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The Economic Impacts on Germany of a Potential Russian Gas Shutoff

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The Economic Impacts on Germany of a Potential Russian Gas Shutoff
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ABSTRACT: We analyze the potential impacts on the German economy of a complete and permanent shutoff of the remaining Russian natural gas supplies to Europe, accounting for the curtailment of flows through Nord Stream 1 that has already taken place. We find that such a scenario could lead to gas shortages of 9 percent of national consumption in the second half of 2022, 10 percent in 2023 and 4 percent in 2024, which would be worse in the winter months, and would likely fall on firms, given legal protections on households. We combine the effects of less gas on production with the consequent effects of reduced supply of intermediate goods and services to downstream firms, and with reduced economic activity due to rising uncertainty. Together, these three channels reduce German GDP relative to baseline levels by about 1.5 percent in 2022, 2.7 percent in 2023 and 0.4 percent in 2024, with no gains in subsequent years from deferred economic activity. The associated rise in wholesale gas prices could increase inflation by about 2 percentage points on average in 2022 and 2023. Our simulations suggest that the economic impacts can be reduced significantly by having households voluntarily share a small part of the burden, and by rationing gas supplies more to more gas-intensive and downstream firms. We also suggest other ways to enhance German energy security.

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1. Introduction

The German economy is highly exposed to the risk of a shutoff of Russian natural gas. Gas makes up just over a quarter of Germany's energy use, almost all of which is imported. As of end-April 2022, about 35 percent of Germany's natural gas imports (33 billion cubic meters (bcm) a year) came from Russia, compared with 12 percent of crude oil, and 8 percent of coal, according to the economy ministry.[1] Moreover, unlike oil and coal that are transported by ship, Russian gas imports are difficult to substitute because Germany lacks pipelines linking it to alternative gas wells or facilities to regasify LNG from ships and distribute it to the existing distribution system. Instead, LNG has to be imported through LNG terminals in neighboring countries like Belgium and the Netherlands. The dependence of gas markets on local pipelines means that prices vary around the world, ranging in 2022Q2 from US$ 16.7 per MWh in Louisiana, USA to US$110 per MWh in the Netherlands.

There is a high risk that Russian gas supplies to Germany suddenly stop. In June 2022, Russia reduced flows through the Nord Stream 1 pipeline by around 60 percent, and Russian gas flows into Germany at Waidhaus on the Czech border fell some 69 percent. If they persist, these cuts will amount to 56 bcm a year. On May 11, 2022, Russia sanctioned Gazprom Germania,[2] which has been managed since April 2022 under trusteeship by the German energy regulator (the Federal Network Agency). The company, whose imports from Russia constituted about 4 percent of all German gas imports, according to media reports, was able to continue purchasing gas on the spot market instead. Also in May, Russia announced new laws that seek to impose a new ruble-based payment mechanism on European gas importers. As of June 2022, the German government and German gas importers were of the view that importers could continue to pay for their gas imports in compliance with both European Union sanctions and Russian law, and thus avoid an associated disruption to supply. One exception is Shell's German subsidiary, which according to media reports did not comply with Russian requirements in May and was denied further gas supplies, amounting to some 1 percent of all German gas imports. As of June 2022, Russian gas supplies were partially or fully stopped to Austria, Bulgaria, Czech Republic, Denmark, Finland, France, Germany, Italy, the Netherlands, Poland, and Slovakia.

To reduce its vulnerability, Germany is diversifying its suppliers, filling its storage facilities, expanding its infrastructure, and enhancing its crisis management toolkit. The government plans to reduce the share of gas that Germany imports from Russia to 10 percent by mid-2024. To this end, the government is requiring operators to fill their leased storage space up to 90 percent of capacity by November 1, 2022, or risk forfeiting this space to the government, who would fill it by a tendering process. The government also bought 1 bcm of gas in March 2022 and announced that it would make credit lines available to the market area manager (THE), through KfW (the state-owned development bank), to finance further purchases. These steps have led to record high imports of gas through neighboring countries that obtain their supplies in liquified form (Belgium and the Netherlands), and imports have been expanded using measures, like limiting reverse pipeline flows, which do not require additional infrastructure. To save more gas from being used in electricity generation, the government has proposed laws to enable the reactivation of coal-fired power plants until March 2024, which it expects would outcompete gas power. The government has leased four floating storage and regasification units (FSRUs) that will further expand its import capacity with its first domestic LNG terminals. It is envisaged that the first terminal will be operational at Wilhelmshaven by the end of the year, the second will be operational

[1] In previous years, 55 percent of gas, 35 percent of oil and 50 percent of coal imports came from Russia.

[2] Gazprom Germania is a group of companies involved in the trading, transport and storage of natural gas.

in Brunsbüttel in early 2023, with capacities of 7.5 bcm and 5 bcm per year, respectively.[3] The government has proposed two new legal amendments that would assist in an emergency. They would give it the power, firstly, to take control of critical energy infrastructure currently under private control, and secondly, allow it to authorize gas suppliers to pass on higher prices to customers that would otherwise be on fixed-price contracts, to ensure the solvency of these suppliers. Finally, the government assessed that nuclear power cannot help to offset gas shortages.[4]

Table 1. Selected Literature Review of the GDP Impacts of a Russian Gas Shutoff

(percent)

Study	Gas loss	GDP loss	
ECB (2022)	10		0.7
OECD (2022)	20		0.9
Bachmann et al. (2022)	30	Full model	0.2-0.3
		Simplified model 1	1.3
		Simplified model 2	2.2
Schnittker et al. (2022)	9		1.5
	36		3.4
German Council of Economic Experts (March 2022)	30		2.0
Joint Economic Forecast (2022)	n.a.		0.8 in '22, 5.3 in '23
Bundesbank (April 2022)	40		5.0
Bundesbank (June 2022)	31 in winter '22/'23, 11 in winter '23/'24		1.5 in '22, 6.75 in '23, 4.5 in '24
Di Bella et al. (2022)	12	with frictions	3
		without frictions	0.4

Recent studies estimate a wide range of possible economic impacts of a gas shutoff. Their results put the impact in Germany in 2022 at up to 5 percent of GDP in the first year, and up to 2.6 percentage points' higher inflation in the same year (Table 1). [5] Studies point to a deeper economic impact in 2023 as inventories are exhausted and lesser impacts in outer years as the economy adapts. The estimated impact on GDP depends on several factors:

- **Comprehensiveness of the transmission channels.** Earlier studies (e.g. ECB, GCEE, Schnittker et al.) analyze the impacts on economic activity through the production (supply) side of the economy, by estimating the direct impact on production of reduced gas quantities and the indirect impact of further

[3] The remaining two FSRUs each have capacities of 5 bcm per year and are expected to be operational by 2024.

[4] On March 7, 2022, the relevant ministries released their assessment of the potential continued operation of Germany's three remaining nuclear power plants beyond their scheduled decommissioning in December 2022 (BMWK and BMUV, 2022). In their assessment, "After weighing up the benefits and risks, an extension of the service life of the three remaining nuclear power plants is not recommended."

[5] The studies reviewed here consider the impacts of a Russian or EU embargo on energy supplies, the economic impacts of which are considered to be largely equivalent, rather than the impact of an EU tariff or price cap on Russian energy. The impacts of a tariff or price cap would be expected to be less than those of a full embargo.

downstream propagation through input—output linkages. Since supply equals demand in a closed economy, analyzing the impact on economic activity through the demand side (for example, through the erosion of consumption and investment due to higher energy prices) should give a similar result. However, models of the demand side typically incorporate features of the economy like sticky prices and unemployment that amplify the effect of shocks and are missing from the models used in some studies (e.g. ECB, OECD, Bachmann et al.). Therefore, studies by the Joint Economic Forecast group and Bundesbank (2022a, 2022b) first analyze the impact of *part* of the shock associated with gas quantity shortages through a model of the supply side, and then use a demand-side model to estimate the additional losses through further gas price effects (that are not captured by the gas quantity shortages) and demand-side amplification effects from both quantity shortages and price increases, and finally add up the results.[6] These studies include the potential amplification effects of tighter financial conditions and higher unemployment, and find larger overall effects than other studies. Di Bella et al. (forthcoming) emphasize the extent to which complementarities between gas and capital inputs into production can magnify the impact of a gas shutoff on economic activity, from 1.3 to 2.1 percent of GDP for Germany.[7]

- **Shock size, composition and duration.** Studies start from different estimates of Germany's dependence on Russian gas—from 40 percent in the GCEE study to 55 percent in Bachmann et al.—due to different data sources and timing of measurement, since Germany has been reducing its dependence in recent months. Moreover, the disruption could affect all of Russia's gas exports or only certain pipelines (as in Schnittker et al.), could be limited to gas or could occur simultaneously with disruptions to other Russian energy or non-energy exports, and could be examined over a few months or longer. For example, the GCEE and the production function approach of Bachmann et al. assume a 30 percent reduction in gas consumption over a full year, while the Bundesbank (2022a) assumes a 40 percent reduction in German consumption of gas, oil and coal over 9 months, and in their full model, Bachmann et al. assume a full cessation of all energy and non-energy trade between Russia and the EU.[8] Bundesbank (2022b) includes a full European embargo of Russian energy products, deeper disruptions to Ukrainian/Russian food exports, and falling external demand.[9] The size of the gas shock also depends on the timing and duration of the gas disruption because existing inventories and lower demand in the summer months could be enough to manage a temporary disruption. The size of the shock also depends on assumptions on the amount of Russian gas that could be replaced in the near term and the extent to which inventories can be used. Most studies do not explicitly state their assumptions on replacement and inventories, but the Bundesbank (2022a) assumes no Russian gas can be replaced and the GCEE assumes that one-quarter can be replaced, and the Joint Economic Forecast group assumes that shortages are only likely to emerge in the winter after inventories are exhausted. Bundesbank (2022b) assumes a 31 percent quantity reduction in non-household gas consumption in winter 2022/23 and an 11 percent quantity reduction in the

[6] This approach splits the shock into a part associated with gas price increases, and a remaining part related to quantity shortages. Quantity shortages could arise if markets do not clear, perhaps due to infrastructure constraints, even at the higher prices.

