Gas-Pipelines & Power

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Motivation

Europe largely depends on gas imports through pipelines. A quarter of total consumption is supplied by Russia.

The architecture of the pipeline network determines the opportunities for trade, hence the power of the various players: producers, transit countries, importers.

Several pipelines have been added to the system over the last two decades (Blue Stream, Yamal I, Nord Stream).

Other projects failed (Bypass, Amber, Yamal II, South Stream, Nabucco)

Questions

1. How can we measure power in a network?

   As networks are ubiquitous, this question is of much broader interest.

2. Can we make sense of the successful pipeline projects as well as the failures, when interpreting them as attempts to change the balance of power in the network?

Overview

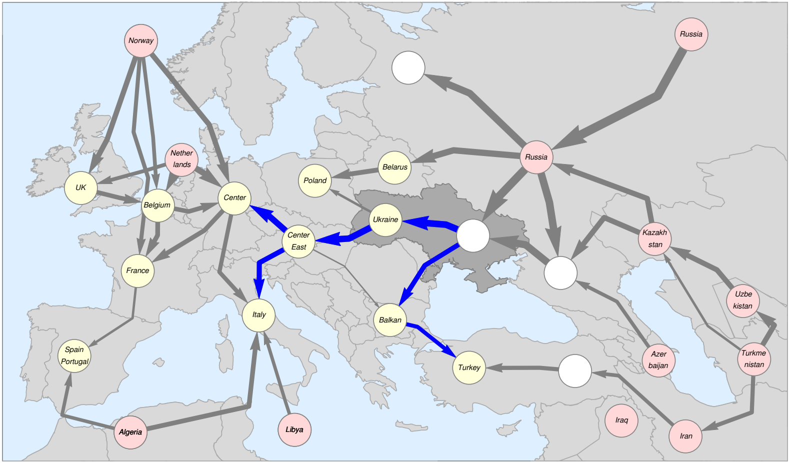
1. The network and its development.
2. Using cooperative game theory to measure power.
3. The network model.
4. Why Nord Stream succeeded, while South Stream and Nabucco failed.

The Network

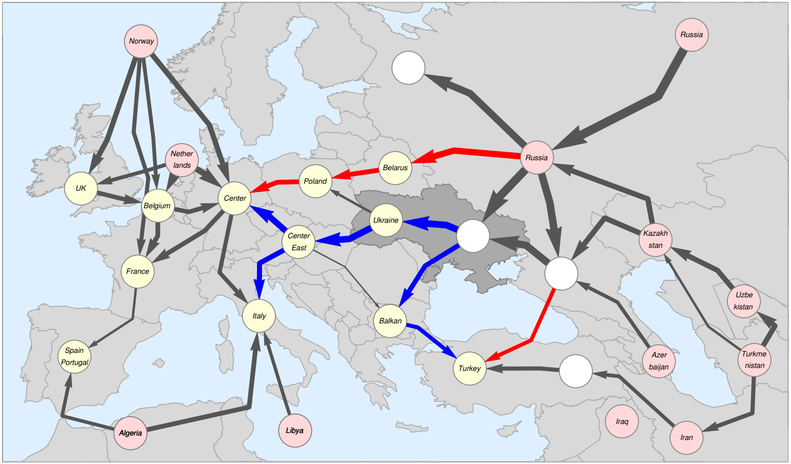
After the collapse of the Soviet empire

1. All Russian exports had to transit through Ukraine.
2. As there was no connection between Central Europe and South Eastern Europe, Russia could effectively separate the Areas.

