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Sharing the Pain from a Potential Russian Gas Shut-off to the European Union

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Sharing the Pain of a Potential Russian Gas Shut-off to the European Union

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ABSTRACT: We assess the supply-side effects on European Union (EU) economic activity if Russian gas imports were to suddenly cease. Unlike other studies, we account for the global scope of the liquefied natural gas (LNG) market. In the absence of frictions, an open-economy, multi-sector general equilibrium model suggests that the adverse economic impact on the EU shrinks five-fold if integration with the global LNG market is considered. While greater integration provides a buffer for the EU through trade, the flip side is that other LNG importers (such as Japan, South Korea, and Pakistan) see adverse effects from higher prices.

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1 Introduction

Motivated by the sharp rise in geopolitical tensions from the war in Ukraine, a recent flurry of studies has attempted to gauge the potential economic effects of sanctions, particularly on energy commodities. Our contribution in this paper is to quantify the role of access to the global liquefied natural gas (LNG) market in buffering the economic impact of a Russian gas shut-off on Europe. More specifically, we examine how a cessation of Russian gas exports would impact the European Union (EU) at the aggregate and member country level, over a one year period, with and without integration into the global LNG market. We also assess the economic spillovers for non-EU economies that are integrated into the global LNG market.

To make our calculations, we build on the approach of Bachmann, Baqaee, Bayer, Kuhn, Löschel, Peichl, Pittel, Moll, and Schularick (2022), who provide estimates of the aggregate output effects of a Russian natural gas shut-off to Germany. Bachmann et al. (2022) use the sufficient statistics result for the economic activity effects of input shocks from the Baqaee and Farhi (2019a) model, making ad-hoc assumptions about the size of changes in natural gas expenditure shares. We extend their approach by combining the sufficient statistic with the results from a competitive model of the global liquefied natural gas (LNG), in which quantities fully adjust to prices and markets clear. By taking into account the global LNG market, we are able to compute the price effect of the supply shock as well as supply and demand responses at the relevant market scale, recovering the endogenous changes in gas expenditures shares.

We find that properly accounting for the global LNG market reduces the adverse economic impact of a cessation of Russian gas exports on the EU by a factor of five, but with significant global spillovers. Based on our model, the shut-off would lead to a decline in EU gross national expenditure (GNE)[1] of about -0.4 percent one year after the shock when taking into account the global LNG market. Assuming that the shock is only absorbed by the EU natural gas market as counterfactual, the negative effect on economic activity grows to between -1.4 and -2.5 percentage points, depending on the specific demand elasticities.

At the same time, the integrated global LNG market leads to substantial negative

[1]We follow Baqaee and Farhi (2019a) and focus on GNE or domestic absorption (total spending made by households, firms and governments in an economy, including for consumption and investment). We use GNE over gross domestic product because it has a welfare interpretation, whereas Gross Domestic Product does not. Note that in the Baqaee and Farhi (2019a) model, nominal GNE is equivalent to nominal Gross National Income. GNE and GDP losses are approximately similar in practice. See section 4.

spillover effects from the rise in prices to countries outside of the European Union, mostly in Asia. In fact, the effects on economic activity for Asia buyers of LNG such as Japan, Korea, and Pakistan are broadly similar in magnitude to those for the EU as a whole, since prices increase in lock-step and demand accordingly adjusts in these countries.

Even with access to the global LNG market, gas prices in the EU would still rise about 100 percent, but they would increase substantially more without global market integration, climbing from 370 to 1,000 percent over their 2022:Q1 levels. Moreover, with access to the global LNG market, output (real economic activity) effects are not overly sensitive to alternative assumptions on demand elasticities. Although a lower price elasticity of demand pushes prices significantly higher with the Russian gas shut-off, the negative effect on the EU's gas consumption is diminished, as demand also adjusts in the global LNG market. In other words, the global LNG market acts as a shock absorber and helps to share the economic pain from the Russian gas shut-off.

There are three caveats to our findings.

First, these estimates represent a first-round, largely supply-side based approximation of the output impacts of the cessation of Russian gas exports. Specifically, the scenarios exhibited here do not account for potential negative aggregate demand effects of the shock, its effects on uncertainty, international spillovers nor any endogenous monetary and fiscal policy responses to offset the shock's effects. For example, if the central bank were to tighten policy in response to higher gas prices (due to its inflationary effects), this could exacerbate the negative effects on activity by further contracting aggregate demand. Related, if fiscal policy were to allow automatic stabilizers to operate or possibly provide discretionary support, this could offset some of the drop in demand stemming from eroded real incomes. We believe that if new-Keynesian business cycle amplification effects were included, the output effects could double.

Second, our approach assumes a fully-integrated global market and that prices are fully passed-through to consumers. However, in a shut-off scenario, infrastructure bottlenecks could fragment markets in some countries. Moreover, price pass-through could be dampened by government interventions. For countries where physical shortages appear, our estimates would be applicable only after markets reintegrate and prices accurately reflect market conditions.

Third, the size and persistence of the shock from an abrupt Russian gas shut-off would be unprecedented for natural gas markets. The lack of historical episodes for comparison is why a scenario, model-based approach is required.

The fast-growing literature on the effects of sanctions related to energy commodities for the EU and European countries has generated a wide array of estimated effects, reflecting differences in modeling frameworks and assumptions. Compared to many studies, our benchmark estimates are lower, as the buffering role of the global LNG market is powerful. Bachmann et al. (2022) find a higher impact on economic activity of a Russian gas shut-off by not taking into account the global LNG market: a Russian natural gas shut-off would affect German GNE by -0.72 percent, assuming a 30 percent gas supply shock, leading to a tripling in the German gas import share. Their estimate climbs to -2.3 percent with elasticities of substitution substantially below estimates from the literature. Using a similar framework but incorporating adverse uncertainty as well as second-round effects, Lan, Sher, and Zhou (2022) estimate that Germany's real GDP is estimated to fall below its baseline path by 1.4 percent in 2022, 2.7 percent in 2023 under the assumption that households adjust consumption very little. Using a multi-sector, partial equilibrium model with demand spillovers, DiBella, Flanagan, Foda, Maslova, Pienkowski, Stuermer, and Toscani (2022) find an average effect of -1.8 percent on EU countries' GDP. Other studies focus on energy imports from Russia more broadly (see Langot and Tripier (2022), Baqaee, Moll, Landais, and Martin (2022), Chepeliev, Hertel, and Mensbrugghe (2022), European Central Bank (2022) and others) and find heterogeneous effects across countries, reflecting country-specific differences.The European Central Bank (2022) takes into account aggregate demand effects of a broader energy shut-off due to nominal rigidities.

