors are taken from the calibration by Hubert (2009). The length of pipelines is roughly estimated to be divided in half along the existing pipeline paths (e.g. The *South* pipeline is divided into a 1000km pipeline between Russia and Ukraine, and a 1000km pipeline between Ukraine and Western Europe). The length of the *Nord Stream* pipeline and the quantities of gas traded through each of the links is based on the data from the Japanese Embassy in Moscow, which is mainly based on data publicized by Gazprom, Russia's state-owned gas enterprise. The rightmost column shows the change in capacity in each of the links for each scenario.

Table 1. Specifications of Pipelines

Scenario	Links Involved	Maintenance	Compressor	Length	Quantity traded	Difference
1: Status Quo	RU	0.1	0.25	10	56.2	
	RB	0.1	0.25	8	26	
	Uwe	0.1	0.25	10	140	
	Bwe	0.1	0.25	8	28	
2: South Upgrade (WE Buys All)	RU	0.1	0.25	10	56.2	0
	RB	0.1	0.25	8	26	0
	Uwe	0.1	0.25	10	155	15
	Bwe	0.1	0.25	8	28	0
3: South Upgrade (U Buys All)	RU	0.1	0.25	10	71.2	15
	RB	0.1	0.25	8	26	0
	Uwe	0.1	0.25	10	140	0
	Bwe	0.1	0.25	8	28	0
4: Yamal Upgrade (WE buys all)	RU	0.1	0.25	10	56.2	0
	RB	0.1	0.25	8	26	0
	Uwe	0.1	0.25	10	140	0
	Bwe	0.1	0.25	8	88	60
5: Yamal Upgrade (B buys all)	RU	0.1	0.25	10	56.2	0
	RB	0.1	0.25	8	86	60
	Uwe	0.1	0.25	10	140	0
	Bwe	0.1	0.25	8	28	0
6: Nord Stream	RU	0.1	0.25	10	56.2	0
	RB	0.1	0.25	8	26	0
	Uwe	0.1	0.25	10	85	(55)
	Bwe	0.1	0.25	8	28	0
	Rwe	0.2	0.5	31	55	55

5 Results

The results of the analysis using the Link-based Flexible Network Allocation Rule and the comparison with results from Hubert (2009) are as shown in the table and graph below.

Table 2. Relative Allocation for Players in Each Scenario

Scenario	R		U		B		We	
Status Quo in Hubert (2009)	57.10%		31.80%		11.10%		N/A	
Status Quo	35.88%		35.20%		14.80%		14.12%	
South Upgrade WE Buy	35.90%	0.02%	35.18%	−0.02%	14.82%	0.02%	14.10%	−0.02%
South Upgrade U Buy	36.59%	0.71%	35.95%	0.74%	14.05%	−0.74%	13.41%	−0.71%
Yamal WE Buy	34.47%	−1.41%	28.02%	−7.18%	21.98%	7.18%	15.53%	1.41%
Yamal B Buy	38.55%	2.67%	28.54%	−6.66%	21.46%	6.66%	11.45%	−2.67%
Nord Stream	40.72%	4.84%	21.23%	−13.97%	11.00%	−3.80%	27.06%	12.94%