[7] The intuition for the complementarity result in Di Bella et al. (forthcoming) is that, if gas and capital are complementary inputs into production, then firms will choose to cut back their investment after a drop in gas supplies.

[8] As explained in their appendix A.4.4.

[9] In communications, the Bundesbank explained that its estimate of the effect of gas rationing in isolation, ignoring other shocks, would be 1-3.2 percent of GDP in the April study. In the June study, the estimates would be 0.5 percent in 2022, 3.0 in 2023, and 0.9 in 2024.

following winter, with further reductions in gas consumption due to higher prices. Albrizio et al. (forthcoming) emphasize the importance of the global LNG market in absorbing the impact of a disruption to Russian gas supply, with the economic impacts on Europe being five times smaller if other importers, especially Asia, share in the burden.

- **Approach to rationing across households, the power sector, and other firms.** The impact on production will depend on how the available gas supplies are rationed between households and firms, and across different economic sectors. In line with Germany's national plan for a gas emergency, the Bachmann et al. (2022) and the Joint Economic Forecast studies assume that households are protected from quantity rationing, leaving the entire burden of quantity rationing to fall on firms. However, most studies do not clarify whether they assume that households are protected. The economic impact of gas shortages also depends on assumptions about how gas is rationed across economic sectors. Most studies assume that rationing is in proportion to normal consumption levels. One exception is Schnittker et al., which considers the possibility that some economic output could be saved if more energy-intensive sectors, like steel and chemicals, face stricter rationing, with milder rationing in other sectors.[10] The studies could also differ in their assumptions about the extent to which the power generation sector—which accounts for almost a third of gas consumption in Germany—is protected from rationing, which would depend on power generators' ability to use alternative fuel sources and the country's ability to use less electricity or heat. Another potential source of difference between the studies is in their assumption about the pass-through of energy to consumer price inflation. Staff find that oil prices typically pass through to German consumer prices within the year, while longer contracts mean that gas prices take about 12 months to do so. However, studies do not consider that rationing would prevent energy prices from matching supply with demand, thereby breaking the usual patterns between energy and consumer price inflation.

- **Substitutability of gas with other inputs.** A higher level of substitutability, which is more realistic in the longer term or for broader groupings of firms, means that firms can switch from gas to alternative inputs (like electricity, coal, oil) with greater ease, or that labor and capital can shift more easily to more gas-efficient firms or firms that use coal, oil, or electricity, resulting in smaller output losses.[11] Supply-side studies that find impacts of less than one percent of GDP (e.g., ECB; OECD; full model of Bachmann et al.[12]) assume some substitutability between gas and other inputs, or substitutability of resources across sectors of production. Other studies make the shorter-term assumption of low substitutability between gas

[10] We analyze the impact of rationing decisions more fully, in Section 4.

[11] Substitutability can be quite limited even in the long term at the level of an individual firm or a narrow grouping of a few firms. However, with broader groupings of firms or indeed at the country level, there are more possibilities for firms to change adapt their production or for resources to shift between firms, making substitutability higher.

[12] Bachmann et al. (2022) analyze the impacts of a potential gas shut-off via three approaches that have different assumptions on substitutability: (1) a general equilibrium model (Baqaee and Farhi, 2019) that features sectoral input—output linkages and international trade; (2) an approximation to this model called the "sufficient statistics" approach; and (3) a production function approach (their so-called 'simplest' model). The general equilibrium model and the sufficient statistic approach capture import substitution through trade links and amplification effects through input—output linkages. The sufficient statistic approach relies on the theoretical result that the change in gas expenditures sufficiently captures all information in the economy's underlying structure (including the elasticity of substitution between gas and other inputs, the input-output linkages, and the trade linkages) that is relevant for calculating the impact on output. The production function approach is an aggregate model that does not differentiate between the production of different sectors, and therefore does not explicitly capture the input—output linkages between them, and it ignores international trade, so that it does not allow for import substitution.

and other energy inputs (e.g., simplified models of Bachmann et al.) or no substitutability between energy and non-energy inputs in some sectors (Bundesbank 2022a, 2022b; Joint Economic Forecast), and find larger impacts for Germany from the supply-side parts of their analyses.

This paper is structured as follows. Section 2 presents estimates of the potential gas shortages that could arise from such a shutoff of Russian gas supplies. Section 0 discusses the potential impacts of such shortages on economic activity and Section 4 illustrates the importance of gas rationing policy for these economic estimates. Finally, Section 5 shows estimates of the effects of the Russian gas shutoff on German inflation.

2. Gas shortage scenarios

We calculate the shortages due to the shutoff of Russian gas supplies as the difference between gas consumption under baseline and adverse scenarios. We project monthly gas flows between June 1, 2022 and end- 2027, using information as of June 22, 2022.[13] We project flows under a 'baseline' scenario, where flows continue at their current pace and inventories are accumulated in advance of the winter 2022/2023 (accounting for the curtailment of Russian gas flows through Nord Stream 1 in June 2022), and an 'adverse' scenario, in which all remaining flows from Russia to the European Union stop on June 1. In these scenarios, we project German gas consumption, gas inventories, and net gas imports from Russia and non-Russian sources.[14] These projections make the following assumptions:

- *LNG and Russian imports.* LNG imports through neighboring countries (via existing pipelines) rose sharply in early 2022. These flows are assumed to continue and to ramp up with Germany's new FSRUs throughout the forecast horizon, even in the adverse scenario. In the baseline, Russian imports account for 35 percent of German consumption in April and May 2022. To capture the curtailment of Russian supply through Nord Stream 1 and Waidhaus in June 2022, these import quantities are scaled down by 45 percent in June and by 60 percent thereafter.[15] Also under the baseline, Germany slowly reduces its Russian import share to zero by end-2024, in line with the government's target. Net non-Russian gas imports are 5.1 bcm a month, which is the difference between observed net gas imports from all countries (8.1 bcm a month) and our estimate of Russia's portion of German consumption (3 bcm), between January and May 2022. (Net inventory accumulation over this period was negligible.)

[13] The baseline assumes average daily wholesale natural gas prices in Germany of US$104 a MWh in 2022, US$83 in 2023, US$64 in 2024 and US$49 in 2025.

[14] In particular, we model net gas imports, rather than gross gas imports and exports separately, for parsimony. In other words, we do not model gas inflows that are usually re-exported. Our assumption is that the 60 percent curtailment in Russian supplies to Germany in June can be passed on to downstream countries, in the form of a 60 percent decline in German re-exports of Russian gas.

[15] The smaller cut of 45 percent in June captures the fact that some Russian supplies were curtailed only in mid-June. Based on data provided on the Federal Network Agency's dashboard, we calculate that Russian supplies through Nord Stream 1 and Waidhaus have fallen by 60 and 69 percent respectively, or 63 percent in total. At the time of writing, the dashboard suggests at best a tiny uptick in supplies from Norway, the Netherlands and Belgium. Therefore, we round down the Russian supply cuts to 60 percent. The dashboard is available at: https://www.bundesnetzagentur.de/EN/Areas/Energy/Companies/SecurityOfSupply/GasSupply/start.html

- *Infrastructure expansion.* FSRUs come online in December 2022 (7.5 bcm/year), February 2023 (5 bcm/year), September 2023 (5 bcm/year) and February 2024 (5 bcm/year), in line with government announcements.

- *Gas-to-coal switching.* In the baseline scenario, the whole grid and capacity reserves of coal-fired power stations are assumed to be activated from July 2022, so that power generation can be kept constant while using less gas. We assume that these power stations can substitute for around 5 GW of power capacity, or 4.5 bcm of gas a year.[16] We assume that the government will extend the use of these power stations from March 2024 to March 2027 in the baseline scenario, which our estimates suggest is necessary to prevent gas shortages. The adverse scenario makes the same assumptions as the baseline scenario with respect to coal-fired power generation.