1992: Ukraine's transit monopoly



Bypassing Ukraine: Yamal I (1998), Blue Stream (2005)



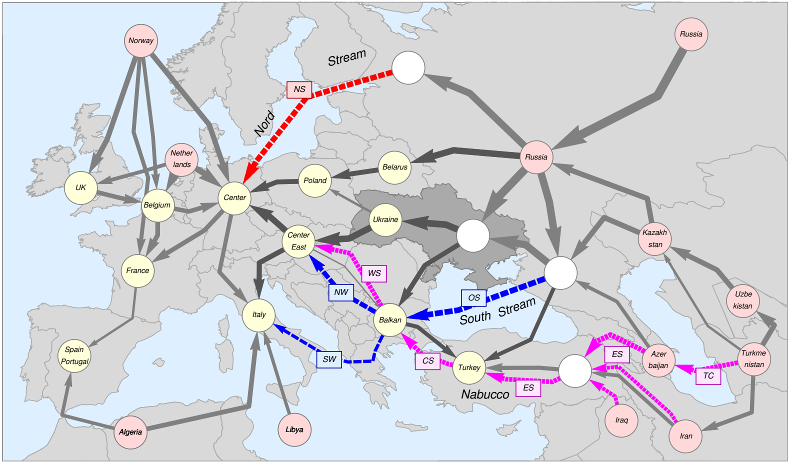
2005: Three new pipelines

Nord Stream: offshore link between Russia and Germany;
55 bcm/a, 12-15 bln €, completed in 2012;
(recently Nord Stream II).

South Stream: offshore link between Russia and Balkans;
63 bcm/a, 22-30 bln €, planned for 2018 but cancelled in 2014;
(Turkish Stream).

Nabucco: new southern corridor: connecting central Europe through Balkans and Turkey with Caspian Region/Central Asia and Iraq/Iran; 31 bcm/a, 20-25 bln €, supported by EU, but European partners dropped off 2013;
(TANAP, TAP).

2002: Nord Stream, South Stream, Nabucco



EU's gas dependency

The EU's dependency on natural gas:

- Russia (40% of imports, 25% of consumption),
- The transit countries, Ukraine and Belarus (before Nord Stream 75% and 25% of Russian imports, respectively).

Nord Stream & South Stream:

- diversify transit routes for Russian gas, but
- increase dependency on Russia and may
- reduce viability of investments in alternative sources.

Nabucco:

- creates an alternative supply chain.

The Puzzle

Three huge projects but neither adequate supply nor demand!

In 2008 Europe's

- Consumption: 489.7 bcm
- Production: 184.2 bcm
- Net imports: 305.5 bcm

(Source: BP (2009), Statistical Review of World Energy)

Nord Stream and South Stream will increase transport capacity for Russian gas from app. 186 bcm/a to 304 bcm/a (63%).

All three pipelines together will increase the European pipeline import capacity by 150 bcm/a (47%) .

Hypothesis & Questions

Pipelines have a strategic role in changing the balance of power in the network.

For the pipeline consortium the gain in bargaining power may justify the investment cost, even if the pipeline is not needed for the efficient supply of gas.

Who benefits in terms of bargaining power? How do the gains relate to investment cost?

Cooperative games and power metrics

How to Measure ‘Power’?

Cooperative game theory (CGT) predicts how players share the surplus of cooperation. The shares can be interpreted as power index.

But it offers several solutions: Shapley Value, core, nucleolus ...

We know a lot about the abstract properties of these solutions.

We know little about their economic relevance in applied industry studies.

CGT has been applied in voting games, cost allocation, but not IO.

Non-cooperative approach

Players: set of players N.

Strategies: strategy space $S := S_1 \times S_2 \times ..S_n$ with S_i denoting player i's strategy set.

Payoffs: $u : S \to \mathbb{R}^{|N|}$, where $u_i(s)$ is player i's payoff (utility) given strategy profile $s \in S$.

Game: the players, the strategy space and the payoff functions: $\Gamma := \{N, S, u\}$.

Solution in strategies s^*: typically the Nash-equilibrium.

Non-cooperative approach: problems

The set of Nash-equilibria is often very sensitive to the (mis)specification of the strategy space (e.g. price matching).

In supply chains, the players usually negotiate complex contracts.

