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Economic impacts of natural gas flow disruptions between Russia and the EU

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Abstract

In this paper we use a non-linear programming approach to predict the wider interregional and interindustry impacts of natural gas flow disruptions. In the short run, economic actors attempt to continue their business-as-usual and follow established trade patters as closely as possible. In the model this is modelled by minimizing the information gain between the original pattern of economic transactions and the situation in which natural gas flows are disrupted. We analyze four scenarios that simulate Russian export stops of natural gas by means of a model calibrated on an international input-output table with six sectors and six regions.

The simulations show that at the lower levels of aggregation considerable effects are found. At the aggregate level of the whole economy, however, the impacts of the four scenarios are negligible for Europe and only a little less so for Russia itself. Interestingly, the effects on the size of the economy, as measured by its GDP, are predominantly positive for the various European regions, but negative for Russia. The effects on the welfare of the populations involved, however, as measured by the size of domestic final demand, have an opposite sign; with predominantly negligible but negative effects for European regions, and very small positive effects for the Russian population.

Keywords: natural gas, supply shocks, non-linear programming, Russia, European Union

Acknowledgements

The paper was written when the first author was still affiliated to the University of Groningen. The views expressed in this paper are those of the authors only and should not be attributed to the European Commission. The article has benefitted from discussions with participants of the 22nd International Input-Output Conference, July 2014, Lisbon, and from comments received from EDGaR partners participating in the project 'Operating the gas transmission system: institutional design challenges and solutions'. The first author gratefully acknowledges the funding provided by a grant of the Energy Delta Gas Research (EDGaR) program. EDGaR is co-financed by the Northern Netherlands Provinces, the European Fund for Regional Development, the Ministry of Economic Affairs and the Province of Groningen. The sponsors have had no role in the research reported in this article, other than providing the funding.

1. Introduction

In aiming to ensure a resilient energy system, the European Union (EU) initiated an extensive energy policy package. Natural gas is given an important role in meeting future EU-wide energy demand. It can be flexibly produced and stored, and therefore represents a good backup for intermittent renewable energy. Significant natural gas demand growth and demand variability is foreseen, especially for certain regions (Smith, 2013). Due to dwindling EU natural gas reserves, dependency on non-EU gas flows will increase. Anticipating of these developments, multiple far-reaching measures have been taken in order to arrive at a single well-functioning internal gas market. The continuing integration of the gas market also contributes to larger gas flows across all EU countries.

Russia is one of the main suppliers of natural gas to the EU-market (International Energy Agency, 2014). Over the years, problems between Russia and the Ukraine have had their impact on natural gas flows to the EU. The European Commission has published a reinforced energy security strategy, focusing on more resolute actions to diversify supply and strengthen the internal infrastructure in order to promote resilience to disruptions (European Commission, 2014a). This strategy is a response to the continuation of the important role of the Ukraine as transit country.

The recent problems in the Ukraine have increased the tension between the EU and Russia. Alternative routes, via Belarus or via the Baltic Sea do not offer enough spare capacity. To assess EU's vulnerability to Russian gas supplies, the European Commission has undertaken a stress test to see whether the EU would be able to get through a winter without any imports from Russia. The sources expected to contribute most to the alternative supply of natural gas are Norway, LNG, and underground storage facilities in the EU. Only in case all Member States cooperate, no household would have to be affected. The Eastern Member States and former Yugoslavian countries would be affected most (European Commission, 2014b).

The strong international dimension of the gas market also implies that any supply shock will be propagated extensively through the network. Not only in terms of the physical flows of natural gas, but also in terms of the economic impact of gas flow disruptions. In this paper, we investigate the wider economic impacts of disruptions in the supply of natural gas with a new approach. A non-linear programming model is used to predict the short-run interregional and interindustry impacts of four disruption scenarios. These short-run impacts are determined by the attempts of economic actors to continue their business-as-usual and stay as close as possible to their established trade patterns. This behavioral response to a disruption is implemented by minimizing the difference between the pre- and the post-disruption pattern of economic transactions.

Several scenarios will be analyzed based on data from the EXIOPOL international input-output database (see Tukker et al., 2013), because this database includes a separate natural gas extraction sector. The set of scenarios we study focuses on the fact that Russia may decide to stop the export of natural gas. This can be a total ban on exports to the EU. Alternatively, it may be a setting in which only particular cross-border flows are hampered. For example, physical pipelines may be damaged, or Russia may decide to limit cross-border flows to certain European regions. These situations will be simulated by reducing or removing the flow of natural gas between countries. Limited changes in gas supply can be accommodated by the gas infrastructure of the EU, because of redundant capacity for security of supply reasons. However, due to limited transport capacity, or limited possibilities to extract additional gas, natural gas quantities that can be supplied in the short run will be limited.

Our type of analysis of the economic impacts of natural gas flow disruptions will inform policy makers on critical gas supplier relations and critical cross-border pipeline connections. It may also provide information regarding strains on the rest of the system following a gas supply disruption. This type of approach can also be used to further investigate mitigation strategies, for example, diversifying supply or investing in additional infrastructure.