- *Gas consumption.* Consumption in the baseline proceeds according to the average levels and seasonal pattern of the last five years (90.5 bcm over 2017–2021), adjusted down by about 1.8 bcm a year to reflect the increase in import prices so far in 2022, which are already reflected in the baseline economic projections.[17] In particular, the calculations assume that temperatures are in line with their recent averages. In the adverse scenario, consumption is calculated as a residual.[18]

- *Inventories.* Germany has about 24.8 bcm of gas storage capacity,[19] which is just over two months' winter consumption (22 bcm). In the baseline, inventories accumulate in summers and are drawn down in winters, following seasonal consumption patterns. In the adverse scenario, the government is assumed to remove all requirements to fill gas storage facilities, so that gas that would have been directed to building inventories in the baseline can instead be used to meet consumption needs. In the adverse scenario, gas inventories are drawn down with perfect foresight of future consumption and always maintain 10 percent of capacity, to allow for so-called 'base' gas, which must be kept in storage facilities to maintain the pressure necessary for injecting and withdrawing gas, and to manage intra-month volatility, inter-regional imbalances and other risks.

[16] The Federal Network Agency releases a report on the need for reserve (standby) power generation capacity every year. The latest report (Federal Network Agency, 2022a) estimates about 5.7 GW of reserve power needed for winter 2021/2022 and a total requirement of 4.2 GW for 2023-2024. 5 GW times 8760 hours in a year equals 43.8 TWh per year of power, equivalent to 4.5 bcm per year of gas. We therefore assume the full capacity of these power plants is converted into gas savings. The latest reports can be found at https://www.bundesnetzagentur.de/EN/Areas/Energy/Companies/SecurityOfSupply/GridReserve/start.html.

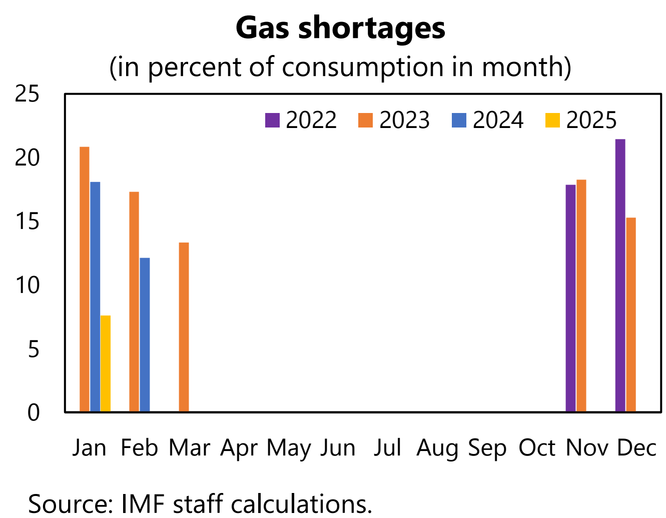
[17] According to Destatis, gas import prices increased by 115 (log) percent between the 2019–2021 average and the average between January and March 2022. Using an elasticity of 0.05 for passthrough to retail gas prices (as estimated in Section 5) and a household demand elasticity of -0.15, household demand would fall by about 0.2 bcm. Similarly, using an elasticity of 0.44 for passthrough to producer gas prices and sector-specific demand elasticities from Andersen (2011), industrial demand would fall by about 1.6 bcm.

[18] We do not explicitly allow for further demand compression (beyond gas-to-coal switching), for example through efficiency gains, as is estimated to be possible in Holz et al. (2022) and BDEW (2022). This is for two reasons: (i) such demand compression could come with costs to economic output that we seek to quantify in this study; and (ii) some efficiency gains are expected even in the baseline, which therefore would not help to limit the economic losses, because these are the difference between the baseline and the adverse scenario. Similarly, information on the government's announced auction mechanism, to encourage reduced gas consumption among firms, was not available at the time of writing to be included in these calculations. Nevertheless, we would not want to allow for such reductions in consumption if they are associated with cuts to firms' production, because these are part of the economic impact that we seek to quantify.

[19] According to the Aggregated Gas Storage Inventory (AGSI) platform.

- *Renewable and nuclear power.* The steady increase of renewable power (equivalent to about 2.7 bcm a year) and the phasing out of nuclear reactors this year (equivalent to about 3.5 bcm a year), would affect the projections for gas consumption equally in both the baseline and adverse scenarios. Since they do not affect the calculation of shortages, which are deviations of the adverse scenario from the baseline, we do not make any special adjustment for them.

Figure 1. Gas Shortages if Gas is Shut Off on June 1, 2022
(in percent of consumption in month)



Note: No shortages are expected in late 2024.

The calculations in the baseline scenario suggest that gas shortages can be avoided, but only narrowly, indicating a vulnerable outlook for gas consumption. To avoid shortages in the winter of the baseline scenario, the calculations suggest that gas-to-coal switching must be extended to March 2027. They also suggest that, while intermediate gas storage filling targets for August 1 and October 1 can be met, the storage levels would only be around 80 percent of capacity by November 1, which is short of the government's target of 90 percent.[20] Moreover, the calculations point to dangerously low gas inventory levels (just above 10 percent of capacity) in all future winters, out to the winter of 2026/2027, which would risk intra-month or inter-region shortages, or national shortages if temperatures are colder than expected. Before the curtailment of Russian gas flows through Nord Stream 1 in June 2022, the baseline scenario projections for gas inventory accumulation were significantly better, with the government able to reach its 90 percent target even without the activation of idle coal-fired power plants.

In a scenario where the remaining Russian gas supplies are shut off, Germany's gas consumption would have to fall, and substantially so in the winter months. The projections indicate that Germany would experience shortages of gas of 3.9 bcm between June and December 2022, 8.9 bcm in 2023, 3.4 bcm in 2024, and less than 1 bcm in each of 2025–2027. These shortages would have to be accommodated by lower gas

[20] This shortfall of gas storage relative to target was also noted on June 23 as reason for increases the emergency level from "early warning" to "alert": BMWK - Bundesministerium für Wirtschaft und Klimaschutz ruft Alarmstufe des Notfallplans Gas aus – Versorgungssicherheit weiterhin gewährleistet.

consumption than in the baseline, which could be brought about by some combination of price increases and quantity rationing. National consumption would have to fall by some 9 percent between June and December 2022 relative to baseline consumption levels, 10 percent in (Jan–Dec) 2023, and 4 percent in (Jan–Dec) 2024. Even with inventories helping to smooth shortages over time, these shortfalls would be concentrated exclusively in the winters, with national consumption having to contract by 10–20 percent each month between November 2022 and March 2023, and similar contractions in the winter of 2023/24 (Figure 1). If households are protected from rationing, as envisaged by Germany's Emergency Plan for Gas, then these shortages would fall on firms, which would therefore have to cut their consumption by 13 percent in the remainder of 2022, 14 percent in 2023 and 6 percent in 2024 (Table 2). On the other hand, if energy transformation[21] activities are also protected from rationing, given their role in district heating and electricity supply (which are already engaging in gas-to-coal switching in the adverse scenario), then the remaining non-energy firms would have to cut their consumption by 19 percent in the remainder of 2022, 22 percent in 2023, and 8 percent in 2024. As explained in Section 0 below, we focus on the latter scenario in the discussion that follows, but the results of both scenarios are presented for reference. Note that these calculations suggest that Germany would have sufficient supplies for protected customers like households even in the worst winter month, which suggests that Germany would not be eligible to request gas supplies from neighbors under its existing or future solidarity agreements. The bottom panel of Table 2 translates these period-by-period gas shortages into shortages over expanding scenario horizons, which are used as inputs into the economic model below.

Our estimates of gas shortages seem smaller than those in the literature to date, partially because Germany has reduced its dependence on Russian gas over time. Our estimates of gas shortages are similar to those of Bundesbank (2022b) in the winter of 2022/23 (they have 31 percent of unprotected sectors' consumption), and larger in the winter of 2023/24 (they have 11 percent of unprotected sectors' consumption while we have around 20 percent). It is difficult to compare our estimated gas shortages with other studies, because they tend not to distinguish between the cuts to national and firms' gas consumption. However, our estimates of gas shortages are smaller than those estimated by the Bundesbank (2022a) and GCEE (2022), because we start from a lower and more recent share of Russian gas in total gas imports and allow for a release of gas reserves. Moreover, our estimates of monthly gas shortages do not exceed 21 percent of consumption in any one month, while the median scenario in Joint Economic Forecast (2022) reaches a shortage of 60 percent in October 2022.

These estimated gas shortages are subject to significant uncertainty. These shortages could be higher than estimated if infrastructure constraints bite. For example, ENTSOG (2022) notes significant bottlenecks in gas infrastructure across German borders and even between Northern and Southern Germany. The shortages could also be higher than estimated here if Germany must supply more gas than usual to neighboring countries, like Austria, the Czech Republic, Hungary and Slovakia, which studies like ENTSOG (2022) and Di Bella et al. (forthcoming) suggest are vulnerable to gas supply disruptions.[22] The winter shortage in these countries could amount to 9 bcm,[23] with which Germany and other countries listed in the risk groups of the EU's

[21] Energy transformation is the conversion of energy from one energy product into another. For example, coking coal can be transformed into coke, crude oil can be refined, and fuel oil can be converted to electricity.

[22] Germany could benefit from extra supplies from neighboring countries, like the Netherlands, Belgium, Denmark and France, but it is likely that cross-border infrastructure is already being used to a high level of capacity, leaving little room to increase supplies further.