Neither the contracts, nor the bargaining process is easily converted to the non-cooperative format.

Cooperative approach

Players & Coalitions: set of players N, and S_N set of all subsets (coalitions) of N.

Value function: $v : S_N \rightarrow \mathbb{R}_+$ such that $v(S)$ is the maximal payoff to coalition $S \subseteq N$.

e.g.: $v(\{\})$, $v(\{a\})$, $v(\{b\})$, $v(\{c\})$, $v(\{a,b\})$, $v(\{a,c\})...v(N)$

Game: is specified by the players and the value function: $\Gamma := \{N, v\}$.

Solution in payoffs $x^* = \{x_a, x_b ... x_n\}$ **(power index)**:
But various solution concepts: Shapley value, core, nucleolus....

Cooperative approach: problems & questions

v is the result of an optimization problem.

Since $|S_N| = 2^{|N|}$, computing v is a 'hard' problem (exponential in the number of players).

When deriving the value function, we assumed there are no externalities between coalitions (partition function form).

There is no universally accepted solution.

How different are the various solutions? Are some solutions 'better' than others?

Shapley Value

The Shapley Value ϕ of a players i is given by his weighted (marginal) contribution to all possible sub-coalitions $S \subseteq N$.

$$\phi_i(v) := \sum_{S: i \notin S} \frac{|S|!(|N| - |S| - 1)!}{|N|!} \cdot [v(S \cup \{i\}) - v(S)],$$

The weights can be motivated by *random order bargaining*, with all orderings having equal probability.

Shapley Value: properties III

individual rationality: no player can improve by unilaterally withdrawing

$$x_i \geq v(\{i\}) \; \forall i \in N$$

group rationality: nothing is wasted

$$\sum_{i \in N} x_i = v(N),$$

(imputation)

Shapley Value: properties II

It is the only imputation fulfilling the axioms of *symmetry* & *dummy player property* & *linearity* (Shapley 1953).

It is the only imputation featuring *balanced contributions* (Myerson 1980).

It is the only imputation featuring *symmetry* & *monotonicity* (Young 1985).

Moreover: It always exists, is unique, and it is easy to calculate — once you have the value function.

Shapley Value: some issues

The Shapley value may be outside the core; in this sense ‘unstable’.

There may be subgroups of players which can do better on their own rather than being content with their payoff under the Shapley Value.

In the following I focus on the Shapley Value. At the end I briefly look at the nucleous, which is in the core (provided the core is not empty).

network model

The network & access

Eurasian gas network: 38 nodes (R) and 43 links (L^N):

- production node R_P
- customer node R_C
- transit node R_T
- link $l = \{i, j\},\ i \neq j \in R$

We aggregate regions to obtain 17 players N. A system of access rights maps coalitions into sub-nets.

$L(S) \subseteq L^N$: set of pipelines available for coalition $S \subseteq N$.

Model: value of a coalition

The value function is obtained by maximizing the joint surplus of the players in coalition S using the gas-flows in the available pipelines:

$$v(S) = \max_{\{x_{ij} | \{i,j\} \in L(S)\}} \left\{ \sum_{\{i,j\} \in L(S),\, j \in R_C} \int_0^{x_{ij}} p_j(z) dz - \sum_{\{i,j\} \in L(S)} T_{ij}(x_{ij}) \right\}$$

s. t.

node-balancing: $\sum_i x_{it} = \sum_j x_{tj},\ \forall\, t \in R_T(S)$,

network capacity: $|x_{ij}| \leq k_{ij},\ \forall\, \{i,j\} \in L(S)$,

positive consumption & production: $x_{ij} \geq 0,\ \forall\, i \in R_P$ or $j \in R_C$,

x_{ij}-gas flows, k_{ij} - capacity limit for the link $\{i,j\}$, $T_{ij}(x_{ij})$ - link specific transportation cost, $p_j(x_{ij})$ - inverse demand

Calibration: main assumptions

We calibrate the model using data on consumption in the regions and flows between the regions from 2009 (IEA (2010))

Demand & cost:

- Production cost are constant up to production levels achieved in 2009.
- Linear demand functions with the same intercept for all regions.
- The slope parameters are estimated as to replicate the consumption in 2009 (given our assumption on production cost).