Our paper also contributes to the large literature on how supply shocks to the economy may propagate. Recent evidence from case studies suggests that there is often a greater capability for economies to adjust to input supply shocks than would be implied by an engineering view of production (see Carvalho, Nirei, Saito, and Tahbaz-Salehi, 2021; Gholz and Hughes, 2021; Ilzetzki, 2022; Bachmann et al., 2022, among others). These case studies illustrate channels of adjustment to input supply shocks at the macroeconomic level, including shifting to alternative domestic or international supplies, substituting with alternative factors as possible given cross-elasticities of substitution among inputs, reallocating production toward more efficient producers, and spurring innovation to make production processes more robust to such shocks. In particular, our paper provides evidence on how the size of the market that is hit by the supply shock is a major determinant for its effect on domestic, aggregate activity.

The remainder of the paper is structured as follows. Section 2 lays out stylized facts about the natural gas market relevant for our modelling choices. Section 3 presents the LNG market model to derive the price shock and quantity adjustments. Section 4 explains the sufficient statistics theorem and section Section 5 outlines our calibration. Section 6 presents our results. Finally, section 7 discusses limitations of our analysis and section 8 concludes.

2 Natural Gas Markets

2.1 To What Extent are Markets for Natural Gas Globally Integrated?

Natural gas markets are globally quite segmented due to infrastructure requirements for transportation such as pipelines and LNG import and export terminals. Global natural gas consumption was roughly 3,850 billions of cubic meters (Bcm) in 2019 based on data from British Petroleum. Roughly 3,000 Bcm is pipeline gas that is mostly not integrated at global scale. These supplies are priced with different pricing formulas, involving a mix of oil and regional gas prices.

The size of the EU's gas market totals about 400 Bcm of annual gas consumption.[2] Domestic production covers roughly 45 Bcm, net LNG imports roughly 70 Bcm, while the remainder (roughly 285 Bcm - net imports) is imported through pipelines. About 145 Bcm of pipeline gas originates from Russia.

The European market has become increasingly integrated with the global LNG market and is now realtively well-connected to it. LNG trade has strongly picked up since the United States lifted its export ban and firms have built more and more LNG import and export facilities around the world. Non-EU LNG consumption is about 436 Bcm (see BP, 2022). Major economies are the United Kingdom, China, India, Japan, Pakistan, South Korea, and Taiwan

[2] Data cited here are sourced from (see Eurostat, 2022)

Province of China.[34]

As a result, LNG prices around the world and European reference prices such as the leading European benchmark, the Dutch Title Transfer Facility (TTF) Virtual Trading Point gas price, have moved strongly upward over the last half year, even though spreads have widened. Substantially higher price levels in both the EU and the global LNG market imply that the effects of higher gas prices lead to demand compression not only within the EU but also in other LNG importing countries (see Figure 1), and LNG cargo are rerouted to Europe.

About 70 percent of global LNG trade is traded via long-term contracts which fix minimum gas volumes. However, the pricing formulas are often linked to major gas benchmarks such as the Dutch TTF or the Korean/Japan marker.[5] Moreover, a sizable share of long-term contracts is with traders that resell LNG to customers at shorter notice on the spot market. When arbitrage opportunities arise LNG cargoes are rerouted from Asia to Europe or vice versa. Recently, Asian customers on long-term contracts with US or Australian LNG sold their LNG cargos on the European spot market.

[3] In addition to LNG, some of these economies are also supplied by pipeline gas, typically under long-term contracts, most of which are still linked to oil prices (especially in Asia). We consider this pipeline gas a non-tradable commodity due to price fragmentation and infrastructure constraints. The only exception is the United Kingdom, because the country is integrated with the European pipeline network.

[4] Based on IMF policy guidelines for IMF publications.

[5] In the past, most gas contracts where linked to oil prices, since gas was seen mostly as by-product of oil extraction. In the last decade, thanks to the shale gas revolution the popularity of linking gas prices to oil prices has substantially declined.

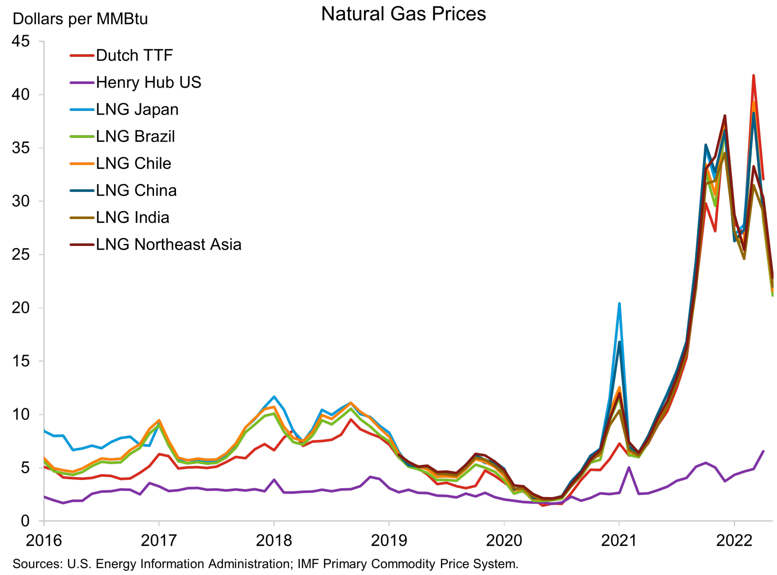

Figure 1: EU Gas and Asian LNG markets are integrated.

The North American natural gas market is only partially integrated with the global LNG market. Natural gas prices in the U.S. have not increased in line with European and Asian and other LNG benchmark prices (see Figure 1). Infrastructure constraints in the form of LNG export terminals limit the amount of gas that can be exported. US LNG export terminals are at full capacity due to high global demand. Capacity keeps expanding, but there are lags in building terminals of two to four years.[6] To obtain bank financing for these 10 to 15 billion USD projects, LNG companies need to secure 15-20 years contracts with overseas customers.

2.2 What are the Frictions within the European Union's Gas Market?

The natural gas market in the European Union is, in principle, relatively well integrated but there are potential frictions in the event of a stop in Russian gas imports. Europe can leverage on (i) non-Russian LNG imports, (ii) EU cross-border pipeline capacity and (iii) storage facilities. However, infrastructure would partially need to be reconfigured.

Non-Russian[7] import capacity in the European Union is substantial. It amounts to 257 Bcm by pipeline and to 232 Bcm by LNG per year (European Network of Transmission System Operators, 2022b)[8], compare to about 400 Bcm of annual consumption (International Energy

[6] A substantial increase in US LNG export capacity is expected for the end of 2023 or 2024.
[7] This does also not include pipelines that go through Ukraine and Belorussian but originate in Russia.
[8] ENTSOG is an industry association of 42 European pipeline operating companies

Agency, 2022). Out of the total LNG import capacity of 232 Bcm, only 31 percent was used in 2021 according to Kpler (2022). Recent utilization has gone up significantly but capacity is still only at 53 percent on an annual basis in April 2022. Countries have also started to install floating LNG import terminals to add more capacity.