2. Modeling methodology, data and scenarios

The model used mimics that, in the short run, economic actors attempt to continue their business-as-usual, and attempt to follow established trade patters as closely as possible. This behavior is simulated by minimizing the information gain between the original pattern of economic transactions, as shown in the base year interregional input-output table (IRIOT) at hand, and the situation in which the flow of natural gas is disrupted, as captured by the measure originally proposed by Kullback (1959) and Theil (1967). Here, we use a slightly adapted version of the information measure that is referred to as IGRAS (Huang et al., 2008). Our type of model was first set-up to analyze the impact of natural disasters (Oosterhaven et al., 2013), but it is also suited to simulated the impacts of trade boycotts. See Oosterhaven (2015) for the reasons of choosing this modelling approach above, e.g., the input-output inoperability model or the hypothetical extraction method.

2.1. Base model

The objective function of the model minimizes the information loss of the disrupted IRIOT compared to the base year IRIOT:

$$\begin{aligned} Minimize \quad & \sum\nolimits_{r,s,i,j}\left[z_{ij}^{rs}\left(\ln z_{ij}^{rs}/z_{ij}^{rs,ex}-1\right)+z_{ij}^{rs,ex}\right]+\sum\nolimits_{r,s,i}\left[y_{i\bullet}^{rs}\left(\ln y_{i\bullet}^{rs}/y_{i\bullet}^{rs,ex}-1\right)+y_{i\bullet}^{rs,ex}\right]+ \\ & +\sum\nolimits_{s,j}\left[v_{j}^{s}\left(\ln v_{j}^{s}/v_{j}^{s,ex}-1\right)+v_{j}^{s,ex}\right], \end{aligned} \qquad \textbf{(1)}$$

where the represented variables are: *z* = intermediate demand, *y* = final demand, excluding changes in inventories and valuables, and *v* = value added at market prices (GDP). The four indices are *i,j* = 1, …, *I*, with *I* = number of industries, and *r,s* = 1, …, *R*, with *R* = number of regions, where · represents the sum over an index, and where *ex* = exogenous, i.e. the actual values from the base year IRIOT. Note that the base year values just in front of the square brackets do not influence the minimization of (1). They are only added to ensure that the base year value of (1) equals zero.

We assume cost minimization under a Walras-Leontief production function, per input, per industry, per region, which results in (Oosterhaven, 1996):

$$\sum\nolimits_{r} z_{ij}^{rs} = a_{ij}^{\bullet s}\, x_{j}^{s} \; and \; v_{j}^{s} = c_{j}^{s}\, x_{j}^{s}, \forall i, j, s \qquad \textbf{(2)}$$

where *x* = total output, *a* = intermediate inputs per unit of output, and *c* = value added per unit of output, where *a* and *c* are calculated from the base year IRIOT as $a_{ij}^{\bullet s} = \sum\nolimits_{r} z_{ij}^{rs,ex} / x_{j}^{s,ex}$ and $c_{j}^{s} = v_{j}^{s,ex} / x_{j}^{s,ex}$, with $\sum\nolimits_{i} a_{ij}^{\bullet s} + c_{j}^{s} = 1$.

We assume that markets are in short run equilibrium, i.e., that demand equals supply, per industry, per region:

$$\sum\nolimits_{s,j} z_{ij}^{rs} + \sum\nolimits_{s} y_{i\cdot}^{rs} - x_i^r = 0, \forall i, r \, . \tag{3}$$

Note that (2) and (3) combined ascertain that total input equals total output, per industry, per region, which implies that any solution of (1)-(3) satisfies the IRIOT accounting identities.

In the specific case studied here, i.e., that of natural resource extraction, the production of additional output is restricted by existing reserves. Our last restriction, therefore, specifies our estimate of the natural gas production restrictions by region.

$$x_i^r \leq x_i^{r,\max}, \forall i, r \, . \tag{4}$$

The above non-linear programming approach (1)-(4), thus combines the assumption of fixed technical coefficients with flexible trade coefficients. This implies that (partial) import and export substitution (cf. Oosterhaven, 1988) is considered to be a realistic solution to supply shocks to the flows of natural gas.

2.2. Data

The input-output database used has been constructed during the EXIOPOL project (Tukker et al., 2013).[1] The full database contains 43 countries and 129 sectors. For this first empirical application of this new model, we have aggregated the data to six sectors and six regions. The sectors and regions represented are given in Table 1. In Appendix A the concordances with the original data are given. The different categories of value added per sector have been combined with the data on taxes less subsidies per sector, resulting in one value that represents each sector's contribution to GDP. In the remainder of this paper, we refer to this single value simply as "value added".

Table 1: Regions and sectors represented in the model

Regions	Sectors
North-West Europe	Primary
South-West Europe	Natural gas extraction
East Europe	Other energy extraction
North-East Europe	Secondary
Russian Federation	Electricity from gas
Rest of the World	Tertiary

The focus of our study is on the European Union. Its countries have been divided into four regions primarily based on their geographical location and the layout of the main gas pipelines, and secondarily based on their position in the gas market. Of all non-EU countries, we have kept the Russian Federation as a separate region, due to its important role in the supply of gas on the

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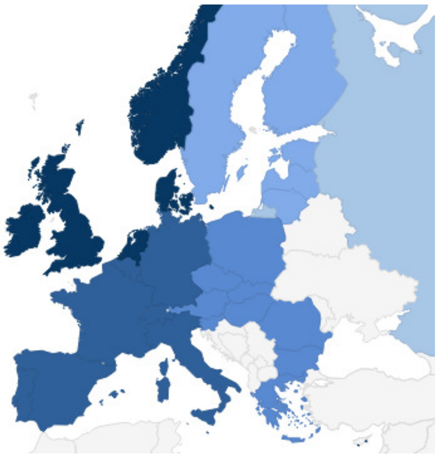
[1] The data are publicly available via the website exiobase.eu. For this study EXIOBASE 1 (year 2000) was used, as the follow-up IRIOT was not available at the time this analysis was undertaken.