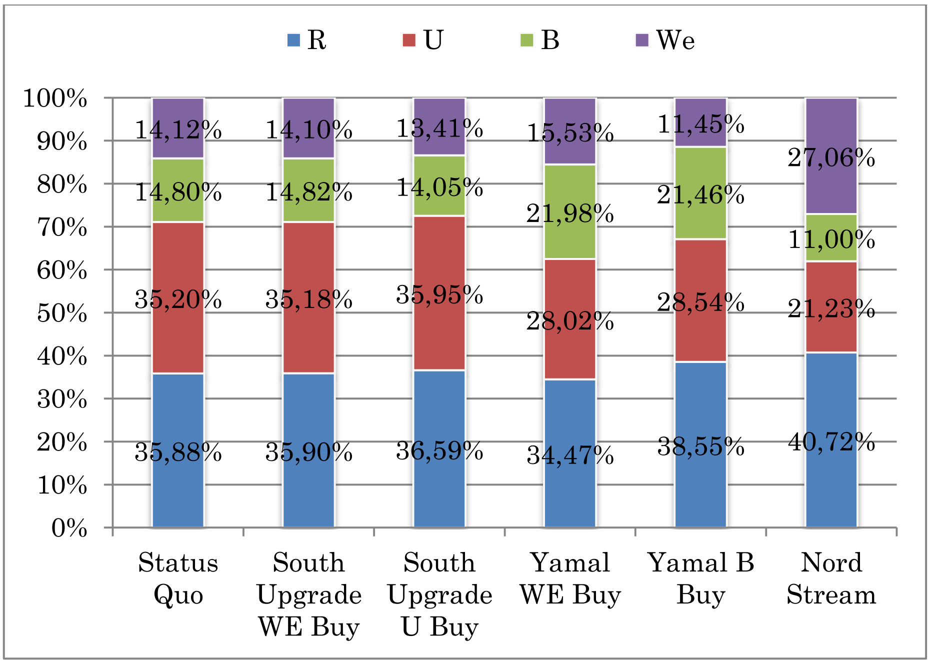

Figure 3. Graph of Relative Allocation for Players in each Scenario

Table 3. Relative Allocation for Links in Each Scenario

Scenario	RU		RB		Uwe		Bwe		Rwe	
Status Quo	49.49%		22.27%		20.92%		7.32%		0.00%	
South Upgrade WE Buy	49.48%	0.00%	22.31%	0.03%	20.87%	−0.04%	7.33%	0.01%	0.00%	
South Upgrade U Buy	52.03%	2.54%	21.15%	−1.12%	19.87%	−1.05%	6.95%	−0.37%	0.00%	
Yamal WE Buy	40.45%	−9.03%	28.48%	6.21%	15.59%	−5.32%	15.47%	8.15%	0.00%	
Yamal B Buy	40.12%	−9.36%	36.98%	14.70%	16.96%	−3.96%	5.94%	−1.39%	0.00%	
Nord Stream	37.71%	−11.78%	20.62%	−1.65%	16.26%	−4.66%	7.34%	0.01%	18.08%	18.08%

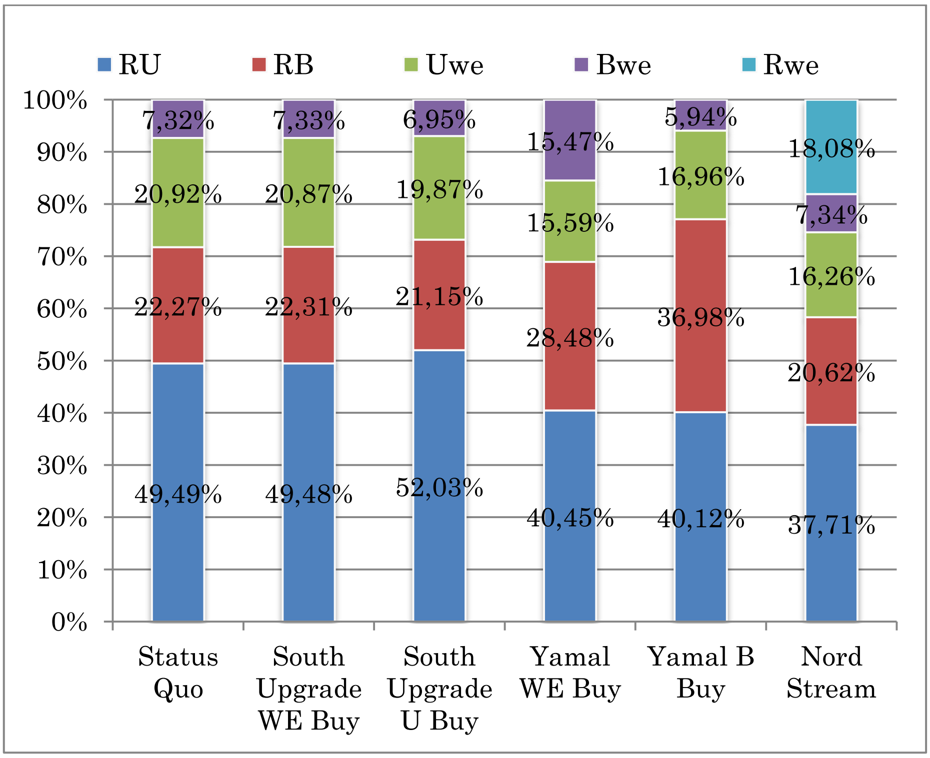

Figure 4. Graph of Relative Allocation for Links in each Scenario

Scenario 1: Status Quo

In the case of Hubert (2009), Russia's relative Shapely Value at the status quo was 57.10% while in our analysis, Russia's relative allocation is 35.88%. Much of this difference is due to the fact that in our analysis, a new player *Western Europe* is playing a vital role as the largest importer, and the two transit countries *Ukraine* and *Belarus* are not mere transit countries, but significant consumers themselves.

The new dimension of analysis added by our analysis is the link-based allocation. In the Status Quo scenario, almost half of the network's value is accrued by the link RU. Link RB receives an allocation of 22.27%, link UWe receives 20.92%, and link BWe receives 7.32%. In terms of the volume of trade in the complete network, link UWe is by far the largest, but it would not generate any value if link RU did not exist. Therefore, the contribution of RU is large, and the results capture this fact quite accurately.

Scenario 2: South Upgrade (Western Europe Buys All)

When the *South* pipeline is upgraded and Western Europe buys an additional 15bcm/year, the change in the relative allocation among players is insignificant. The change in relative allocation among links is also insignificant but intuitively confusing. The cost of trading through link UWe is higher than trading through link RU, and thus causes a slight loss in the value of the entire network. This loss ironically decreases the relative allocation for link UWe and distributes the amount to links RB and BWe. As a result, Russia and Belarus would gain from the upgrade in *South*, while Ukraine and Western Europe would lose.