[23] This estimated shortage assumes that all three of Czech Republic, Hungary and Slovakia experience the winter shortage of 91 percent of national consumption estimated in Di Bella at al. (forthcoming). It assumes that Austria experiences a shortage of 18 percent of national consumption (Di Bella et al., forthcoming). National winter consumption is taken to be 9.2 bcm total for the first three countries, and 3.2 bcm for Austria, based on consumption in January, February and December 2019.

Security of Gas Supply Regulation ((EU) 2017/1938) could be required to assist.[24] If the winters are colder or longer than usual, consumption could increase by up to 3.1 bcm a year.[25] On the other hand, if the gas shutoff leads to further increases in imported and retail gas prices, households might reduce their demand for gas by up to 0.8 bcm a year more than what is assumed in the calculation above (which is based on the increase in prices seen to date).[26] Higher prices could also compress firms' gas demand, but this does not require a separate adjustment in our calculation because such demand compression would be part of the GDP impact that we seek to estimate. Note that we do not take a stand on the extent to which the gas shortages estimated here occur through higher prices that compress firms' demand, or through missing gas quantities due to a situation where gas demand outstrips supply and the gas price does not clear the market (which could be caused by infrastructure bottlenecks). Both types of shortages are included in our analysis. (Section 5 presents potential scenarios for prices.)

Table 2. Estimated Gas Shortage Scenarios

Scenario: Russian gas shutoff to Germany on June 1, 2022
(bcm, unless otherwise noted)

	Feb-May 2022	Jun-Dec 2022	2023	2024	2025	2026	2027
(1) Consumption without shutoff	32	45	89	89	89	89	89
Non-Russian supplies	23	36	75	83	83	83	83
Russian supplies	12	-	-	-	-	-	-
(2) Russian supplies lost		7	8	3	0	0	0
(3) Net release of inventories		2.1	0.5	-2.4	-0.3	0.2	3.4
(4) Inventories not built up due to shutoff		0.9	-1.1	2.0	-0.7	-0.7	-4.0
Shortage (=(2)-(3)-(4))		3.9	8.9	3.4	0.9	0.4	0.6
Shortage (% of national consumption in period)		9	10	4	1.0	0.5	0.7
Replacement ratio (=((3)+(4))/(2)x100)		44	< 0	< 0	< 0	< 0	< 0
Demand compression (% of non-protected consumption in period):							
• If only HHs are protected		13	14	6	1.5	0.7	1.0
• If HHs and energy transformation are protected		19	22	8	2.3	1.1	1.6
	From Jun '22 until:						
	Dec 2022	Dec 2023	Dec 2024	Dec 2025	Dec 2026	Dec 2027	
Demand compression (% of cumulative non-protected consumption):							
• If only HHs are protected	13	14	11	8	6	5	
• If HHs and energy transf. are protected	19	21	16	12	10	8	

Notes: Consumption line (1) is adjusted down for price increases observed in 2022 so far. Even though there is no shortage of gas in the year 2025, the shortages between 2022 and 2024 imply that cumulative gas consumption between 2022 and 2025 must be reduced.

[24] Requests for Germany to supply gas to these countries are unlikely to take the form of official requests under solidarity agreements. Germany only has solidarity agreements with Austria and Denmark. Di Bella et al. (forthcoming) estimate that Denmark would not experience gas shortages in a full shutoff scenario, and Austria might experience shortages of around 18 percent of winter consumption, which would be insufficient to threaten gas supplies to households. Households in Austria accounted for 19 percent of gas consumption in 2019.

[25] 3.1 bcm is the difference between the 93.6 bcm consumed in 2021 and the average consumption over the past five years (90.5 bcm). The year 2021 was the coldest of the last five years (3,114 heating degree days) and the year with the highest gas consumption.

[26] Under the most extreme scenario of a 370 percent increase in Netherlands TTF gas prices considered in Section 5, and assuming that all of it passes through to German import prices, the historically low passthrough of 0.05 from import to retail gas prices and the historical -0.15 household elasticity of gas demand imply that household gas consumption would only fall by 0.8 bcm a year.

3. GDP impacts

Approach to Estimating GDP Impacts

Our estimate of the impact on GDP captures three mechanisms: production cuts due to a lack of gas, downstream amplification through intermediate products, and increases in uncertainty. We estimate the impact on GDP by adding together the results from two models. The first model captures the dependence of firms' production on gas, and therefore the drop in production due to a lack of gas. It also accounts for the dependence of firms' production on the intermediate goods and services produced by other firms, which means that the reductions in firms' production in the first stage also restrict the subsequent production of downstream firms, thus amplifying the effects of the gas shortage. For example, a gas shortage would restrict production of steel products, which would then leave less steel to produce cars.[27] These effects would emerge even if all actors in the economy knew every firm's gas usage requirements and all the relationships between suppliers. However, this information is not public, and moreover, the size and timing of gas shortages are highly uncertain. Therefore, out of caution and to conserve resources, firms might cut back investment and hiring in a crisis, households might cut back consumption, and banks might tighten lending standards, further restricting economic activity. Therefore, the second model captures these effects of higher uncertainty in a summarized way, based on the historical relationship between uncertainty and economic activity. The baseline projections of GDP and inflation used in this study are explained in the forthcoming staff report: IMF (forthcoming).

The model of firms' production specifies the way that firms produce using gas, oil, electricity and intermediate inputs from other firms. Each of 17 sectors of the economy has a representative firm that produces using a constant return to scale technology. The firm's production function is nested, with a Cobb—Douglas form converting energy and other intermediate inputs into output, and a constant elasticity of substitution form converting gas, oil, coal and renewables into energy. The model is static, so to estimate GDP impacts over time, we apply the model over different scenario horizons. A key parameter in the analysis is the elasticity of substitution between gas and other types of energy.[28] We assume that the elasticity of substitution increases with the scenario horizon. For the period between June and December 2022, we assume an elasticity of 0.1, which is the lower bound of the estimated elasticities in the energy literature (Steinbuks, 2012; Labandeira and others, 2017), and 0.4 for the period between June 2022 and December 2027. This model extends the so-called 'simplest' production function approach of Bachmann et al. (2022) to the sectoral level, to allow for the possibility of sector-specific gas consumption shocks, and includes input—output links between sectors, to capture downstream amplification (second round) effects from constrained production of intermediate inputs due to gas shortages.[29] Therefore, the model we use here is a generalization of the so-

[27] Downstream amplification effects can propagate indefinitely (although their total effect is finite). For example, reduced production of cars could restrict the provision of transport services, which could in turn affect the availability of iron to produce steel. However, it's not known how long it would take for these various stages of propagation to take place, and estimates of their economic effects might be misleading because substitutability increases over time. Therefore, in this study, we analyze one round of downstream propagation only. Typically, as one examines second, third and fourth round effects, and so on, the effects shrink rapidly.

[28] The elasticity of substitution governs how the share of gas in firms' total expenditures changes in response to the gas supply shock. Specifically, a higher elasticity of substitution means that firms can switch from gas to alternative resources more easily, so that a smaller increase in the price of natural gas is needed to bring about the fall in demand needed to clear the market; this implies smaller increases in gas expenditure shares.

[29] The simplest model in Bachmann et al. (2022) is an aggregate model of the economy's production which does not differentiate between the production of different sectors and therefore does not explicitly capture the input—output linkages between them.

called ‘simplest’ production function model in Bachmann et al. (2022), and it is able to replicate the 2.2 percent decline in GDP shown in their Table 2. Consistent with the findings in Barrot and Sauvagnat (2016), our analysis assumes that these second-round impacts materialize 6 months after the direct impact. Thus, if the gas shutoff occurs in June 2022, the gas shortages and corresponding direct impacts on GDP will be seen in 2022, but the second-round effects will only start to be seen in December 2022, meaning that most of the second-round effects of the shortages in 2022 will be felt only in 2023. This 6-month delay assumption should be seen as holding on average across many sectors, because in some sectors like steel, inventories are currently low, so shortages might emerge more quickly (Arif and Steven, 2022). The model of firms’ production is described in detail in Annex I. Results pertaining to the first scenario, where only household gas consumption is protected from rationing, are included only for reference.

There are three reasons why we focus on the gas shortage scenario where energy transformation activity is protected from gas rationing, in addition to protections on households’ gas consumption. The first reason is simply that gas-to-coal switching is already factored into the estimation of gas shortages. This means that further gas supply cuts to this sector could significantly affect the provision of electricity, and even heating, with potentially serious non-economic welfare effects. The second reason is that this model, like others used in the literature to date, does not describe the energy sector in detail. This shortcoming means that the model could underestimate the economic effects of cutting gas supplies to energy transformation activities by naively relying on their small share of the economy and high gas intensity of production. This well-known potential limitation of such models was noted by Summers (2013),[30] and is another reason that we prefer to focus on the results from the scenario where energy transformation activity is protected from gas rationing. The third reason is that the protection of energy transformation activity imposes a larger contraction on the gas consumption of productive industries, which is an indirect way of capturing the extra burden on such industries that could result from protections on the gas consumption of other users, like hospitals and social services.