European market. All countries outside the European Union and Russia have been combined into one large region called ‘Rest of the World’. The grouping of countries is visually represented in Figure 1.

Figure 1: Grouping of EU countries into regions



With respect to the sectors, we have kept two single sectors from the extensive set of sectors represented in the full EXIOPOL database. These are the natural gas extraction sector and that part of the electricity sector that is fuelled by natural gas. The natural gas extraction sector will allow us to look at the specific effects of changes in the supply of natural gas. The electricity from gas sector is fully dependent on the supply of natural gas and is directly harmed by a reduction in the supply of natural gas. The third small sector, other energy extraction, is an aggregation of all other individual energy extraction sectors that are present in the EXIOPOL database. This sector may function as a substitute for natural gas extraction in an indirect sense. Given the Leontief technology assumption in Equation (2), natural gas inputs cannot be directly substituted. However, sectors in different countries may rely on different energy sources. Consequently, the output of such a sector may be substituted for the output of a sector that relies on natural gas, which represents an indirect type of substitution. The remaining sectors are aggregated into a primary sector representing agriculture, forestry and fishing, a secondary sector representing manufacturing, and a tertiary sector representing services.

Europe’s capacity to produce additional natural gas domestically is severely limited due to limited reserves. To include this in the model, all scenarios are implemented with constraints on additional production. The percentages for North-West Europe and for the Rest of the World have been derived from European Commission (2014b). The percentages for the other regions are set in relation to their current production capacity and represent general estimates of what could additionally be produced given the present reserves. These output constraints are listed in Table 2.

Table 2: Natural gas production capacity constraints

Region	Additional production cap
North-West Europe	15%
South-West Europe	10%
East Europe	10%
North-East Europe	0%
Russia	50%
Rest of the World	100%

2.3. Scenarios

To study the economic impacts of disruptions in the flows of natural gas, we have defined four scenarios. All scenarios focus on Russia due to its role as single most important supplier of natural gas to the EU economy. In the first scenario Russian exports to all European countries are stopped, in the second only its exports to North-East Europe, in the third only its exports to East Europa, and in the fourth only its exports to North-West and South-West Europe. The first scenario is thus a combination of the latter three. The different scenarios are shown in Table 3. A list of the specific countries belonging to the different regions can be found in Appendix A.

Table 3: Natural gas disruption scenarios

Scenario	Region imposing export ban:	On its natural gas exports to:
1	Russian Federation	All four EU regions
2	Russian Federation	- North-East Europe
3	Russian Federation	- East Europe
4	Russian Federation	- South-West Europe and North-West Europe

Although natural gas exports are not as important for the Russian economy as oil exports, fully cutting off the European market, as in Scenario 1, will not go unnoticed in terms of economic activity. To reduce its dependency on Europe as a buyer, Russia is diversifying its customers´ portfolio by working towards opening up Asian markets for Russian gas exports (Dickel et al, 2014). However, negotiations with China have been slow and cumbersome (Henderson and Stern, 2014). Even though the recently agreed contract with China includes building a pipeline, it is not expected to be operational before 2020 (International Energy Agency, 2014). In addition, this pipeline will not even compete directly with exports to Europe, because the networks are not connected. Construction of a pipeline that would allow Russia to alternate gas flows between Europe and China is only a sketchy plan (Dickel et al, 2014). Therefore, especially, Scenario 1 represents an extreme variant, only meant to establish the maximum economic effect that could follow from possible natural gas flow disruptions.

3. Results

3.1. Base scenario with natural gas dependencies

First, the base scenario, with which the natural gas disruption scenarios need to be compared, is set up. For this scenario we exclude the discrepancy column present in the IRIOT (Tukker et al., 2013) and we also exclude all changes in inventories and valuables. Both types of data do not represent actual economic transactions for which we assume that economic actors will try to maintain them as much as possible. The removal of these data results in an IRIOT in which supply does not equal demand. In the base scenario, this equilibrium is restored using the base model, i.e., Equations (1)-(3). The specific functional form of the objective function can be used in this case, as all negatives are removed from the data.

To evaluate the resulting change in the IRIOT, the mean absolute percentage error (MAPE) and the weighted mean absolute percentage error (WAPE) are used.[2] The MAPE is found to be 387% and the WAPE is equal to only 0.11%, which indicates that large percentage changes predominantly occur in the smallest cells of the IRIOT. The size of the world economy, as measured by world GDP, which relates to the largest cells, was equal to 34,009 billion Euros in the original IRIOT, whereas in the base scenario IRIOT the total is 34,002 billion euros (99.98% of the original total). Hence, we conclude that the base scenario IRIOT is sufficiently close to the original IRIOT to serve as the starting equilibrium for the scenario simulations.

Using the outcomes of the base scenario IRIOT, new coefficient matrices for $a_{ij}^{\bullet s}$ and c_j^s are calculated, which are used for the disruption scenarios. Also, all values with *ex* in Equation (1) are replaced with the corresponding values of *bm*, where *bm* indicates the base scenario values. In addition, the initial market equilibrium, from which the optimization procedure starts, is updated to the outcome of the base scenario. For each scenario this procedural starting IRIOT is adjusted such that the cells directly affected by the scenario are already set equal to zero, in order to speed up the convergence of the non-linear programming algorithm.