The European pipeline network is quite integrated in most regions and most countries in the European Union have substantial within EU cross-border pipeline capacity that is not linked to Russia. For example, Germany has a total pf 114 Bcm of capacity from Norway, Austria, Belgium, Switzerland, Denmark, and the Netherlands, while total annual consumption is 94 Bcm according to European Network of Transmission System Operators (2022b).[9]

However, potentially regional bottlenecks could show up in the case of a Russian gas shut-off as the European pipeline infrastructure for natural gas is still partially geared towards imports from Russia. In the event of a Russian gas shut-off, more imports would flow through LNG import terminals and pipelines from Norway, North Africa and through Turkey. As a consequence, some pipeline flows would need to be reversed from West to East. Potential pipeline bottlenecks between Spain and France, Italy and Central Europe, Central Europe and South-Eastern Europe as well as within Germany and Italy could appear if consumption does not adjust according to the European Network of Transmission System Operators (2022a). The actual extent and timing of potential bottlenecks are hard to predict as higher prices also induce demand compression and consumption also varies with winter weather conditions. Physical shortages could appear and the market could break down in individual countries or governments could step-in with quantity regulations.[10] The pipeline bottleneck between France and Spain also restricts the amounts of LNG that could be imported into Spain and then distributed to central Europe. In anticipation, the private sector and governments are working on mitigating this risk by purchasing additional LNG import terminals, foster storage, and installing additional technology to reroute pipelines.

Natural gas storage facilities are also available across member countries to partially

[9]The data refer to contractually guaranteed gas transmission capacity as submitted by European transmission system operators (TSOs). The actually peak capacity can be higher. Data do not take into account reductions in capacity due to maintenance. Gas import and production capacity, as well as trade agreements, may limit the actual amount of gas that can be shipped to Germany through these pipelines.

[10]DiBella et al. (2022) show that Hungary, Slovakia and the Czech Republic are at highest risk, while most EU countries will likely not see physical gas shortages. See European Network of Transmission System Operators for Gas (ENTSOG) (2022) for an overview of potential infrastructure bottlenecks and European Commission (2022) for a list of existing projects to address these.

buffer seasonal variations in demand. They would help to buffer a potential Russian gas cut-off and buy some time. Total EU storage capacity is approximately 103 Bcm and filled 54 percent as of June 20th, according to Gas Infrastructure Europe (2022). However, there is significant heterogeneity in storage capacity and filling levels across countries which could interact with regional bottlenecks (see DiBella et al. (2022). Moreover, the role of storage is mostly to smooth the sizeable seasonal variations in consumption as storage facilities typically target a 90 percent fill by end-September. By the end of the winter season, storage levels are, instead, about 30 percent of their capacity which leave no more than 30 Bcm of "strategic" natural gas storage.

The pass-through from natural gas spot prices to prices for households, industry and the power sector is lagged and not complete. Gas delivery contracts in Europe typically refer to some weighted average at monthly or quarterly frequency of the Dutch TTF gas spot price and futures prices. This is why there is typically a lag in the price pass-through between spot and wholesale prices. Some pipeline gas contracts still rely oil prices for their pricing formulas, such as the Algerian gas. Furthermore, pass-through to households is incomplete and even slower. Contracts for households' gas consumption are often only adjusted once a year. Some governments also prevent the full pass through of wholesale prices to consumers.

Overall, a full natural gas shut-off from Russia would create an unprecedented shock to European natural gas infrastructure. Even though storage would allow households, firms and governments some time for adjustment, there is high uncertainty about potential infrastructure bottlenecks, the scope of the policy response, and the pass-through of prices.

2.3 What is the Relative Size of the Supply Shock from a Russian Gas Shut-off?

We assume a complete and persistent cessation of Russian natural gas exports to the EU. Russian total exports of natural gas to the EU summed up to 155 Bcm in 2021, of which about 13.2 Bcm in LNG form. We assume that Russian LNG exports will be rerouted and are therefore not counted as part of the gas supply shock. The size of the gas supply shock $\Delta \log E$ is, thus, 142 Bcm, about -16.8 percent relative to the combined EU and global LNG gas market of 845 Bcm (see Table 1). The size of the net supply shock relative to the European market is

-34.7 percent. [11]

Russian total gas exports to EU (2021)	-155 Bcm
Russian LNG exports (2021) diverted to other places	+13.2 Bcm
Size of supply shock	**-141.8 Bcm**
Size of EU natural gas market	409 Bcm
Size of the global LNG market (including UK)	436 Bcm
Total size of market	845 Bcm
Size of supply shock in terms of EU and global LNG market	**-16.8%**
Size of EU natural gas market only	409 Bcm
Size of supply shock in terms of EU gas market	**-34.7%**

Table 1: What Would a Russian Natural Gas Shut-off (Supply Shock) Look Like?

Russian pipeline gas can not be rerouted from Europe to other parts of the world. Russia's gas fields in the North and West are only connected to pipelines going to Europe. If the gas flowing from Russian pipelines to Europe is halted, the associated gas production in Russia will have to cease by and large, representing a true supply shock to the global market. The pipeline that connects to China sources its gas from fields in Russia's Far East. China and Russia have agreed to build a second pipeline that would connect to the natural gas fields of the North, but the timeline for full construction is 2030 and its capacity will only cover 1/3 of the current Russian exports to Europe. Building additional LNG terminals and connecting them via pipeline will likely also take a decade when doing so at scale and under sanctions.

2.4 Price Elasticities of Natural Gas Demand and Supply

A key ingredient into the computation of the price and quantity effects are price elasticities of demand and supply. Fuel sustitutability in production and consumption is captured by

[11] Russian LNG exports to Europe are about 13.2 Bcm which are assumed to be rerouted and are thus not counted as part of the gas supply shock.

fuel demand own-price elasticities. Elasticities vary greatly across sectors, are smaller over the short term and larger over the long term. We assume a one-year, short-term horizon and thus use short term elasticities.

In the EU, natural gas accounts for almost 30 percent of the energy source mix, with large heterogeneity across member countries and sectors. It is mostly used for heat production in the household and industrial sectors, and relatively less in the transportation sector (see Figure 2). It also contributes significantly to electricity generation. In major non-EU LNG importing countries the power sector is more important and the residential sector less so. This leads to a lower non-EU average elasticity because the power sector has a lower elasticity of demand than the residential sector.