Explicitly modelling exports and imports could reduce the economic effects estimated here. Our model does not differentiate between production that is consumed domestically and production that is exported, or between inputs that are sourced domestically and those that are imported. Explicitly separating out exports and imports in the models could reduce the economic effects estimated here in two ways. First, as one of the hardest-hit countries, German demand could be expected to fall by more than foreign demand. Thus, separating the two types of demand would make overall demand fall by less. Second, it could open the possibility that some German firms adjust to the shock by substituting imports for domestically sourced inputs.

We estimate the historical relationship between economic output and uncertainty. We use two uncertainty measures from the literature. One is the number of occurrences of the word “uncertainty” from reports of the Economist Intelligence Unit about Germany (Ahir et al., 2022), and the other is the dispersion of economic forecasts (Jurado et al., 2015; Grimme and Stöckli, 2018). The regression takes the following specification for each horizon h:

$$g_{t+h} = \alpha + \beta u_t + \eta u_{t-1} + \lambda \tilde{g}_{t-1} + \boldsymbol{\Gamma_k X_{t-k}} + \epsilon_{t+h} \qquad (1)$$

where g_{t+h} denotes the deviation of GDP from its (Hamilton (2018) filter) trend in quarter $t+h$, and u_t denotes

[30] Summers writes, “There would be a set of economists who would sit around explaining that electricity was only 4% of the economy, and so if you lost 80% of electricity, you couldn’t possibly have lost more than 3% of the economy.” However, “we would understand that [...] when there wasn’t any electricity, there wasn’t really going to be much economy.”

the uncertainty measure. The parameter of interest is β, which measures the impact of uncertainty on growth at this horizon h. This local projection controls for lags of relevant macroeconomic variables ($\boldsymbol{X}$) for growth, including historical sequential growth, uncertainty, inflation, ECB monetary policy stance, and DAX stock market returns. Based on the availability of uncertainty measures, the sample runs from 1991Q2 to 2019Q3.

Estimated GDP Impacts

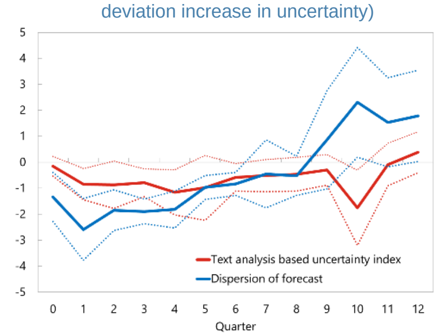
The direct and second-round effects on GDP tend to diminish over longer horizons. Panel (a) of Table 3 shows the gas shortages and GDP impacts, of direct and second-round (downstream) production cuts, over expanding scenario horizons. The direct impact on production of the 19 percent contraction in firms' gas consumption between June and December 2022 is to reduce GDP by 0.9 percent relative to its baseline level in this period. The direct impact on GDP is the same, at 0.9 percent, between June 2022 and December 2023, as the larger shock to gas consumption (21 vs. 19 percent) offsets the higher elasticity of substitution (0.12 vs 0.1). Over longer horizons, as the cumulative gas shortage shrinks and the elasticity increases, the direct impact on GDP falls. For example, between June 2022 and December 2027, gas consumption is reduced by 8 percent, and the direct effect is to reduce GDP by less than 0.05 percent. In addition to the direct effects on production, the gas shortages also generate second-round (downstream) effects. For example, the gas shortages between June and December 2022 generate second-round effects that reduce GDP by a further 0.9 percent, which we assess will be felt 6 months later, between December 2022 and June 2023. (The direct output losses of subsequent periods have second round effects as well.) These second-round effects are roughly the same size as the direct impacts, similar to the pattern in Bundesbank (2022a); like the direct impacts, they diminish with the expanding scenario horizons.

On a yearly basis, these direct and second-round effects imply lower GDP in 2022, 2023 and 2024, followed by negligible catch-up effects in subsequent years. Combining the direct and lagged second-round effects and converting them from expanding windows to an annual basis suggests that GDP would be lower than baseline levels by 0.7 percent in 2022, 1.8 percent in 2023 and 0.4 percent in 2024 (not shown).[31] The impact for the calendar year 2022 is smaller than the impact between June and December 2022, because GDP between January and May is not affected by the gas shutoff.

The associated rise in uncertainty could further reduce GDP in 2022 and 2023, with no clear impact in 2024 and beyond. Our estimates of β from equation (1), averaged across the two uncertainty measures, suggest that a one-standard deviation increase in uncertainty could lower GDP by about 1 percent relative to trend levels up to two years after the shock, with statistically unclear effects thereafter (Figure 2). This estimate is consistent with Bloom et al. (2018). We assume that the gas shutoff would lead uncertainty to rise to the 95th percentile of its historical distribution in 2022Q2 and then decay by half from 2022Q3 to 2023Q1. This shock would reduce GDP by 0.8 percent in 2022, 0.9 percent in 2023 and 0.1 percent in

Figure 2. Impulse Responses to Uncertainty Shocks

(Deviation from trend, in response to a one-standard-deviation increase in uncertainty)



Sources: Ahir et al. (2022), Destatis, Grimme and Stöckli (2018), IMF staff calculations.

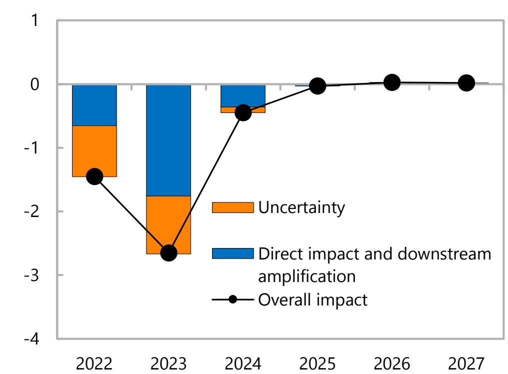
[31] Note that these are percentage deviations from baseline GDP levels, not percentage growth rates from one year to the next.

2024. There would be no clear effect on GDP in subsequent years.

Therefore, the shutoff of Russian gas would have sizable effects on German economic activity. Combining the direct, second-round and uncertainty effects, the gas shutoff would reduce GDP by 1.5 percent in 2022, 2.7 percent in 2023 and 0.4 percent in 2024 (Panel (b) of Table 3). These economic losses would be permanent in the sense that they are not "caught up" by deferring production, consumption, or investment to subsequent years. Our cumulative GDP loss between 2022 and 2024 is 4.8 percent of 2021 GDP. Losses in 2022 would mostly be driven by uncertainty effects, because downstream amplification effects materialize with a lag and emerge mostly in 2023 (Figure 3). By contrast, losses in 2023 would be evenly split between these three channels. From 2024 onwards, there would still be losses overall, but they would be driven almost entirely by downstream amplification effects. If energy transformation activities help to bear some of the gas shortages, losses would be smaller, with the model used here suggesting that GDP would be 1.2 percent lower than baseline in 2022, 1.9 percent lower in 2023, and 0.4 percent lower in 2024, with no catch-up effects of deferred economic activity in subsequent years (Panel (b) of Table 3).

Figure 3. Impacts on German GDP

(Percent deviation from baseline levels)



Sources: IMF staff calculations.

Our estimates of GDP losses are in line with the estimates in other key studies. The impacts on GDP estimated here are difficult to compare with other estimates in the literature that do not specify their time horizon exactly, like Bachman et al. (2022), ECB (2022) and OECD (2022).[32] Our estimated impact of 1.5 percent in 2022 matches the 1.5 percent in Bundesbank (2022b), but it is smaller than the 5 percent estimated by Bundesbank (2022a), due to the narrower scope and smaller size of energy shortages estimated here (see Section 2), not least because some of their price-based gas shocks (see footnote 6) would already be incorporated in our baseline, given the price increases seen to date. Like Bundesbank (2022b), our GDP losses continue into 2023 and 2024, but ours are smaller, likely because our baseline already accounts for the curtailment of Russian gas supplies through routes like Nord Stream 1 in June 2022, we do not include disruptions to other energy or food supplies, and as explained above, we envisage smaller effects of external demand. Over twelve months, our GDP losses are similar to the 2-3 percent impact in the model of Di Bella et al. (forthcoming) with adjustment frictions, because our inclusion of losses from downstream and uncertainty effects roughly offsets their allowance for complementarities between gas and capital inputs into production. Over two years, our estimated GDP loss is smaller than the estimate of the Joint Economic Forecast (2022). Specifically, while the Joint Economic Forecast (2022) reports a cumulative loss in GDP over 2022 and 2023 of 6.5 percent of GDP in some base year, we find a cumulative loss of 4.3 percent of 2021 GDP for that period. The larger GDP impacts in Joint Economic Forecast (2022) are likely due to their assumption of an extreme inability of firms in some sectors to substitute the missing gas, their extra channels of transmission, including tighter financial conditions and unemployment, and their potentially larger estimates of gas shortages (see Section 2). Our finding of a larger impact in 2023 than 2022 agrees with

[32] Specifically, these studies each estimate the GDP lost over one period, rather than a path of GDP losses over future calendar years. Furthermore, the studies do not define precisely the period used; it is left as an unspecified number of months, perhaps one year.

the pattern in Bundesbank (2022b) and Joint Economic Forecast (2022), but our result owes more to delayed second-round effects than a depletion of gas reserves in 2022.