To better interpret the results of the disruption scenarios, Table 4 summarizes the role of the Russian natural gas in the base scenario. The first two columns show the importance of the various buyers from a Russian perspective. They show that especially South-West Europe and East Europe are important buyers of the Russian gas, while most natural gas flows to the secondary sector and the electricity from gas sector. For North-East Europe, these two sectors also demand most of the gas supplied by Russia. The last two columns of the table show the importance of the Russian gas supplies from the perspective of the buying sectors and regions. This shows that North-West Europe is hardly dependent on imports of Russian gas, due to its availability of large quantities of local natural gas, whereas East Europe is very dependent on Russian natural gas.

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[2] $\text{MAPE} = \sum_{i=1}^{n} \left|\frac{ex_i - bm_i}{ex_i}\right| * \frac{100\%}{n}$, and $\text{WAPE} = \frac{\sum_{i=1}^{n} |ex_i - bm_i|}{\sum_{i=1}^{n} ex_i} * 100\%$, where ex_i represents the original IRIOT values, and bm_i represents the base model IRIOT values (i.e. z_{ij}^{rs}, v_{ij}^{rs} and y_{ij}^{rs}).

Table 4: Russia's natural gas sector's role as supplier

Region	Sector	Sales of Russian gas to a specific region-sector in million €	Sales to a region-sector as % of total output of the Russian gas†	Russian sales as % of total gas inputs per region-sector	Russian sales as % of total gas imports per region-sector
North-West Europe	Primary	0.1	0%	0%	8%
	Natural gas extract.	0.1	0%	0%	2%
	Other energy extr.	0.2	0%	0%	1%
	Secondary	1.4	0%	0%	2%
	Electricity from gas	0.3	0%	0%	2%
	Tertiary	0.2	0%	0%	1%
	Final demand	0.4	0%	0%	2%
South-West Europe	Primary	1.8	0%	4%	4%
	Natural gas extract.	0.4	0%	2%	5%
	Other energy extr.	0.9	0%	2%	5%
	Secondary	277.7	6%	4%	4%
	Electricity from gas	477.7	11%	7%	8%
	Tertiary	21.1	0%	2%	4%
	Final demand	73.2	2%	2%	4%
East Europe	Primary	2.1	0%	35%	41%
	Natural gas extract.	10.4	0%	18%	92%
	Other energy extr.	2.8	0%	12%	67%
	Secondary	514.9	12%	31%	41%
	Electricity from gas	411.3	9%	35%	50%
	Tertiary	278.4	6%	73%	87%
	Final demand	5.4	0%	12%	21%
North-East Europe	Primary	0.5	0%	11%	11%
	Natural gas extract.	0.0	0%	18%	20%
	Other energy extr.	0.0	0%	19%	19%
	Secondary	44.5	1%	18%	18%
	Electricity from gas	79.7	2%	81%	81%
	Tertiary	1.0	0%	6%	6%
	Final demand	4.1	0%	13%	13%

† In total 48% of Russian natural gas flows to EU regions.

3.2. Trade adjustments in the four scenarios

Given the Leontief technology restriction (2), substitution between products of different sectors is ruled out. However, local products may be substituted for products of the same sector from a different country. We therefore, first, focus on the shift in trade shares in each gas export ban scenario.

3.2.1. Import patterns for each of the regions under all scenarios

To assess the impact on trade patterns, we study the import and self-sufficiency shares (in short: import shares) for each region-sector combination for the base model and for each scenario. These shares are defined relative to the total use of the product at hand as shown in the Equation (5). This allows us to focus on the geographical origin of the inputs from the natural gas sector.

$$\boldsymbol{t_{ij}^{rs} = z_{ij}^{rs} / \sum_r z_{ij}^{rs}}, \qquad \boldsymbol{tf_i^{rs} = f_i^{rs} / \sum_r f_i^{rs}} \tag{5}$$

Table 5 shows these intermediate demand and final demand import shares under the various scenarios. The supply of natural gas from North-East Europe is not shown, as it equals zero in all cases.

Table 5: Intermediate and final demand import shares of natural gas for each affected region*

5-A	Intermediate demand import shares					Final demand import shares				
North-West Europe	B. Sc.	Sc. 1	Sc. 2	Sc. 3	Sc. 4	B. Sc.	Sc. 1	Sc. 2	Sc. 3	Sc. 4
North-West Europe	99.4	99.4	99.4	99.4	99.4	99.2	99.1	99.2	99.1	99.2
South-West Europe	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
East Europe	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Russia	0.0	-	0.0	0.0	-	0.0	-	0.0	0.0	-
Rest of the World	0.2	0.3	0.2	0.2	0.2	0.5	0.6	0.5	0.5	0.5

5-B	Intermediate demand import shares					Final demand import shares				
South-West Europe	B. Sc.	Sc. 1	Sc. 2	Sc. 3	Sc. 4	B. Sc.	Sc. 1	Sc. 2	Sc. 3	Sc. 4
North-West Europe	44.0	45.1	43.8	42.9	46.0	57.4	58.0	57.3	57.0	58.2
South-West Europe	13.2	14.1	13.3	13.2	13.8	39.2	40.9	39.2	38.9	40.6
East Europe	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Russia	5.1	-	5.2	6.4	-	2.4	-	2.5	3.1	-
Rest of the World	37.7	40.8	37.7	37.5	40.2	1.0	1.1	1.0	1.0	1.1