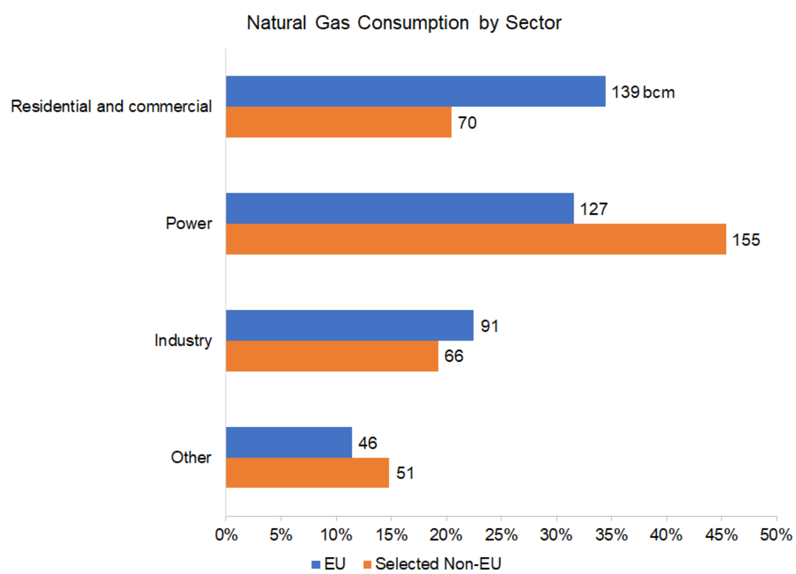

Figure 2: Gas consumption by sector (IEA, 2019).

We employ sector-based estimates for the elasticities that are common in the literature (see Table 2). These are assumed to be the same for both the EU and non-EU countries. Going from the lowest to the highest demand elasticity, manufacturing for natural gas displays the most inelastic demand. For example, it is difficult to substitute for natural gas in nitrogen-based fertilizer production and some other petrochemical processes. The demand elasticity is higher in the power sector, as natural gas can be replaced by other fossil fuels, but remains limited in the near term. Moreover, natural gas is the preferred fuel in power generation to offset the intermittency of renewable energy sources. The household sector has the highest price elasticity of demand, since consumption could be foregone or rationalized to some extent. In some cases, it is also possible to substitute with other fuels in the near term.

Sector	Own-price demand elasticity	EU natural gas consumption share (%)	Weighted non-EU natural gas consumption share (%)
Industry	0.084	23	19
Households	0.24	34	35
Power sector	0.136	32	45
Other sectors	0.22	11	

Table 2: Price elasticities of demand by sector. Sources: Industry: Andersen, Nilsen, and Tveteras (2011), households: Asche, Nilsen, and Tveteras (2008, p. 37); power sector: Serletis, Timilsina, and Vasetsky (2010, p. 743); other sectors: Labandeira, Labeaga, and López-Otero (2017, p. 11).

Global gas production is quite inelastic in the short term. The region with the highest natural gas elasticity in the near term is the US through shale gas. However, as discussed before the US gas market is not fully integrated with the European and Asian markets. As this paper focuses on a 12 months horizon, we assume an isoelastic supply function for natural gas with a local price elasticity of 0.06 from Krichene (2002).

3 A LNG Market Model to Derive the Price Shock

We use an iso-elastic demand and supply system for the natural gas market to quantify the price shock. For each sector i (households, industry, and power generation), and each country

j, in log-deviation from a pre-shock equilibrium, the quantity demanded $\hat{q}^d$ depends on the price elasticity of demand η^d, the real natural gas price $\hat{p}$ and an error term ϵ^d:

$$\hat{q}^d_{ij} = -\eta^d_i \hat{p} + \epsilon^d_{ij} \tag{1}$$

The quantity supplied $\hat{q}^s$ is a function of the price elasticity of supply η^s, the price and an error term.

$$\hat{q}^s = \eta^s \hat{p} + \epsilon^s \tag{2}$$

In equilibrium, the quantity demanded $\hat{q}^d$ (aggregated across sectors and countries) is equal to the quantity supplied net of the quantity stored. The contribution of the change in the quantity stored, up to a first order approximation, is defined using the inverse of the steady state gas consumption λ and the change in stocks Δs :

$$\hat{q}^s - \lambda \Delta s = \hat{q}^d, \tag{3}$$

Solving the system, the equilibrium price is characterized as a function of the supply shock and the price elasticities of supply and demand. Assuming that storage is at the historical average ($\Delta s = \bar{s} - s$) we obtain:

$$\hat{p} = \frac{\epsilon^d - \epsilon^s + \lambda \left(\bar{s} - s\right)}{\eta^d + \eta^s} \tag{4}$$

or, in the absence of demand shocks ϵ^d and without changes in storage (which is consistent with a quite persistent shock and a not-above-average starting stock level),

$$\hat{p} = -\frac{\epsilon_s}{\eta^d + \eta^s}. \tag{5}$$

where η^d, with a slight abuse of notation, now represents the consumption-weighted average of the sector-level elasticities[12].

4 Approximation of the Macroeconomic Impact

Following Bachmann et al. (2022), we use a second order approximation of a multi-sector open-economy model with rich input-output linkages as in Baqaee and Farhi (2019a).

Energy supply shocks can lead to significant macroeconomic non-linearities (see Baqaee and Farhi (2019a)). The Hulten (1978) theorem states that the impact of a microeconomic total factor productivity shock on aggregate TFP is equal to the shocked producer's sales as a share of GDP. This first-order approximation is based on an efficient economy under the assumption of a Cobb-Douglas production function. However, energy typically has a lower elasticity of substitution than assumed by a Cobb-Douglas production function. That's why it seems reasonable that a shock to sales of natural gas would be much more damaging to the economy than a similar sized sales shock to retail trade, for example. Other microeconomic details that may be important for natural gas but are not captured by a simple Cobb-Douglas production function include network linkages, microeconomic returns to scale, and the degree to which factors can be reallocated within sectors, across sectors and across countries.

Baqaee and Farhi (2019a) show generally that including these microeconomic aspects in an efficient general equilibrium economy causes the whole input-output matrix to endoge-

[12]The average elasticity is first calculated at country level and then aggregated across countries

nously respond to shocks, and the resulting nonlinearities are shaped by the microeconomic details of the production structure. The authors prove that these nonlinearities can by approximated by a second order approximation of the production function. Bachmann et al. (2022) apply the prove in the context of shocks originating from imports, which we explain in the following.