Calibration cont.

Access rights

- Within the EU: Open third party access (TPA) to the international high pressure transport pipelines.
- Outside the EU: Every country has unrestricted control over its pipelines and gas fields.

Horizon

- A stationary environment with constant demand, technology, production cost, etc.
- Short term / stationary network: All pipelines can be made bi-directional, but capacities cannot be increased. (Robustness check for flexible networks.)

Calibration

Data for 2009 from IEA (2010a) on consumption and production in the regions and flows between the regions.

Constant production cost up to the production levels achieved in 2009.

Linear demand functions with the same intercept for all regions.

Slope parameters estimated as to replicate the consumption in 2009, given assumption on production cost.

Only Strategic Benefits of Investments

Given the demand and the cost of producing gas, the pipeline network as existing in 2009 has sufficient capacity (no congestion).

None of the expensive pipeline projects considered in this paper can be justified in narrow economic terms.

The investments change the power structure, hence, redistribute surplus. They do not create surplus.

A project is 'strategically viable' for a group of players, if their gains in bargaining power exceed the investment cost.

changing the power-structure

strategic investments in new pipelines

Pipelines and Power

1. Calculate the value function and Shapley Value for the network without the pipeline $\phi_i(v^o)$.

2. Calculate the value function and Shapley Value for the network with the pipeline in place $\phi_i(v^1)$.

3. The difference $\phi_i(v^1) - \phi_i(v^o)$ yields the gross impact of the pipeline on the surplus of player i, which is then compared to the investment cost of the pipeline.

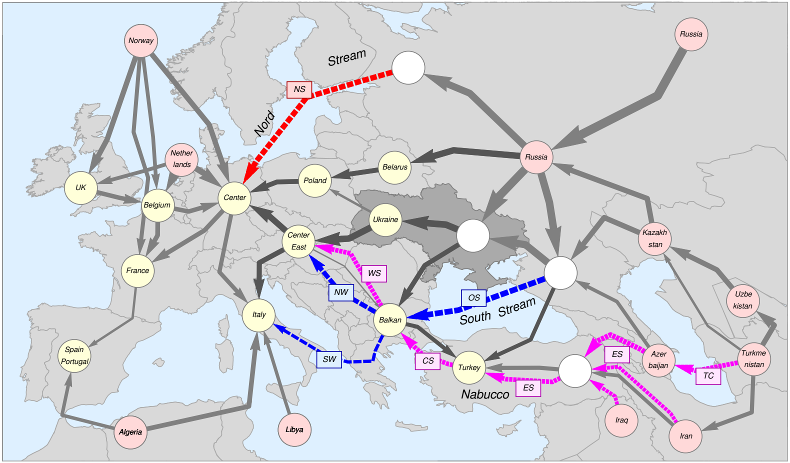
4. The following table gives the change of shares $(\phi_i(v^1) - \phi_i(v^o)/v(N)$

Shapley: Pipeline Impact [% total surplus]

	Nord Stream	South Stream	Nabucco
Russia	3.0	0.8	-3.1
Ukraine	-2.5	-0.9	-0.7
Belarus	-0.8	-0.2	0.0
Norway	-2.5	-0.6	-0.8
Netherlands	-0.9	-0.2	-0.3
Center	1.5	0.5	0.3
Center-East	0.8	0.2	0.2
Italy	0.4	0.1	0.0
Poland	0.2	0.0	0.0
France+Belgium	1.0	0.3	0.2
Balkan	0.0	0.2	0.2
Turkey+Azerb.	0.0	0.1	3.5

In the base variant 1% justifies investment cost of 11.1 bln €.