5-C	Intermediate demand import shares					Final demand import shares				
East Europe	B. Sc.	Sc. 1	Sc. 2	Sc. 3	Sc. 4	B. Sc.	Sc. 1	Sc. 2	Sc. 3	Sc. 4
North-West Europe	22.6	39.8	22.4	39.8	21.5	12.2	16.5	12.1	17.4	11.8
South-West Europe	5.7	10.6	5.7	10.7	5.3	10.9	16.2	10.9	15.4	10.5
East Europe	27.3	31.7	27.1	31.7	26.1	41.0	32.2	41.1	32.7	41.2
Russia	36.6	-	37.0	-	39.9	12.1	-	12.4	-	13.4
Rest of the World	7.9	17.9	7.8	17.7	7.2	23.8	35.0	23.6	34.4	23.2

5-D	Intermediate demand import shares					Final demand import shares				
North-East Europe	B. Sc.	Sc. 1	Sc. 2	Sc. 3	Sc. 4	B. Sc.	Sc. 1	Sc. 2	Sc. 3	Sc. 4
North-West Europe	54.0	81.6	82.0	50.8	51.8	71.4	80.4	81.7	68.7	69.4
South-West Europe	1.6	2.1	2.0	1.5	1.5	7.9	9.6	9.0	7.7	7.8
East Europe	0.1	0.1	0.1	0.0	0.1	0.3	0.2	0.3	0.2	0.3
Russia	34.7	-	-	38.3	37.5	12.6	-	-	15.8	14.9
Rest of the World	9.7	16.2	15.9	9.4	9.1	7.9	9.8	9.0	7.7	7.7

* In scenarios indicated by a black border, the region is directly impacted (zero imports from Russia).

For North-West (NW) Europe and South-West (SW) Europe Table 5-A and Table 5-B, respectively, show that the trade patterns for these regions do not change much even if they are fully cut off from Russian gas. In Table 5-B, we see that SW Europe relies most on NW Europe and Rest of the World for its intermediate gas supplies. The final demand import shares react notably different from the intermediate demand import shares; most natural gas is sourced close to home, in NW and SW Europe itself. Scenario 4 shows that, if possible given the production restrictions, preference is given to NW European gas over additional own production and supplies from the Rest of the World. The share imported from NW Europe is higher in scenario 4, than in Scenario 1, where also East Europe and NE Europe demand additional gas from NW Europe.

For East Europe, Table 5-C shows that the reliance on Rest of the World increases relatively most, followed by SW Europe and only then NW Europe. Still, instead of Russia, NW Europe is the largest supplier for the scenarios under which East Europe is directly affected. For the scenarios where the region is not directly affected, the supply share of NW Europe actually decreases somewhat.

North-East Europe in Table 5-D is a special case. Four of the five countries of this region (the Baltic States and Finland) are almost fully dependent on Russia for their gas supplies, whereas Sweden fully relies on gas supplies from NW Europe. Since the natural gas demand in Sweden is relatively high compared to the other four countries, the intermediate and final demand import shares as regards NW Europe are relatively high for this heterogeneous region. The possibility of additional supply from NW Europe will, in the current situation, therefore will actually be lower than shown in Table 5-D.

For the last three scenarios, in the Tables 5-B to 5-D, we see that if a region is not directly affected by the export ban, it will actually import a somewhat larger share of natural gas from Russia, as Russia will look for alternative buyers. Our model thus simulates reality in that it does not allow for an extreme switch to Russian gas because of the assumption that under each disruption all economic actors will attempt to maintain as closely as possible to their business-as-usual flows.

3.2.2. Change in the supply of natural gas sectors in the different regions

Table 5 considered the spatial origin of the trade in natural gas in the different scenario´s. Table 6 instead focusses on the change in supply of natural gas and its spatial destination. The latter table reports these changes as a percentage of the base scenario´s total supply of natural gas by producing country.

In Scenario 1, the fall in supply from Russia is clearly largest for SW Europe (–19.31%) and East Europe (–27.75%). Russia itself absorbs some of this fall in exports domestically, as does the Rest of the World to a greater extend (+6.34%). However, the total output of the Russian natural gas extraction sector will still fall with as much as -41.42%, which will definitely hurt the Russian economy as we will be shown in Table 8.

The most notable increase in supply (+11.52%) is the additional percentage that East Europe supplies to itself for both scenarios that affect the region directly. With this increase, East Europe is the only region that hits the maximum production capacity that we defined exogenously in Table 2. In contrast, in the two scenarios where East Europe is not directly hit, the supply of its own natural gas sector falls, as Russia will then sell more to East Europe.

Also remarkable are the changes in the supply of NW Europe, not because they are large, but because they are small. This is the more remarkable because we know from Table 5 that all regions import more from NW Europe when they are affected, especially East Europe and North-East Europe. The explanation is that the domestic use of natural gas in North-West Europe is large compared to the demand from the other regions, which makes the percentage point changes in its exports small.