Let's assume that there are domestic factors of production h (such as different types of labor), imported goods m, and domestically produced goods k. Each producer of good k is located within borders of generic country n. Good k can be a consumed domestically or abroad as final good or be used as an intermediate input. The production function for k is constant return to scale in labor and intermediate x inputs

$$y_k = A_k f(\{l_{h,k}\}_{h \in H}, \{x_{k,j}\}_{j \in J}), \tag{6}$$

where A is the Hick-neutral productivity for sector k.

In each country n there is a representative household with homothetic preferences on all goods k

$$C_n = C(\{y_{n,k}\}_{k \in K}), \tag{7}$$

where $y_{n,k}$ denotes the consumption of good k in country n. Since there is no capital accumulation in the model, consumption is equal to gross national expenditure (GNE), Y.[13] In equilibrium $y_k = \sum_n C_n + \sum_j x_{kj}$ for all k.

In this economic environment Bachmann et al. (2022) prove that in a given country (we are dropping the subscript) the change in GNE, up to a second order approximation, can be

[13]Note that given the presence of intermediate inputs the gross output in each economy is greater than GDP

written as (see also Baqaee and Farhi (2019a))

$$\Delta \ln Y = \sum_j \frac{p_j x_j^m}{Y} \Delta \ln x_j^m - \sum_k \frac{p_k x_k^X}{Y} \Delta \ln x_k^X + \frac{1}{2}\left[\sum_j \Delta \frac{p_j x_j^m}{Y} \Delta \ln x_j^m - \sum_k \Delta \frac{p_k x_k^X}{Y} \Delta \ln x_k^X\right], \quad (8)$$

where p are the set of prices, Y is real GNE before the shock hits, while the superscripts m and X distinguish between exported and imported inputs. Assuming that the shock is only for the sector consuming gas $k = gas$ (i.e., natural gas) and the impact on exports is zero the above equation simplifies to

$$\Delta \ln Y = \frac{p_{gas} x_{gas}^m}{Y} \Delta \ln x_{gas}^m + \frac{1}{2} \Delta \frac{p_{gas} x_{gas}^m}{Y} \Delta \ln x_{gas}^m, \quad (9)$$

where the first part of the equation based on the first-order approximation of the Hulten (1978) theorem and the latter part is the second-order approximation for the non-linearities due to the micro-founded production structure.

In the second order approximation, the input-output inter-linkages are preserved and would determine the reactions of the endogenous p_{gas} and x_{gas}^m. Unfortunately, there is no disaggregated global input-output data that would allow us to determine the endogenous reactions of gas prices and quantities using the full model. That's why we use the approximation in conjuncture with the LNG model, to evaluate the economic impact of the shock.

5 Calibration

5.1 Four Scenarios

The goal of our calibration is to separately and jointly quantify the different roles of market size and demand elasticities in computing the output effects of a cessation of Russian natural gas exports to the EU. We thus lay out four different scenarios based on the stylized facts presented in section 2.

The first scenario assumes a -16.8 percent supply shock – based on the EU and non-EU market – and a sector-weighted demand elasticity by country or region. The second scenario presumes the same size of the supply shock but a lower price elasticity of demand, equal to the elasticity for the manufacturing sector. This allows us to trace out the sensitivity of our results to different demand elasticities.

To examine the counterfactual output effects if there was no global LNG market or LNG imports were completely price inelastic, we assume that the natural gas market is only the EU and the supply shock becomes -34.7 percent. This way we can better understand the role of the global market in absorbing the shock. As in scenarios 1 and 2, scenarios 3 and 4 differ in the underlying assumed demand elasticities.

5.2 Calibration Steps

We use equation (9) to compute the effects of the supply shock originating from a cessation of Russian natural gas exports to the EU on aggregate output. In the following, we will describe the procedure for the EU-aggregate for ease of exposition. It is similar for individual countries.

First, we derive the expenditure on net imports of natural gas in 2021 by multiplying the difference between natural gas consumption and production data sourced from the Eurostat (2022) by the annual average European reference price for natural gas (Dutch TTF) for 2021 from the International Monetary Fund (2022a). For the non-EU countries we employ 2019 data from BP (2022). Data for 2021 is not available yet and 2020 was a special year due to the pandemic. Data on nominal gross national expenditure (GNE) from International Monetary Fund (2022b) is employed to compute expenditure shares.

Second, we compute the price effects based on equation (5) for the four scenarios (see Table 3). We use the Dutch TTF natural gas price for the first quarter in 2022 as the basis when computing the scenario prices. This way we capture the price increases that have happened in the run-up of the conflict, impacted among others by low levels of natural gas in Gazprom's European gas storage facilities and by anticipation effects.[14]

Scenario	Scope	Elasticity	log Price (%)	Price level	Price increase (%)	Price ($/MMBtu)
1	Global	Weighted	0.75	2.1	110.9	68.0
2	Global	Minimum	1.17	3.2	220.7	103.3
3	EU	Weighted	1.54	4.7	367.4	150.6
4	EU	Minimum	2.41	11.1	1010.8	357.9

Table 3: Price Impact from a Russian Natural Gas Shut-off.

Third, the price effects allow us to derive the adjusted quantities of natural gas consumption and production using equations (1) and (2). We compute the net natural gas imports for the new steady state by subtracting adjusted production from adjusted consumption.

Fourth, we compute the expenditure share of natural gas imports in GNE over a twelve month horizon in the four scenarios. We use the computed net gas imports and multiply them

[14] Both of these effects are not directly captured in the model. That's why we use Q1 2022 instead of the average of 2021 as a base. We provide results for computations based on average 2021 TTF prices in tables 10 and 11 in the appendix. As expected, resulting output effects are below our baseline results.

by the estimated prices to compute the natural gas import expenditure. We then divide it by the International Monetary Fund (2022b) forecast of nominal GNE for 2022. Note that nominal GNE is take as given and feedback effects are omitted. However, contractions in nominal GNE are likely offset by unusually high inflation for 2022. Table 4 shows the expenditure shares of natural gas imports in the European Union's GNE. The change in natural gas import expenditure shares in the four scenarios range from 3.3 to 20.8 percent.

Scenario	Scope	Elasticity	Equil. EU consump. adjusted (Bcm)	Import Expenditure share (2021) (%)	Import Exp. share (after shock) (%)	Change in Expenditure share (%)
Scenario 1	Global	Weighted	312.9	1.4	4.7	3.3
Scenario 2	Global	Minimum	322.2	1.4	7.3	5.9
Scenario 3	EU only	Weighted	265.1	1.4	8.8	7.4
Scenario 4	EU only	Minimum	264.0	1.4	22.2	20.8

Table 4: Macroeconomic Impacts of a Russian Natural Gas Shut-off for the European Union: Gas Consumption and Expenditure Shares.

Finally, we plug the natural gas import expenditure shares into equation (9) and derive the change in output.