Table 3. Estimated GDP impacts of Gas Shortages

Panel (a): Expanding windows, direct and second-round effects

Expanding windows	From May '22 until:					
	Dec '22	Dec '23	Dec '24	Dec '25	Dec '26	Dec '27
Required demand compression (percent of consumption):						
• If only households are protected	13	14	11	8	6	5
• If households and transformation are protected	19	21	16	12	10	8
Elasticity of substitution	0.10	0.12	0.16	0.20	0.30	0.40
Implied change in expenditure share /1	2.0	1.8	1.0	0.5	0.3	0.1
First-round impact on cumulative GDP (percent deviation from baseline):						
• If only households are protected	-0.5	-0.5	-0.2	-0.1	-0.1	-0.04
• If households and transformation are protected	-0.9	-0.9	-0.4	-0.2	-0.1	-0.1
Second-round impact on GDP in 6 months' time (percent deviation from baseline):						
• If only households are protected	-0.6	-0.6	-0.3	-0.2	-0.1	-0.1
• If households and transformation are protected	-0.9	-0.9	-0.4	-0.2	-0.1	-0.1

Panel (b): Yearly direct, second-round and uncertainty effects

	In the calendar year:						
	2021	2022	2023	2024	2025	2026	2027
Real GDP level (percent deviation from baseline)							
• If only households are protected	0.0	-1.2	-1.9	-0.4	-0.1	0.0	0.0
• If households and transformation are protected	0.0	-1.5	-2.7	-0.4	0.0	0.0	0.0

Notes:
1/ Based on the formula $100(1-1/\sigma)\alpha(1-\alpha)\log(1-z/100)$, where z is the required demand compression in percent with households and energy transformation protected (the second row of numbers in this table), σ is the elasticitiy of substitution (the third row of numbers in this table), and $\alpha = 0.025$ is the national expenditure share on gas.

4. The importance of how gas is rationed

This section illustrates how sensitive these GDP impacts are to different schemes for rationing the available gas supplies. As noted in Section 0, the way that scarce gas supplies are allocated to different economic activities can substantially affect the estimates of lost GDP due to a gas supply shock. The analysis above implicitly assumes that gas supplies to the different unprotected economic sectors are cut in proportion to their gas consumption. (For example, with households and energy transformation activity protected, each remaining unprotected sector faces the same 19 percent cut to gas consumption between June and December 2022.) This is a plausible starting point, given that there might be short term technical constraints on differentiating between (especially smaller) end-users when cutting gas supplies.[33] However, in the medium term, these constraints can be overcome, so that firms in some sectors could face deeper cuts to their gas supply than other sectors. Therefore, the experiments here examine the GDP impacts of other schemes for apportioning the cuts to gas consumption that could also achieve the same 7 percent reduction in gas consumption at the national level, which is the shortage experienced between June and December 2022 in Table 2.

[33] For example, according to Federal Network Agency (2022b), “With the data currently available or obtainable at short notice, individual orders [to cut gas supply] for specific end-consumers are only possible in exceptional individual cases.”

The analysis suggests that the impacts on GDP can be reduced substantially by cutting gas supplies to gas-intensive and downstream industries by more. Table 4 shows the results from four rationing schemes. The first scheme, labelled "naïve" rationing, cuts gas consumption by equal (19 percent) proportions in every unprotected sector. The direct and second-round GDP impacts between June and December 2022 of this rationing scheme, which are shown in the last two rows of the table, match those in Table 3 above (both equal to 0.9 percent). The other three rationing schemes cut gas consumption to different sectors in a way that minimizes the direct and second-round economic impacts, under different constraints.[34] The direct impacts are minimized by cutting gas supplies to sectors in the order of their gas intensity of production (which means the ratio of their gas use to their value added), and the second-round impacts are minimized by cutting gas supplies to sectors in the order of their 'downstreamness'. In all rationing schemes, households and energy transformation activities are either fully or partially protected from rationing. Comparing the results in the first two columns of numbers, we see that the direct GDP impact could be reduced by three-fifths (from 0.88 to 0.31 percent), and the second-round impact by a similar magnitude (from 0.88 to 0.32), if gas supplies to some economic sectors are rationed more severely than to others. In Table 4, the industrial sector rows are sorted from most gas-intensive to least gas-intensive, and a pattern that emerges is that the GDP losses are minimized when sectors higher up the order are rationed first. However, this pattern is not followed strictly, and in some cases a sector is skipped (like paper or iron and steel)—this skipping occurs when a sector has more downstream linkages that outweigh its gas intensity alone. The sectors that the analysis identifies for rationing, in various orders and combinations, are non-metallic minerals; iron, steel and non-ferrous metals; paper, pulp and printing; chemicals and petrochemicals; and food, beverages and tobacco. The rationing algorithm chooses these sectors because they are relatively gas-intensive or appear to have fewer downstream linkages than other sectors.[35]

The analysis also suggests that the GDP loss can also be reduced by having households share in the burden of gas shortages. Comparing the second and third columns of numbers shows that the GDP losses can be reduced even further if households share in some of the burden of gas rationing. Specifically, direct GDP losses can be reduced by one-third (from 0.31 to 0.21 percent), and second-round losses can be reduced by over one-third (from 0.32 to 0.20 percent), if households' gas consumption is cut by 10 percent. A 10 percent reduction in gas consumption is equivalent to reducing heating temperature by about 2 degrees, over the period where heating is needed (BDEW, 2022). Reductions in households' consumption could occur voluntarily, as Japan's *setsuden* movement achieved after the 2011 earthquake, or in response to rising prices.[36]

[34] Specifically, the three rationing schemes shown are each the solution to a linear programming problem, where the objective function to minimize is the formula for GDP loss due to direct and second-round effects, as explained in Annex I. We assume that no sector can have its gas consumption cut by more than 50 percent.

[35] The analysis here uses the 2021 edition of the OECD Inter-Country Input—Output Table.

[36] Even customers on fixed-price contracts could see increases in gas prices in a crisis. The government has passed laws that allow it, in a gas emergency, to permit gas suppliers to pass through wholesale price increases to customers, even if those customers are notionally on fixed-price contracts. The intention of these powers is to preserve the solvency of gas suppliers. Households' purchasing power could then be supported via income transfers or other policy measures.

Table 4. GDP impacts Between June and December 2022 of Different, illustrative Rationing Schemes

(percent cut to gas consumption)	"Naïve" Rationing	"GDP Loss-Minimizing" Rationing		
	Given households and energy sectors protected	Given households and energy sectors protected	Given households rationed by 10% and energy sector protected	Given households and energy sectors rationed by 10%
Industry				
Non-metallic minerals	19	50	50	50
Iron, steel and non-ferrous metals	19	19	0	0
Paper, pulp & printing	19	0	0	0
Chemical & petrochemical	19	50	50	23
Food, beverages & tobacco	19	50	5	0
Textile & leather	19	0	0	0
Mining & quarrying	19	0	0	0
Wood & wood products	19	0	0	0
Not elsewhere specified (industry)	19	0	0	0
Machinery	19	0	0	0
Transport equipment	19	0	0	0
Construction	19	0	0	0
Transportation	19	0	0	0
Service	19	0	0	0
Agriculture	19	0	0	0
Households	0	0	10	10
Energy sector	0	0	0	10
Direct impact on output	0.88	0.31	0.21	0.12
Second-round impact on output	0.88	0.32	0.20	0.16

Note: The direct and second-round impacts on output, shown in the last two rows, are not added together because the second-round impacts might occur with a lag. Within industrial activities, the rows are sorted from most gas-intensive to least gas-intensive, and the GDP impacts are minimized when more gas-intensive industries have their gas supplies cut by more. The GDP-minimization algorithm rations gas supplies to different sectors by balancing both gas-intensity and downstreamness of sectors.

5. Inflation impacts

International gas prices could rise substantially with a shutoff of Russian gas. The gas shutoff for Europe would lead to a surge in gas prices across the continent.[37] Albrizio et al. (forthcoming) estimate that a shutoff could make the average Netherlands TTF gas price in 2022 between 110 to 370 percent higher than 2022:Q1, depending on the demand elasticity of natural gas and the feasibility of rerouting LNG from Asia to Europe. Their worst-case scenario assumes no LNG supplies are rerouted from Asia. As of June 2, part of these price increases has already been seen in 2022, as described above, and are therefore factored into our baseline.

Such increases would pass through to domestic consumer price inflation, as oil and gas prices have done historically. Historically, international energy prices have been important drivers of consumer price inflation in Germany. International oil and gas prices affect inflation directly, through the prices that households

[37] For reference, the Netherlands TTF natural gas price more than doubled right after the invasion of Ukraine on February 24 and at the end of May remained about 15 percent higher than February.

pay for refined oil and gas products, and indirectly, by pushing up the costs of producing other goods and services. The literature documents a significant passthrough from international energy prices to headline inflation, with magnitudes depending on the conduct of monetary policy, the level of trade openness, and the energy intensity of the economy (e.g., Chen, 2009; Choi et al., 2018; Habermeier et al., 2009).