2002: Nord Stream, South Stream, Nabucco



Shapley: Nord Stream

The strategic value for the initiators of the consortium, Wintershall and EON Ruhrgas of Germany and Gazprom of Russia (in our model Center and Russia) is huge and clearly exceeds the project's cost.

Ukraine and Belarus are badly hurt from increased transport competition.

Norway and Netherlands suffer from increased supply competition in the European markets.

Shapley: South Stream

As a alternative to Nord Stream (counterfactual), it has similar, but somewhat smaller effects on bargaining power. It is viable in spite of higher cost.

With Nord Stream's large capacities in place, South Stream provides much less additional leverage and the benefit cost relation becomes critical.

Shapley: Nabucco

Increased supply competition harms Russia.

The lion's share of the benefits accrues to Turkey while the impact on the EU regions is small.

The EU's support makes little strategic sense.

South Stream has almost no impact on the strategic viability of Nabucco.

Shapley: summary

A clear ranking of projects nicely corresponding with observed investments.

1. Nord Stream: the strategic value for the initiators of the consortium, Germany (Center) and Russia, is large and clearly exceeds the project's cost.

2. South Stream: given its higher cost, the viability is questionable, in particular if Nord Stream's capacity is accounted for. It is not worthwhile for Russia if the North-West section is subjected to TPA.

3. Nabucco: the gains for the EU are marginal and do not cover cost. The eastern sections are profitable for Turkey (TANAP).

Robustness

Are these results robust to reasonable changes in the parameters / calibration.

Yes!

Are they robust with respect to the solution concept?

No!

Nucleolus — a solution in the core

None of the projects has a *significant* impact on bargaining power. All are strategically irrelevant.

1. Nabucco: there are small gains for Turkey and small losses for Russia — much smaller than project cost.

2. South Stream: No effects whatsoever.

3. Nord Stream: No effects, except for a tiny loss(!) for Russia.

Thank You!

core & nucleolus

Excess

For a given x, the excess of coalition S is the difference between what it can achieve alone and what it receives with x:

$$e(S, x) := v(S) - x(S)$$

The larger the excess is, the 'worse' is the coalition doing under x.

If the excess is positive, the the coalition has an incentive to reject (block/veto) x, because it can do better on his own (provided there are no cost of doing so).

Core & stability

Suppose we define a threshold ϵ, then the ϵ-core (Shapley & Shubik 1966) is defined as

$$c(\epsilon) := \{x \in I : e(S, x) \leq \epsilon, \ \forall S \subset N\}$$

Allocations in $c(\epsilon)$ cannot be blocked, if the (fixed) cost of blocking is larger than ϵ.

Core: properties

The core is characterized by $2^{|N|} - 2$ inequalities.

The (simple) core $c(0)$ may be empty, and if not, it is rarely unique.

Any $x \in I$ will be in the ϵ-core, provided ϵ is large enough.

The ϵ-core will be empty ϵ, provided is small enough.

Nucleolus

The nucleolus is the imputation which maximizes 'equality' among coalitions (Schmeidler 1969).

let $\theta(x)$ be the vector of excesses *arranged in decreasing order* for a payoff vector x and let $\preceq$ stand for lexicographical smaller.

$$n := \{x \in I : \theta(x) \preceq \theta(y) \text{ for all } y \in I\}$$

First excess is made minimal for the coalition, which is doing worst. Then excess is reduced for the coalition, which comes second. And so on.

Nucleolus - properties

The nucleolus always exists and is unique.

If the core ($c(0)$) is not empty, then the nucleolus is in the lexicographic center of the core (Maschler & Peleg & Shapley 1979).

The nucleolus can be computed by solving a nested sequence of linear optimization problems.

This is a 'hard' problem for which we use an algorithm proposed by Potters & Reijnierse & Ansing (1996).