6 Impact on Aggregate Output

Our goal is to quantity how the size of the global LNG market affects the output impact of a potential Russian gas shut-off. We evaluate the impact of the shock over a one year period across the four different scenarios. Scenario 1 implies a 111 percent rise in gas prices (compared to Q1 2022) and a decline in the quantity of EU gas net imports of 50.6 Bcm. This results in a 0.42 percent decline in aggregate output (see Table 5).[15]

[15] We reiterate that our approach assumes a fully integrated market within the EU and full price pass-through. In a shut-off scenario, infrastructure bottlenecks and emergency policies could fragment markets in some coun-

Lower demand elasticities (Scenario 2) lead to a substantially stronger increase in natural gas prices, but only entail a small change in the decline in output (to about 0.50 percent). The reason is that the higher increase in gas prices is partly offset by a dis-proportionally smaller consumption decline, as the impact also spreads across non-EU countries. The global LNG market acts as a shock absorber.

In the absence of substitution through LNG trade, however, the size of the shock for the EU is substantially larger, driving a larger EU output decline and increasing the importance of nonlinear effects. Output declines by almost 1.38 percent (Scenario 3). When coupled with lower elasticities of demand, the decline in output would be sizeable, at about 2.65 percent (Scenario 4). The effects are amplified by the sharp increase in the gas expenditure share.

Scenario	Scope	Elasticity	Output (%)	Supply shock as share of consumption (%)	Price elasticity of demand	Net Imports adjusted (Bcm)	Price increase (%)
1	Global	Weighted	-0.42	-16.8	0.170	313	111
2	Global	Minimum	-0.50	-16.8	0.084	322	221
3	EU	Weighted	-1.38	-34.5	0.170	265	367
4	EU	Minimum	-2.65	-34.5	0.084	282	1011

Table 5: Macroeconomic Impact of a Russian Natural Gas Shut-off for the European Union.

Results for individual countries also show large differences between the scenarios depending on the inclusion of the global LNG market or not (see Table 6). Countries with a large expenditure share of net natural gas imports such as Hungary, Slovakia or the Netherlands (Scenarios 1 and 2) could see substantial effects on aggregate output in the event of a Russian natural gas shut-off. These more than triple when assuming no global natural gas market based on a weighted demand elasticity (Scenario 3). Using a minimum demand elasticity, they

tries and price pass-through may be further distorted. We also do not take into account demand side effects, which alone could double our estimates.

increase by a factor of six without the global LNG market.

Scope Elasticity	Scenario 1: Global Weighted	Scenario 2: Global Minimum	Scenario 3: EU only Weighted	Scenario 4: EU only Minimum
Austria	-0.30	-0.39	-1.00	-2.09
Belgium	-0.49	-0.57	-1.64	-3.14
Bulgaria	-0.55	-0.74	-1.88	-4.01
Croatia	-0.73	-0.90	-2.24	-4.55
Czech Republic	-0.55	-0.63	-1.82	-3.41
Denmark	-0.12	-0.18	-0.35	-0.76
Estonia	-0.21	-0.26	-0.72	-1.40
Finland	-0.10	-0.15	-0.37	-0.84
France	-0.23	-0.26	-0.77	-1.40
Germany	-0.39	-0.45	-1.29	-2.44
Greece	-0.42	-0.52	-1.44	-2.87
Hungary	-1.06	-1.19	-3.36	-6.29
Ireland	-0.27	-0.37	-0.84	-1.82
Italy	-0.63	-0.73	-2.09	-3.94
Latvia	-0.45	-0.55	-1.51	-3.00
Lithuania	-0.60	-0.63	-1.96	-3.45
Luxembourg	-0.22	-0.25	-0.73	-1.35
Malta	-0.35	-0.48	-1.22	-2.65
Netherlands	-0.77	-1.02	-1.89	-4.02
Poland	-0.59	-0.73	-1.84	-3.73
Portugal	-0.30	-0.42	-1.04	-2.27
Romania	-0.51	-0.68	0.08	0.73
Slovakia	-0.77	-0.85	-2.55	-4.64
Slovenia	-0.20	-0.29	-0.69	-1.60
Spain	-0.33	-0.45	-1.15	-2.45
Sweden	-0.03	-0.04	-0.11	-0.22
EU	-0.42	-0.50	-1.38	-2.65
United Kingdom	-0.33	-0.45	-0.83	-1.91

Table 6: Macroeconomic Impact of a Russian Natural Gas Shut-off for EU Countries.

On the flip side, as the global LNG market provides a buffer to the effects of a cessation in Russian gas exports on EU aggregate output, the same mechanism leads to spill-over effects on aggregate output in other LNG importing countries. Results for the UK and other LNG importers show substantial aggregate output effects ranging from -0.05 percent for China to -0.42 percent in the case of South Korea in Scenario 1 (see table 7). Differences between countries reflect divergent expenditure shares of gas in the economy and countries' sectoral composition of gas consumption. The results under the assumption of a low demand elasticity are slightly more negative.

Scope Elasticity	Scenario 1: Global Weighted	Scenario 2: Global
China	-0.05	-0.07
India	-0.13	-0.16
Japan	-0.27	-0.36
Korea	-0.42	-0.53
Pakistan	-0.40	-0.47
Taiwan Province of China	-0.38	-0.55
Mexico	-0.06	-0.08
Argentina	-0.04	-0.05
Chile	-0.14	-0.18
Turkey	-0.26	-0.33
Kuwait	-0.38	-0.66
Singapore	-0.18	-0.27
Thailand	-0.14	-0.22

Table 7: Macroeconomic Impacts of a Russian Natural Gas Shut-off for LNG Importing Economies.

7 Discussion

What is the Effect on Output if Governments Exempt Households from Demand Adjustment? If policymakers chose to offset the impact of prices and completely insulate household demand, the shock would be levered up in the industry and power generation sector which have demand elasticities that are half to one-third the magnitude of those in the household sector. In scenarios 2 and 4, we have assumed that all sectors have the same price elasticity of demand of the industrial sector (-0.08), which is the lowest. It would give quite similar numerical results if we set the EU household sector's elasticity equal to zero in our framework.

Estimates refrain from any consideration on long term effects on output potentially coming from public finance deterioration. Note that the concept of household protection means that households are only protected from supply disruptions. At the same time, most countries still allow for prices to pass-through to certain extent, providing households still with incentives to lower consumption.