To assess the effects of a Russian gas shutoff on German inflation, we estimate the historical relationship between international energy prices and domestic inflation. In our model, we allow for the possibility that larger international energy price shocks have larger effects on German inflation. One possible interpretation of this inflation behavior is that firms face “menu costs” to adjusting their prices, so they only do so when it would create profits in excess of the adjustment cost (Mankiw, 1985). Therefore, the larger the increase in international energy prices, the greater the profit from a newly set price, and the greater the likelihood that a given firm would choose to adjust its price. Following Hamilton (2003), define a large increase in international energy prices in quarter t as $\tilde{\pi}_t^* = \max(0, \tilde{p}_t/\tilde{p}_t^{3yr} - 1)$, where $\tilde{p}_t$ denotes the international energy price in quarter t and $\tilde{p}_t^{3yr}$ denotes the maximum price during the most recent 3 years up to quarter $t-1$. The regression follows a standard local projection specification with state-dependent passthrough for each horizon h:

$$\pi_{t+h}^E = \alpha + \beta\tilde{\pi}_t^E + \gamma\tilde{\pi}_t^{E*} + \Sigma_{k=1}^4 \eta_k \tilde{\pi}_{t-k}^E + \Sigma_{k=1}^4 \lambda_k \tilde{\pi}_{t-k}^{E*} + \Sigma_{k=1}^4 \delta_k \pi_{t-k}^E + \epsilon_{t+h}$$

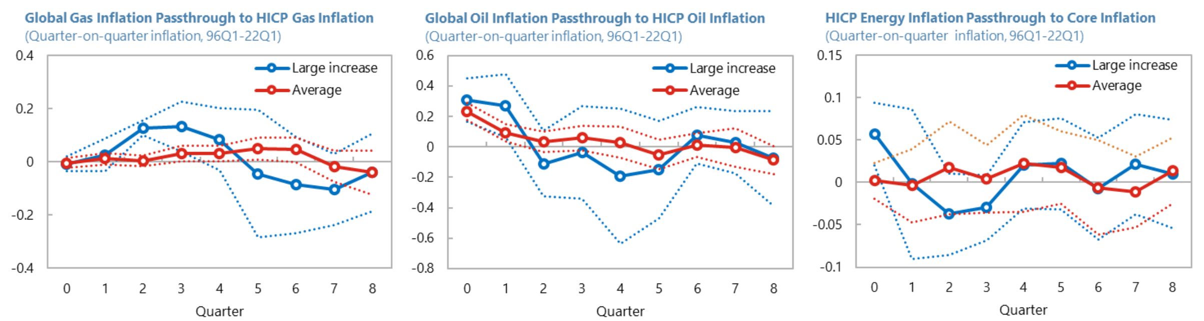
where *E* indexes oil or gas,[38] π and $\tilde{\pi}$ denote quarter-on-quarter energy inflation based on the relevant Germany HICP component or international prices, respectively, β represents the average passthrough to HICP oil/gas inflation h quarters ahead, and $(\beta + \gamma)$ is the passthrough corresponding to a large increase in international oil/gas prices h quarters ahead. $\tilde{\pi}_t^{E*}$ denotes the large increase in international prices, as defined above, of energy type *E*. The specification controls for four lags of HICP and international energy price inflation. The specification is estimated by ordinary least squares and point standard errors are estimated by the Newey—West method to allow for serial correlation in the error term. Since international energy prices are relatively exogeneous for a domestic price taker, this historical relationship should be a useful guide to prospective shocks to international prices. Besides the passthrough from international energy prices to HICP energy inflation, we also estimate the passthrough from HICP energy inflation to core inflation. To do this, we use the same specification, but replace international energy inflation with HICP energy inflation as the independent variable, and add a five-year consensus inflation expectation and output gap (which corresponds to a forward-looking Phillips curve specification). Brent crude and Netherlands TTF are used as international oil and gas prices, respectively. The sample is from 1996Q1 to 2022Q1.

The passthrough from international energy to Germany inflation is significantly higher than average when international energy prices rise substantially. The passthrough from international to domestic gas prices averages around 0.02 over 2-3 quarters, but rises fivefold to 0.1 following large increases in international gas prices (Figure 4). Similarly, the contemporaneous passthrough of international oil price averages at 0.2 in normal times but jumps to 0.3 in the case of a price surge. Note that the passthrough of the international gas price is more lagged than that of oil, and this is due to customers’ gas (and electricity) prices usually being fixed in 12-month contracts. The nonlinearity also holds for the passthrough from HICP energy inflation to core inflation. In normal times, HICP energy inflation barely affects core inflation, but in the case of large energy

[38] HICP oil inflation includes solid and fluid fuels and fuels and lubricants for vehicles, and HICP gas inflation includes natural gas, electricity, and heating.

price jumps, the passthrough reaches 0.05 contemporaneously. The wide confidence bands for outer quarters partly reflect the small number of large increase in energy prices.

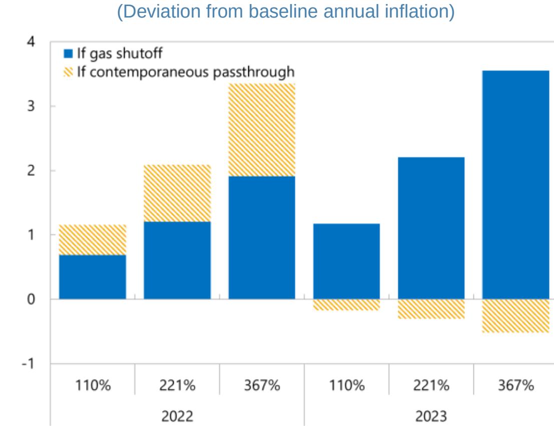
Figure 4. Energy Inflation Passthrough



Note: Confidence bands are estimated at 1% significance level.
Sources: Eurostat, IMF GAS dataset, IMF staff calculations.

Using these estimated relationships, a shutoff of Russian gas could significantly increase Germany's inflation rate in both 2022 and 2023. We assume that international gas prices rise in 2022Q2 by 110, 221 or 367 percent (as explained above) and last for 12 months, and that the GDP impact from uncertainties will widen the output gap. The estimates suggest that, if international gas prices rise by 110 percent, which is consistent with a scenario where Asia shares the Russian supply shock with Europe in equal proportions, German inflation would be about ¾ of a percentage point higher in 2022, and 1¼ percentage points higher in 2023, than without the shutoff (Figure 5). On the other extreme, if international gas prices rise by 370 percent, which is consistent with a scenario in which Asian LNG supplies are not rerouted to Europe, inflation could be higher by about 2 and 3.5 percentage points in 2022 and 2023 respectively. However, in such a gas emergency, the government might activate its recently introduced powers that allow it to permit firms to pass on price increases to consumers regardless of existing contracts. This could trigger a contemporaneous passthrough, instead of the lagged passthroughs shown by historical data, which would lead to more frontloaded impacts on inflation. Under the previous scenario of a 370 percent increase in international gas prices with such powers activated, inflation could be 3¼ percentage points higher than without the shutoff in both 2022 and 2023. These estimates of inflationary effects are larger than those in Bundesbank (2022b) (0.5 in 2022, 1.5 in 2023 and 0.25 in 2024, in percentage points), which may be because: (i) their demand-side analysis would contain more deflationary forces; and (ii) our model is non-linear, in that larger price shocks have larger effects. It is worth noting that the international gas price increases considered in this paper are without precedent prior to 2021, meaning that the passthrough and resultant consumer price inflation rates could be greater than these estimates.

Figure 5. Inflation Under Gas Shutoff Scenarios
(Deviation from baseline annual inflation)



Sources: Eurostat, IMF GAS dataset, IMF staff calculations.
Note: The horizontal axis shows scenarios for the increase in international gas prices following the Russian gas shutoff.

6. Policy discussion

Given the sizable economic impacts estimated here, it is important to enhance energy security and build resilience. This requires new sources of gas supply. The national and European authorities have explored possibilities of acquiring additional gas from major suppliers, including the United States, Norway and Qatar, and Germany is establishing terminals to be able to import more LNG (see Section 1). Enhancing energy security also requires filling gas storage facilities before the winter, finding ways to enhance energy efficiency, accelerating the development of renewable energy, ensuring that financial constraints do not exacerbate energy scarcity, maintaining strong international cooperation, and developing plans to distribute the available gas supplies in a crisis. These elements are discussed in this section.

The scarcity of imported fossil fuels increases the urgency of accelerating the development of domestic renewable energy production and decarbonizing the economy. The so-called “Easter package” of legislative proposals, announced in April 2022, is aimed at speeding up the expansion of renewable energy generation. It would raise the target to 80 percent of electricity demand to be met with renewables by 2030, from 42 percent observed in 2021. It would speed up investment processes by establishing in law an overriding public interest in the development of renewables. It would also increase the volume of public tenders for solar and onshore wind power to 22 and 10 GW a year, respectively.

