A risk-based evaluation of European natural gas supply security

The case of Nordstream 2
(PRELIMINARY WORK)

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Contents of our project

- Optimal flows
- Market influence and costs (see Balázs Sziklai’s talk)
- Supply security
A description of the European gas network

Large, complex network – parallel edges, smaller/larger nodes
Our model of the network

Gas network as a graph

- **Vertices** = countries idealised as points
  - occasionally countries are combined
  - all demand is at this locus
  - produces or consumers,
  - produced and consumed gas quantities
  - (alternative) energy source to cover shortages
    - at a fixed replacement cost
  - net demands

- **Edges** = transnational pipelines
  - known transportation capacities and costs (i.e. lengths)
  - ... between idealised vertices.

- **LNG**
  - artificial vertex
  - edges connected to terminals; special costs
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A simplified model

Simplification: pointlike countries, idealised pipelines
An abstract model

(HAS-CERS/BME/PPCU) Risk in gas supply AIEE 2018 6/20
Optimal flows

Minimalise the total supply cost of member countries!

\[
\min x \left( \sum_{n=1}^{N} C_n T_n \right) x
\]

where

\[
x = \begin{bmatrix} f + f - I \end{bmatrix}
\]

Assuming that

- all demand is satisfied (perhaps from own source)
- no resources from outside the coalition
- resources within the coalition only up to their capacities
- flows are bounded by transportation capacities
- flows are nonnegative
Optimal flows

Minimise the total supply cost of member countries!

\[
\min_x \left( \begin{bmatrix} 1 \, T_n & 1 \, T_n & p^T \end{bmatrix} \right) x \quad \text{where} \quad x = \begin{bmatrix} f^+ \\ f^- \\ I \end{bmatrix}
\]

Assuming that

- all demand is satisfied (perhaps from own source):
  \[
  \begin{bmatrix} A & A & I^{n \times n} \end{bmatrix} x = d_i e^i
  \]
- no resources from outside the coalition: \( l_k = 0, \text{ if } k \notin S \)
- resources within the coalition only up to their capacities: \( I_j \leq S_j \)
- flows are bounded by transportation capacities:
  \[
  \begin{pmatrix} I^{2m \times 2m} & 0^{2m \times n} \\ 0^{n \times 2m} & 0^{n \times n} \end{pmatrix} x \leq q
  \]

- flows are nonnegative: \( x \geq 0 \).
Flow-optimisation

Optimum = optimum for the grand coalition
How to determine sources and thus costs for individual countries?
Countries

- near sources
- that are large

have an advantage. Cannot be solved in general.

Second best:

- Fixed order of countries
- Large countries near sources are listed first
- The first country is served optimally; the corresponding supply and transfer capacities are removed from the network
- The next country is served using the remaining resources.

Note: For consistency, the order is not updated
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Supply security
What is supply security?

Literature focuses on efficiency. — What if something goes wrong? What happens if a pipeline is closed due to:

- accident
- sabotage
- natural disaster
- terrorism.

Will countries still get all its demanded gas supply?
- If yes, is the price (including transit) the same?
- If the price is higher, how much more?
- ... and how can we measure this??

“The cost increase induced by the closure of a single pipeline*”
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“The cost increase induced by the closure of a single pipeline*”
Supply security

- Each pipeline, with the same probability is closed down
- We recalculate the (constraint) optimum
- This results in a list of possible costs for each closure
- We look at the 5% *expected shortfall* (worst 5% of cases’ avg)
  - Focuses on bad scenarios (i.e. conservative)
  - Looks beyond the worst case
  - ES is a *spectral risk measure* widely used in finance.

Limitations

- We do not model incident risk: may depend on length, age, politics
- We use idealised pipelines: no multiedges, etc.
  - Note: the largest capacity edges consist of single pipelines
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Some design considerations

(feedback needed!)

**Model A**  "Winter crisis"
- remaining network must deliver
- shortage covered from (expensive) alternative source

**Model B**  "Summer crisis"
- shortage is supplied from reserves
- network must resupply reserves in 3 months
- Extra demand over the network
- Any *remaining* shortage is supplied from (expensive) alternative source

**Reality**  Somewhere in between...
Scenarios

- **Baseline**: Current network setup
- **Nordstream**: NS2 added to the current network.
  - Probably the most important current development
  - Drastic influence on the power balance in the European natural gas network (see our other paper)
  - Unlike other projects, NS2 has received permits and construction is in progress
- **Ukraine**: NS2 is added and the Ukrainian pipeline is closed down.
  - The maintenance of excess capacities is costly: Nordstream only makes sense as a replacement of Brotherhood
  - Gazprom hinted that the renovation is too costly
  - Ukraine repeatedly demanded the stop of NS2 construction
  - Past tensions, current conflicts make further cooperation difficult

*Presentation compares 1st and 3rd scenarios.*
Data and calculations

Data
- 2016 network, production, price and consumption data (ENTSOE; BP Statistical Yearbook)
- Pipeline lengths from various sources; including estimations
- The cost of alternative source is 600 M USD/bcm.

Limitations
- Idealized network; prices not directly observable
- Uniform gas quality; bidirectional pipelines, etc.
- Uniform incident probabilities

Calculations
- Implemented in Java by research assistant Attila Nás.
Results 1: Prices

The % change in supply *costs* (without transit fees, etc.)
Results 2: Supply security

Baseline winter scenario

Baseline summer scenario

Target winter scenario

Target summer scenario
Results 2: Supply security: change (winter/summer)

- West: closer source
- East (AT to UA): lasting damages; longer transit routes, smaller transit capacities.
- South-East: bottlenecks remain; Turkey gets its supply through countries with shortages.
- We do not consider power changes, only costs.

(HAS-CERS/BME/PPCU)
Results 2: Supply security: change (winter/summer)

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Conclusion 1

- The supply of Easter Europe is already very fragile
- NS2 with the likely closing of the Brotherhood increases the costs, and makes supply *far more* risky
- (Shifts all the power to Germany)
- Goes against the principles of the Energy Union
- Other developments, such as TAP may mitigate the damage.
Further research

An alternative model with mixed inflows
- At each node inflows are mixed
- outflows at the same prices.
- optimal flows
- like an exchange-based model (as planned in the EU)

Preliminary findings for replacing Brotherhood with NS2
- Greater benefits to the West
- Turkey loses much
- Ambiguous results for CEE
And more

In a complementary paper we consider Third Party Access pipelines: free capacities can be used by anyone.

Nord Stream 2 may be the most controversial, but the model is not specific to Nord Stream 2. We plan to do a similar analysis for other pipelines under construction.