Why do Large Changes in Gas Prices and Import Expenditure Shares not Translate to Proportional Changes in Economic Damages? Comparing scenario 1, in which gas prices double, with scenario 2, in which they triple, the impact on GNE would only increase from -0.42 to -0.50 percentage points, as table 4 illustrates. At the same time, the total expenditure on gas would increase by 2.5 percentage points (see table 5). Similarly, in scenario 4 gas prices would increase by over 1,000 percent and the gas import expenditure share would go up to more than 20 percent of GNE, but the impact on GDP would only be 2.7 percent. But in such a scenario, total spending on natural gas would be almost 20 percent of GNE. Why do the strong increases in prices and import shares not lead to higher downside effects on GNE?

The reason is that the underlying Baqaee and Farhi (2019a) model does not include sticky prices (unlike Neo-Keynesian models). That's why higher gas prices and import expenditure shares are offset by lower relative prices of other goods and services, including real wages. If there were downward sticky prices in the model, it would mean that inflation would be even higher (to get the appropriate relative price adjustment). This would likely overestimate the expenditure share change and hence the real activity effect.

It is also worth considering that with large shocks non-linearities may kick-in that make relative prices more flexible. Second, prices are likely more flexible in an inflationary environment (see Gagnon (2009), Nakamura, Steinsson, Sun, and Villar (2018), Petrella, Santoro, and

Porte Simonsen (2018)).

What are the Spillover Effects to Downstream Sectors of the Economy? One could imagine that natural gas price increases would have a significant impact on unit costs in some gas intensive industries, e.g., chemicals and fertilizers. As these products are traded goods, there may be limited capacity to pass these through into prices. Are we going to observe a spike in business failures concentrated in the most exposed sectors? Or will this be absorbed into the public sector balance sheet via support policies? These questions cannot be fully addressed within this simple framework, since it neither allows for bankruptcies nor includes credit frictions. Outside the presented framework, the impact on individual industries and their upstream and downstream integrated firms could be larger, and it would be a function of the specific exposure of the sector to the shock and the strength of the complementarity across sectors' production. Firms that face international competition would also be more affected if their competitors source gas from gas markets that are less integrated (such as US and Canada)
.

For sectors where gas is an essential input, there is some scope for the shock to be mitigated depending on firms' market power and the integration with the international gas market. As a first pass, we could think of the gas shock as isomorphic to a negative TFP shock. If gas markets are integrated (within the EU and with the global LNG market; Scenario 1), it affects both EU and non-EU producers. In this case, higher costs will be passed to producer (and eventually consumer) prices, dampening the impact for the EU. Even though the European TTF reference price and LNG Asia gas prices co-move strongly, they are not perfectly correlated so the law-of-one-price assumption in Scenario 1 represents an assumption, which is why it is important to also consider scenarios 3 and 4.

In scenarios 3 and 4, there is no gas market integration at all (which is the other extreme), so the entire shortfall in gas from the shut-off hits the EU. If this is the case, our output estimates may underestimate the loss of competitiveness of some industries but at the macro level the Euro would likely depreciate (again isomorphic to a TFP shock affecting only one region of the world). Finally, since the US gas market is segmented from the global LNG market to a good extent too, US (gas-intensive) firms that compete on the global market will benefit.

Is a Market-Based Approach Socially Acceptable Given the Size of the Price Shock? For the calculations of the EU as an aggregate in scenarios 1 and 2 the overall increase in the gas expenditure divided by the EU population is between $ 2,000 and $ 10,000 per capita, since gas consumption of the household sector (narrowly defined) is about 17% of the total, we have an extra bill of $ 350 and $ 1,700 per capita based on our estimates. The framework is symmetric by construction and homothetic preferences, implying a steady proportion of expenditure shares across rich and poor households and member states. In reality, there will be substantial heterogeneity based on the initial gas usage and the pass-through from the power sector and industry to consumer prices. Also, as mentioned above, households' gas consumption could be sanctuarized and in some countries electricity prices for consumers are sticky.

How Does the Implicit Assumption of an Economy at Capacity Bias our Results? Hulten's theorem and the Baqaee and Farhi (2020) results hold only if the economy is at the efficiency frontier and at full capacity. We know that many economies are still recovering from the pandemic and catching up. The Baqaee and Farhi (2019b) macro-envelope theorem result allows for the expenditure share to be a sufficient statistic for expressions involving various elasticity parameters. Differently than the economies for which Hulten's theorem holds, it is important to incorporate the higher order terms for any local marginal effects, due to the importance of nonlinearities implied by the richer production structure.

If the shock is large and the value chains amplify the upstream negative effects, nonlinearities kick in strongly regardless of whether there is slack in some other sectors. This is the finding in Baqaee and Farhi (2019b), where the authors look at the 1970s oil shock and find that these nonlinearities likely tripled the output effects. Critically, this amplification assumes limited fuel substitution possibilities in some sectors, which in turn need to be highly integrated into production chain. This could be true for selected sectors (like nitrogen fertilizer and some chemical processes), but it remains unclear for sectors producing other intermediate inputs.

What Would Estimates for the Long Run Look Like? Our paper focuses on the impact effect and the comparative static comparison for a 12 months horizon without a true dynamic path. The local approximation is not well suited for comparative static of different steady states which would require dynamic general equilibrium considerations. The persistence of the shock is also unclear. Assuming a no change in storage as we do would be more consistent with a persistent shock. The change in the natural gas expenditure share $\Delta((p_E E)/PY)$ is positive and large at impact but will become smaller and possibly negative in the long run, as supply catches up and prices normalize. However, if there is a permanent component to price increases (e.g., higher LNG costs compared to Russian pipeline gas), there could also be more persistent effects on output, as certain sectors may become less competitive.

Under What Assumptions is it a Valid Approach to Use the Global LNG Model in Combination with the Sufficient Statistic? We assume that the elasticities used in the calculation of the gas equilibrium are also implicitly those used in the expenditure share change. They would hence implicitly appear in the consumers' and producers' problems in the full Baqaee and Farhi (2019a) model. We leave a formal prove to future research.

8 Conclusion

We estimated the aggregate output effects of a cessation of Russian natural gas exports to the EU. We contribute to the literature by taking into account the role of the global LNG market as a shock absorber. This dampens the output effects in Europe. At the same time, we find important spill-over effects to other countries that are substantial importers of LNG.

Our estimates represent a first-round—largely supply-side—approximation of the output impacts of the Russian gas shut-off shock. We would need a full scale macroeconomic model with monetary policy, to derive second round effects through monetary policy tightening as a result of higher gas prices, as well as fiscal policy, to factor in support measures that could offset some of the drop in demand

We assume fully integrated European markets, but there are still some frictions in the pipeline and LNG import infrastructure that could lead to a break down in the price mechanism and physical supply shortages in some Central and Eastern European countries (see DiBella et al., 2022). Government policies such as regulating gas prices or rationing of gas quantities could also distort markets In these case, scenarios without a fully integrated LNG market and market frictions are more relevant.