Scenario 3: South Upgrade (Ukraine Buys All)

When the *South* pipeline is upgraded and Ukraine buys an additional 15bcm/year, this increases the relative allocation for Russia and Ukraine each by approximately 0.7%. Here, we can see that the 0.71% increase in relative allocation for Russia was taken from Western Europe, and the 0.74% increase in relative allocation for Ukraine was taken from Belarus. The result for the relative allocation among links is obvious, that link RU would receive a higher relative allocation due to the increased trade between Russia and Ukraine.

Scenario 4: Yamal (Western Europe Buys All)

When the *Yamal* pipeline is upgraded by 60bcm/year and Western Europe buys the entire amount, Western Europe takes 1.41% away from Russia, whilst Belarus takes 7.18% away from Ukraine. This result is intuitively confusing because Russia seems to be losing from the *Yamal* upgrade, and such upgrade would not happen if Russia does not consent. This can be explained by the fact that the overall volume of trade has increased by 60bcm/year, and due to this increase, Russia would still be receiving a larger payoff from the upgrade, although it might not be gaining as much relative to what Belarus and Western Europe might gain. Thus, the absolute payoff increases while the relative allocation decreases, and such upgrade might be justifiable for Russia if the economic gain from the upgrade outweighs the political loss from the decrease in relative allocation (i.e. relative power).

An upgrade in *Yamal* would clearly affect the relative allocation for *South*.

Scenario 5: Yamal (Belarus Buys All)

When the *Yamal* pipeline is upgraded by 60bcm/year and Belarus buys the entire amount, Russia takes 2.67% away from Russia, whilst Belarus takes 6.66% away from Ukraine. This result is obvious but unfortunately, such scenario is not realistic. A 60bcm/year increase in natural gas import by Belarus would more than triple the current quantity imported. It would be highly unlikely that Belarusian gas consumption would increase by 300% in the foreseeable future.

Here also, an upgrade in *Yamal* would clearly affect the relative allocation for *South*.

Scenario 6: Nord Stream

When the *Nord Stream* pipeline is built and 55 bcm/year is bypassed through this underwater pipeline rather than through Ukraine, Russia would gain 4.84% and Western Europe would gain 12.94%, while Ukraine would lose 13.97% and Belarus would lose 3.80%. This result is distinct from the other scenarios in that we do not have a one-to-one match of the gains and losses in each player's relative allocation. For example, of the 13.97% that Ukraine lost, we do not know how much Russia took and how Western Europe took. In other words, the change in relative allocation can be accredited to an overall reshuffling of relative power within the network that occurred as a result of building the *Nord Stream* pipeline.

The change in relative allocation among links provides a clearer picture. The building of the *Nord Stream* pipeline takes the largest amount of power away from link RU and UWe (i.e. *South*). The link BWe, one the other hand, slightly increases its relative allocation.

6 Conclusion

The results provided in this paper are examples of some basic scenarios showing that the network game approach and the link-based flexible allocation rule are indeed applicable to the context of natural gas pipelines in order to analyze the change in relative allocation of surplus among the countries involved in natural gas trade. Because the link-based flexible network allocation rule employed in this paper is a concept similar to the Shapley Value, it can be interpreted as the fair allocation of surplus according to each player's contribution to the overall value of the network. A larger contribution to the overall value would usually lead to stronger bargaining power (and thus the larger relative allocation), and thus the relative allocation of surplus can be interpreted as the relative power of each player. Thus, in this paper we refer to this set of relative allocations as the "power structure" of players within the network.

The results generated are consistent with what one would intuitively expect the strategic relationship among these states to be. The strategic aim of the *Nord Stream* pipeline was precisely to bypass Ukraine and Belarus in order to lessen their bargaining power (i.e. control over the flow of gas from Russia to Western Europe) and mitigate the risk of gas disputes. The results indeed predict the strengthening of bargaining power for Russia and Western Europe, and the weakening of the power for Ukraine and Belarus.

The model used network games defined by graphs and value functions rather than coalitional cooperative games defined by coalitions and characteristic functions, and thus opened way to overcome the following shortcomings of modeling with cooperative games:

(1) Where existing works using characteristic functions were able to assign value only to coalitions of players (i.e. countries), the network game approach allowed modeling based on the value accrued from links. The relative allocations defined for these links seemed intuitively convincing, adding an extra dimension of analysis.

(2) Where existing works using characteristic functions could not incorporate both producers (e.g. Russia) and consumers (e.g. Germany, Italy) in the model, the network game approach taken was able to incorporate both by assigning value to the entire network of producers and consumers.
(3) Where existing works using characteristic functions could not take into consideration the fact that transit countries (e.g. Ukraine, Belarus) are also consumers of natural gas, the network game approach taken was able to define the value of trade between the producer and these transit countries. Thus, the value accrued from the "consumer-aspect" of these countries was incorporated into the model.
(4) Where existing works using characteristic functions could not incorporate externalities, the network game approach taken in this research was able to assign separate values for each possible network structure in a computable manner.

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