Comparing the sum of the different scenarios in which a subset of the regions is affected (Scenarios 2-4) with Scenario 1, the sum of the ‘individual’ scenarios generally turns out to be smaller than the changes in supply in Scenario 1. When the shock is smaller, there is obviously more flexibility in finding substitute sources of supply then when all regions are affected simultaneously.

Table 6: Change in sales of the natural gas sector by region of origin, as a percentage of total output

	Regions of destination of natural gas sales						Total change
Scenario 1: all EU	NW	SW	East	NE*	Russia	RoW	
North-West Europe	-0.55	0.10	1.46	0.25	0.00	-0.10	1.16
South-West Europe	0.08	2.08	3.74	0.04	0.00	-0.56	5.38
East Europe	-0.05	-0.21	11.52	-0.01	-0.02	-1.23	10.00
Russia	-0.06	-19.31	-27.75	-2.94	2.31	6.34	-41.42
Rest of the World	0.00	0.31	0.21	0.01	-0.11	-0.30	0.12
Scenario 2: NE Europe	NW	SW	East	NE*	Russia	RoW	
North-West Europe	-0.05	-0.12	-0.02	0.25	0.00	-0.01	0.06
South-West Europe	0.00	-0.01	-0.02	0.04	0.00	0.06	0.07
East Europe	0.00	0.00	-0.52	0.01	0.00	0.01	-0.49
Russia	0.00	0.50	0.36	-2.94	0.13	0.24	-1.70
Rest of the World	0.00	0.00	0.00	0.01	-0.01	-0.01	0.00
Scenario 3: East Europe	NW	SW	East	NE*	Russia	RoW	
North-West Europe	-0.33	-0.66	1.45	-0.03	0.00	-0.02	0.41
South-West Europe	0.02	-1.48	3.78	-0.01	0.00	0.07	2.39
East Europe	-0.04	-0.20	11.52	-0.02	-0.02	-1.24	10.00
Russia	0.02	4.90	-27.75	0.32	1.00	2.56	-18.94
Rest of the World	0.00	-0.02	0.21	0.00	-0.05	-0.11	0.03
Scenario 4: SW+NW	NW	SW	East	NE*	Russia	RoW	
North-West Europe	-0.22	0.63	-0.09	-0.02	0.00	-0.02	0.28
South-West Europe	0.00	1.77	-0.29	0.00	0.00	0.18	1.66
East Europe	0.01	0.03	-3.56	0.00	0.00	0.17	-3.35
Russia	-0.06	-19.31	2.64	0.25	0.71	1.80	-13.98
Rest of the World	0.00	0.25	-0.01	0.00	-0.04	-0.13	0.06

Note: the changes within the marked and darker shaded boxes represent the values that are set to zero.
In all cases where the 2-digit value is equal to 0.00, a minus sign is included if the (small) change is negative.
* North-East Europe is not included as a row in the different scenarios due to the non-existing gas extraction.

3.2.3. Impacts on the trade balances

The previous sections investigated the changes in trade shares for the natural gas sector only. To place these changes in perspective, the changes in the trade balance for each region are presented here. The balance for each region is calculated as follows.

$$\boldsymbol{b}^{s} = \sum\nolimits_{r\neq s,i,j} \boldsymbol{z}_{ij}^{sr} + \sum\nolimits_{r\neq s,i} \boldsymbol{y}_{i}^{sr} - \sum\nolimits_{r\neq s,i,j} \boldsymbol{z}_{ij}^{rs} - \sum\nolimits_{r\neq s,i} \boldsymbol{y}_{i}^{rs} \tag{6}$$

In Table 7, the first column shows the balance for each region in the base scenario in absolute values. The total of this column equals zero, because total exports equal total imports at the world level. For Russia, the export ban to all of Europe (Scenario 1) has a relatively large negative impact on the value of its trade balance, which is now less positive than in the base scenario. The trade surplus of NW Europe and SW Europe increases in all scenarios. Most remarkable, however, is the relatively small size of the impacts on the trade balances of all scenario´s. This raises the question whether the impact on welfare indicators such as GDP and total final demand will be comparably small.

Table 7: Balance of payments, percentage change compared to base scenario

	B. Sc. (M €)	Sc. 1	Sc. 2	Sc. 3	Sc. 4
North-West Europe	74,110	0.74%	0.05%	0.32%	0.22%
South-West Europe	27,469	1.65%	0.05%	0.69%	0.84%
East Europe	-32,866	-0.41%	0.03%	-0.49%	0.17%
North East Europe	26,185	-0.03%	0.06%	-0.06%	-0.05%
Russia	45,194	-3.12%	-0.13%	-1.41%	-1.05%
Rest of the World	-140,092	-0.20%	0.00%	-0.05%	-0.11%

3.3. Impact on value added

The changes in trade patterns in Table 5 and Table 6 influence value added generated in each region-sector. Table 8 shows the change in value added for the three smaller sectors for each region separately. The three large sectors (primary, secondary and tertiary) are only represented indirectly by the total change of GDP, because the changes in terms of inputs from the natural gas sectors, and other shifts in the input structure, are relatively small compared to the overall size of these sectors.

Alike the changes in trade shares, we see again that the overall change in value added for Scenario 1 is larger than the sum of the changes in the three sub-scenarios. Clearly, in the case of complete Russian gas export ban to the entire EU, fallback systems, where other regions step in for the loss of Russian supply, are also hit, including the feedback loops between these systems, resulting in a larger impact than with the sum of parts.