In the presence of coordination problems or market disruptions a government may impose rationing of natural gas usage. This is, however, a potentially inefficient approach since it is not driven by competitive market price signals. In a functioning market and in absence of frictions, firms that use gas as an input to produce an essential intermediate input for other firms will be able to pass-through higher prices and can therefore pay higher prices for gas. This mechanism allows for an efficient allocation of gas taking into account downstream firms. The effects of rationing on the economy are beyond the focus of the current study. Some European countries have also adopted price subsidies, price ceilings and other measures, which may slow or even exempt certain sectors from adjustments in the quantity demanded. This is also beyond our model but risks to amplify aggregate output effects. Amaglobeli, Hanedar, Hong, and Thévenots (2022) provide an overview of fiscal policies to mitigating the social impact of high energy while preserving price signals and demand adjustment.

Countries' policies could influence demand and supply elasticities and as a result affect output effects in both ways. Negative output effects could be more substantial if governments hinder price-pass through, distribute quantities centrally allowing for inefficiencies due to lobbying, or shut-down intra-European cross-border pipeline flows. At the same time, output effects could also be more muted if governments can help to substitute gas for other energy sources (e.g., reopening of coal and nuclear plants), initiate voluntary gas savings campaigns or foster domestic gas production above and beyond the relatively low elasticities assumed here.

We show that the European Union is, in fact, well connected to the global LNG market, but that integration in the internal market is imperfect, as it is partially geared towards Russia. One important open question for policy makers and the private sector is what is more cost-efficient: investment into additional regasification capacity with a broader regional scope or strengthening interconnection capacity to carry gas from existing regasification terminals across Europe.

Finally, our comparative statics work on a one year average basis. We do not include natural gas storage and seasonality but which are important features of the natural gas market. Storage provides an additional buffer in a shut-off scenario and helps to smooth seasonal fluctuations on the demand side. At the same time, the seasonal peak in demand in the winter could lead to infrastructure bottlenecks that are highly uncertain to quantify in a linear model. We leave this to future research.

A Additional Tables

Scope Elasticity	Scenario 1: Global Weighted	Scenario 2: Global Minimum	Scenario 3: EU only Weighted	Scenario 4: EU only Minimum
Austria	8	8	7	8
Belgium	16	17	14	15
Bulgaria	3	3	3	3
Croatia	3	3	2	2
Czech Republic	8	9	7	8
Denmark	3	3	2	2
Estonia	0	0	0	0
Finland	2	2	2	2
France	36	37	31	33
Germany	82	85	72	76
Greece	6	6	5	5
Hungary	10	10	8	9
Ireland	5	5	4	4
Italy	67	69	59	62
Latvia	1	1	1	1
Lithuania	2	2	2	2
Luxembourg	1	1	1	1
Malta	0	0	0	0
Netherlands	37	38	33	35
Poland	21	21	18	19
Portugal	5	5	5	5
Romania	11	11	9	10
Slovakia	5	5	4	4
Slovenia	1	1	1	1
Spain	30	30	27	27
Sweden	1	1	1	1
EU	360	371	315	334
United Kingdom	69	72	60	65

Table 8: EU Consumption Adjusted (Bcm) due to a Russian Natural Gas Shut-off.

Scope Elasticity	Scenario 1: Global Weighted	Scenario 2: Global Minimum	Scenario 3: EU only Weighted	Scenario 4: EU only Minimum
China	76	77	68	69
India	29	29	25	26
Japan	94	96	84	86
Korea	49	50	43	45
Pakistan	10	11	9	10
Taiwan Province of China	21	21	19	19
Mexico	6	6	5	5
Argentina	2	2	1	1
Chile	3	3	3	3
Turkey	12	12	10	11
Kuwait	5	5	4	4
Singapore	4	4	4	4
Thailand	6	6	6	5

Table 9: Consumption Adjusted (Bcm) due to a Russian Natural Gas Shut-off for Non-EU economies.

Scope Elasticity	Scenario 1: Global Weighted	Scenario 2: Global Minimum	Scenario 3: EU only Weighted	Scenario 4: EU only Minimum
Austria	-0.18	-0.22	-0.56	-1.09
Belgium	-0.29	-0.32	-0.91	-1.63
Bulgaria	-0.33	-0.42	-1.05	-2.10
Croatia	-0.45	-0.52	-1.28	-2.40
Czech Republic	-0.33	-0.36	-1.01	-1.78
Denmark	-0.08	-0.10	-0.20	-0.40
Estonia	-0.13	-0.14	-0.40	-0.73
Finland	-0.06	-0.08	-0.20	-0.44
France	-0.14	-0.15	-0.43	-0.73
Germany	-0.23	-0.25	-0.72	-1.27
Greece	-0.25	-0.30	-0.80	-1.49
Hungary	-0.65	-0.68	-1.91	-3.30
Ireland	-0.16	-0.21	-0.47	-0.96
Italy	-0.38	-0.41	-1.17	-2.05
Latvia	-0.27	-0.31	-0.84	-1.57
Lithuania	-0.36	-0.36	-1.09	-1.80
Luxembourg	-0.13	-0.14	-0.41	-0.70
Malta	-0.21	-0.27	-0.67	-1.37
Netherlands	-0.48	-0.59	-1.12	-2.16
Poland	-0.36	-0.42	-1.04	-1.96
Portugal	-0.18	-0.23	-0.58	-1.18
Romania	-0.35	-0.43	-0.15	0.17
Slovakia	-0.47	-0.48	-1.43	-2.42
Slovenia	-0.12	-0.17	-0.39	-0.83
Spain	-0.20	-0.25	-0.64	-1.28
Sweden	-0.02	-0.02	-0.06	-0.11
EU	-0.26	-0.29	-0.78	-1.39
United Kingdom	-0.18	-0.24	-0.45	-0.98

Table 10: Macroeconomic Impacts of a Russian Natural Gas Shut-off for EU countries using the average 2021 price as a baseline for the price effect.

Scope Elasticity	Scenario 1: Global Weighted	Scenario 2: Global
China	-0.03	0.02
India	-0.07	-0.08
Japan	-0.14	-0.18
Korea	-0.22	-0.27
Pakistan	-0.21	-0.24
Taiwan Province of China	-0.20	-0.29
Mexico	-0.03	-0.04
Argentina	-0.02	-0.03
Chile	-0.07	-0.09
Turkey	-0.15	-0.19
Kuwait	-0.20	-0.34
Singapore	-0.10	-0.14
Thailand	-0.08	-0.11

Table 11: Macroeconomic Impacts of a Russian Natural Gas Shut-off for LNG importing economies using the average 2021 price as a baseline for the price effect..

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