At the level of the three small sectors, the behavior of the gas extraction sector, on the one hand, and the other energy extraction and the electricity from gas sectors, on the other hand, is opposite in almost all cases. The equal signs of the changes for both the other energy extraction sector and the electricity sector indicate that the theoretical possibility of indirect technical substitution does occur in our model simulations. The aggregate character of the other three sectors, obviously, prevents this indirect substitution to dominate the direct technical complementary assumed in Equation (2).

The opposite sign of the changes in, especially, the electricity from gas sector and the gas extraction sector requires a longer explanation. The increases in local gas extraction in the EU regions, in fact, occur to compensate for the drop in Russian imports, but this compensation appears to be partial, and, therefore, it is combined with an opposite change in the use of gas by the electricity from gas sector. The case of East Europe is especially interesting in both cases where it is not itself subject to a Russian export ban, i.e., in the Scenario´s 2 and 4. In those cases, Russia will increase its exports to East Europe, its largest customer in the EU, in order to compensate for its losses in the rest of the EU. Consequently, we see an increase in the output of the electricity from gas sector in East Europe combined with a decrease in its home extraction of natural gas.

Furthermore, in all scenarios, we see that the change in the local natural gas extraction sector determines the sign of the change in total GDP for almost all regions. Higher order spatial substitution processes mitigate the direct impact on the natural gas extraction sector, but do not change the sign of its impact on total value added. The exception is North-East Europe that does not have a natural gas extraction sector. In that case, we see that the change in the secondarily impacted sector, i.e., the electricity from gas sector, determines the sign of the total GDP impact.

As to the size of the total GDP impact, the only region that really suffers from the export bans is Russia itself, but even that impact is almost negligible at the level of the aggregate economy, i.e., –0.5% in case of the maximum supply shock of Scenario 1. NW and SW Europe profit from all four types of export bans, but their gains are both absolutely and percentagewise much smaller that the already small losses for Russia.

Table 8: Percentage change in value added in the gas-related sectors and the total economy

Scenario 1: all EU	NW	SW	E	NE	Russia	RoW
Natural gas extraction	1.16	5.38	10.00	-	-41.42	0.12
Other energy extraction	-0.02	-0.01	-0.07	-0.07	0.01	-0.00
Electricity from gas	-0.28	-0.47	-7.50	-8.48	1.74	-0.05
Total value added	0.01	0.00	0.00	-0.00	-0.50	0.00
Total absolute change*	320	150	18	-9	-1280	105

Scenario 2: NE	NW	SW	E	NE	Russia	RoW
Natural gas extraction	0.06	0.07	-0.49	-	-1.70	0.00
Other energy extraction	-0.00	0.00	0.00	-0.16	0.00	-0.00
Electricity from gas	0.01	-0.00	0.19	-8.18	0.25	-0.00
Total value added	0.00	0.00	-0.00	-0.00	-0.02	0.00
Total absolute change*	16	2	-2	-7	-52	1

Scenario 3: E	NW	SW	E	NE	Russia	RoW
Natural gas extraction	0.41	2.39	10.00	-	-18.94	0.03
Other energy extraction	-0.01	0.00	-0.06	0.04	0.01	-0.00
Electricity from gas	-0.13	0.09	-7.98	0.52	0.46	-0.01
Total value added	0.01	0.00	0.00	0.00	-0.23	0.00
Total absolute change*	113	80	20	0	-588	28

Scenario 4: SW+NW	NW	SW	E	NE	Russia	RoW
Natural gas extraction	0.28	1.66	-3.35	-	-13.98	0.06
Other energy extraction	-0.01	-0.00	0.00	0.01	0.00	-0.00
Electricity from gas	-0.09	-0.35	1.25	0.38	0.26	-0.03
Total value added	0.00	0.00	-0.00	0.00	-0.17	0.00
Total absolute change*	77	37	-14	0	-435	47

* in absolute M€ compared to base model

3.4. Impact on total domestic consumption

As a second measure of welfare, next to value added, and in fact even more relevant for domestic welfare, we also look at the impact of the four scenario´s on domestic final demand.

The changes in the underlying final demand import and self-sufficiency shares of the directly impacted gas extraction sector were shown in Table 5. The associated impact on the volume of the final consumption of natural gas, irrespective of its geographic origin, is shown in Table 9. Again note that the sum of the Scenario´s 2 to 4 is smaller than the impact of the combined Scenario 1. Furthermore, it is obvious that the domestic consumption of the more abundant natural gas in Russia will increase in all scenarios, whereas the natural gas consumption of the European regions decreases in almost all cases.

Interesting are the two plusses. Take the +2.6% of the consumption of natural gas in East Europe in case of a supply shock in SW and NW Europe (Scenario 4). East Europe being near, obviously, serves as a substitute market for Russian gas in that case. The same holds for the +0.2% increase in North -East Europe, in case of a supply shock in East Europe (Scenario 3). The most puzzling outcome of Table 10 seems to be the decrease in the consumption of natural gas in the RoW. However, this can also be explained easily. The strong increase in the exports of natural gas from the RoW to the boycotted regions of Europe partly goes at the cost of their local consumers.

Table 9: Change in the final consumption of natural gas, in percentages

	B. Sc. (abs. M€)	Sc. 1	Sc. 2	Sc. 3	Sc. 4
North-West Europe	2,533	-8.2	-0.8	-4.7	-3.4
South-West Europe	3,075	-7.7	-0.6	-4.0	-4.8
East Europe	44	-32.5	-0.1	-32.2	2.6
North-East Europe	32	-16.7	-13.1	0.2	-1.0
Russian Federation	21	46.2	1.2	15.3	9.3
Rest of the World	26,674	-0.9	0.0	-0.2	-0.4

Finally, consider Table 10 that shows the impacts of the four scenarios on the welfare of the population of the regions involved. Remarkably, in contrast with the negative impact on GDP, the Russian population will benefit from the Russian refusal to export its natural gas to parts or the whole of the EU. Part of the reason for this outcome is the increase of the domestic consumption of natural gas shown in Table 9. The other part of the reason is summarized in Table 7, which shows a decrease of its trade balance surplus, which enables Russian consumers to consume more of the negatively impacted domestic value added. Whether this change is sustainable in the longer run may be doubtful, but in the short run, which is the focus of our model, this impact is quite likely.

The reverse impact may be observed for most European regions with most scenario´s. There, increases in total value added, concentrated in the local gas extraction sector, go together with decrease of total domestic consumption. Again, part of the reason is found in the lower consumption of natural gas shown in Table 9, and another part of the reason is found in the more positive trade balances in Table 7.

Table 10: Change in total final consumption, in percentages

	b.sc abs 1,000 M€	Sc. 1	Sc. 2	Sc. 3	Sc. 4
North-West Europe	2,166	-0.011	-0.001	-0.006	-0.004
South-West Europe	5,524	-0.005	0.000	-0.002	-0.004
East Europe	717	-0.016	0.001	-0.020	0.006
North-East Europe	355	0.000	-0.006	0.005	0.004
Russian Federation	212	0.062	0.002	0.024	0.018
Rest of the World	25,027	-0.001	0.000	0.000	0.000

4. Conclusion and evaluation

In this paper we have analyzed several scenarios pertaining to reductions or obstructions in the supply of natural gas across country borders. The pattern of impacts found with our new modelling approach reflects the partially compensating and partially enhancing simultaneous forces of supply and demand and spatial substitution effects. At the lower levels of aggregation, for example for the import and self-sufficiency shares for the use of natural gas, considerable effects are found. At the aggregate level of the whole economy of the regions studied, however, the effects of Russian natural gas export bans are negligible for Europe and only a little less so for Russia itself. Interestingly, the effects on the size of the economy, as measured by its GDP, are predominantly positive for the

European regions, but negative for Russia. The effects on the welfare of the populations involved, however, as measured by the size of the domestic final demand, have an opposite sign; with predominantly negligible but negative effects for the European regions, and very small positive effects for the Russian population.

In view of this empirical conclusion, the question arises whether the outcome of negligible impacts of various Russian export stops is not overly optimistic and due to the aggregate character of the present simulations. This question can be considered from a sectoral aggregation perspective and a spatial aggregation perspective. First consider the sectoral aggregation used in this application. Having a further disaggregation of sectors that use natural gas intensively might show vulnerabilities that now remain undetected. On the other hand, however, separating the electricity production based on other energy carriers from the secondary sector and allowing for technical substitution between the different types of electricity will introduce more flexibility, and thus mitigate the present negative forward effects from electricity on the secondary sector.

Next, consider the spatial aggregation. Having a further disaggregation between the different EU member states will allow modeling the fragmentation of the EU natural gas market by introducing bilateral trade capacity constraints, which reflect the actual natural gas pipeline capacities. The model then would not depict the presently assumed full flexibility of the interregional EU natural gas trade, which will most certainly lead to several eastern EU-countries being hurt more and maybe some northwestern EU-countries being hurt less than is shown in the present simulation outcomes. In any case, this new modeling approach appears to be promising and, for the moment, confirms the EU expectation that it could well cope with the consequences of a Russian gas boycott.

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Appendix A: Data aggregation

Country aggregation

North-West Europe	
(5 countries)	Denmark
	Ireland
	Netherlands
	Norway
	United Kingdom

South-West Europe	
(9 countries)	Belgium
	France
	Germany
	Italy
	Luxembourg
	Malta
	Portugal
	Spain
	Switzerland

East Europe	
(10 countries)	Austria
	Bulgaria
	Cyprus
	Czech Republic
	Greece
	Hungary
	Poland
	Romania
	Slovak Republic
	Slovenia

North-East Europe	
(5 countries)	Estonia
	Finland
	Latvia
	Lithuania
	Sweden

Russian Federation	
(1 country)	Russia

Rest of the World	
(13 countries	Australia
+ original RoW region)	Brazil
	Canada
	China
	India
	Indonesia
	Japan
	Mexico
	South Africa
	South Korea
	Taiwan
	Turkey
	United States
	Rest of World (region)

Sector aggregation

Code	**Aggregate sector**
i01.a – i05	Primary sector
i10	Other energy extraction
i11.a	Other energy extraction
i11.b	Natural gas extraction
i11.c	Other energy extraction
i12	Other energy extraction
i13.1 – i14.3	Primary sector
i15.a – i40.11.a	Secondary sector
i40.11.b	Electricity from gas
i40.11.c – i45	Secondary sector
i50.a – i99	Tertiary sector

Aggregate sector	**# of subsectors**
Primary sector	27
Natural gas extraction	1
Other energy extraction	4
Secondary sector	62
Electricity from gas	1
Tertiary sector	34

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