The government is appropriately ensuring the solvency of energy companies. Gas import prices have risen substantially, given the combination of rising LNG prices and a shift from long-term contracts to spot market purchases. Moreover, prices of other energy sources, including electricity, oil and coal have been volatile due to the war in Ukraine and the associated sanctions. Volumes of trade in gas, oil and coal are also experiencing big shifts, as Germany and the EU diversify away from Russian imports. These rapid and unusual moves in prices and quantities risk worsening the solvency position of energy companies, which could in turn affect the supply of energy products in Germany. It is therefore important to monitor the financial health of energy companies, which could include regular calls or surveys. Recent legal amendments that allow more flexibility in retail prices could help maintain the solvency of energy companies. If used, they may need to be accompanied by further targeted, discretionary income support for vulnerable households, whether through one-off energy relief payments or housing benefits (which preserve price signals and therefore the incentive to save energy). The government plans to support firms’ liquidity with loans through KfW, an extension of the pandemic-era loan guarantee programs, and loans to energy producers to post margins on their hedging contracts.[39]

While the government is taking important steps to promote energy efficiency, more can be done. The government has called for households, firms, public sector agencies and non-profits to reduce energy consumption, which would help store up gas for the winter season. A successful energy-saving campaign is needed, like Japan’s *setsuden* after the 2011 earthquake. A program could be offered to exchange gas heaters for heat pumps. The government has announced its intention to develop an auction mechanism that could compensate firms for reducing gas consumption, which could also help fill gas storages. This policy contrasts with earlier announced intentions to provide temporary and targeted subsidies for firms’ increased gas costs—

[39] Energy producers guarantee their sales prices ahead of time by selling their products (e.g., gas or electricity) through forward contracts. When the spot price rises above their contracted forward price, they have to post a security deposit (margin) that increases with the price difference. By financing the margin calls that have followed sharp increases, the government is preventing financial stress in energy producing firms.

given the urgency of accumulating additional gas reserves following the curtailment of Russian gas supplies in June, these subsidies should be dropped. A simple analogue of the gas-saving program for firms could be considered for households as well, using rebates or discounts on gas bills to encourage gas-saving, depending on technical feasibility. Smart meters are not widely available in Germany, which prevents users from monitoring their gas consumption in real time. Instead, consumers could be provided with up-to-date, online gas usage statistics. The government has announced that coal-fired power plants will be reactivated to help save gas that would otherwise be used for electricity generation. In this effort, it will be important to ensure that even if some gas power plants are able to compete with coal power plants, these plants cut their gas consumption. The Federal Network Agency's daily dashboard provides a transparent overview of the current supply situation. In addition, regular publication of gas projections, like those provided on June 23, 2022,[40] would help encourage energy saving. Also on June 23, the government announced that it would not immediately be exercising its powers to allow gas utilities to adjust retail gas prices. If activated, this tool would likely lead to price increases that would provide a powerful incentive to save gas in an economically efficient way, but vulnerable people would likely require protection from associated financial hardship.

To encourage investment, the authorities should provide a clear diagnosis of infrastructure gaps under the scenario of a full shutoff of Russian gas supplies to Europe. ENTSOG (2022) identifies several infrastructure gaps, including within Germany. However, a transparent diagnosis by German authorities is also needed. The plan for the development of the gas infrastructure network over the period 2022-2032 (the "network development plan") could help with this, but publication of its consultation document was postponed on May 2, 2022. Given the urgency, a diagnosis of infrastructure gaps could be published before the network development plan.

International cooperation is key to building resilience and managing any future gas shortages. Cooperation with the EU is key, given the level of integration of energy markets in the EU and the role of EU institutions in energy market regulation, international trade policy, and coordinating cross-border investment. As explained in Di Bella et al. (forthcoming), REPowerEU is an important step towards energy security in the EU. Germany could work with France to solve the 'odorization' issue,[41] which could include the financing of a deodorization plant. Germany could also benefit from additional gas flows from the LNG terminal at Dunkirk (which may not be odorized) and from a planned FSRU at Eemshaven, in the Netherlands. Germany has signed solidary agreements (under EU Regulation 2017/1938) with Denmark and Austria, and further agreements are possible with other neighboring countries. Germany's dependence on gas imports underscores the importance of it keeping exports flowing.

Further elaboration of rationing policy is needed, which should take its economic implications into account alongside other dimensions. This paper presented some model-based experiments that illustrate the economic importance of rationing decisions. They also illustrate principles that might be helpful when deciding on rationing, like involving households in (potentially voluntary or price-based) burden sharing, and applying stricter rationing to more gas-intensive and downstream firms. However, the decision of how to ration

[40] The June 21 projections are published here: https://www.bmwk.de/Redaktion/DE/Downloads/Energie/220622_gas-mengengeruest_2022-23_BNetzA.html.

[41] Odorization is a safety procedure by which elements like sulfur are added to natural gas to give it a smell, so that it is easier for people to identify gas leaks. France and Germany have different approaches. While France odorizes gas in its system, Germany only odorizes gas in the final stage when it is distributed to customers, and not in its transmission network or storage facilities. Germany's approach protects some consumers with sensitive industrial processes from potentially damaging odorized gas. The different odorization practices between France and Germany mean that French gas cannot easily flow to Germany.

gas depends on non-economic considerations like social welfare, environmental and health implications, and technical and legal constraints. Some of these considerations are set out in Federal Network Agency (2022b). Therefore, an economic analysis of rationing, like the one presented here, cannot be conclusive. Similarly, major rationing decisions, like which sectors should be protected entirely, require political participation and, if left entirely to a technical agency like the energy regulator, could exceed its mandate, tools and capacity and thereby undermine its credibility and functioning. For its part, the Federal Network Agency has collected crucial information on firms' gas usage needs to help develop plans for gas distribution in a crisis. It might be well placed to act as a central authority that could manage rationing policy on a day-to-day basis, as the UNDP and World Bank (2005) have explained is important in such situations.

Annex I. Production model

Nested Production Model and Extensions

Assume that a representative firm in sector k operates a constant return to scale production function

$$Y_k = Z_k E_k^{\alpha_{E_k}} \Pi_{j=1}^{J} X_{jk}^{\alpha_{jk}}, \qquad (1)$$

where $\alpha_E > 0$ parameterizes the importance of energy input in production; X_{jk} is the intermediate input from sector j used in the production of sector k and α_{jk} reflects the relative importance of intermediate goods from sector j in the production of output in sector k; and E_k is an aggregation of gas and other energy inputs, such as coal, oil, and renewables .

$$E_k = \left(\omega e_{gas_k}^{\frac{\epsilon-1}{\epsilon}} + (1-\omega) e_{oth_k}^{\frac{\epsilon-1}{\epsilon}}\right)^{\frac{\epsilon}{\epsilon-1}}, \quad (2)$$

where $\omega > 0$ captures the importance of gas in total energy inputs and ϵ is the elasticity of substitution between gas and other energy inputs.

Following Kmenta (1967), the CES production function of energy inputs could be approximated by a function of the form

$$E_k \approx e_{gas_k}^{\omega} e_{oth_k}^{1-\omega} \left(\frac{e_{gas_k}}{e_{oth_k}}\right)^{\frac{1}{2}\left(1-\frac{1}{\epsilon}\right)\omega(1-\omega) ln\left(\frac{e_{gas_k}}{e_{oth_k}}\right)},$$

and a second-order approximation gives

$$d\ln E_k = \omega\, d\ln e_{gas_k} + \frac{1}{2}\left(1-\frac{1}{\epsilon}\right)\omega(1-\omega)\, d\ln e_{gas_k}\, d\ln e_{gas_k}. \qquad (4)$$

The constant return to scale production function for a representative firm in sector k can be approximated by

$$d\ln Y_k \approx \alpha_{E_k}\, d\ln E_k + \sum_j \alpha_{jk}\, d\ln X_{jk}. \qquad (5)$$

Plugging equation (4) into equation (5) allows us to obtain the relationship between changes in gross output and gas usage, which summarizes the direct impact of gas shocks on gross output,

$$dln\, Y_k^d \approx \alpha_{E_k}\left(\omega\, ln\, e_{gas_k} + \frac{1}{2}\left(1-\frac{1}{\epsilon}\right)\omega(1-\omega)\, dln\, e_{gas_k}\, dln\, e_{gas_k}\right), \qquad (6)$$

where $d\ln Y_k^d$ is denoted as the direct impact on gross output.

Direct impact

Given that the distribution parameters α_E and ω reflect the importance of energy inputs in production and the importance of gas in energy inputs respectively, we calibrate α_E to energy expenditure share $\frac{P_E E_K}{P_k Y_k}$ in total output and ω to the gas share in energy inputs $\frac{P_{gas} e_{gas_k}}{P_E E_K}$. Equation (6) can be rewritten as

$$d\ln Y_k^d \approx \frac{p_{gas} e_{gas_k}}{P_k Y_k}\, d\ln e_{gas_k} + \frac{1}{2}\Delta \frac{p_{gas} e_{gas_k}}{P_k Y_k}\, d\ln e_{gas_k}, \qquad (7)$$

where changes in gas expenditure shares $\Delta \frac{p_{gas} e_{gas_k}}{P_k Y_k} = \alpha_E\left(1-\frac{1}{\epsilon}\right)\omega(1-\omega)\, d\ln e_{gas_k}$. ϵ reflects how easy it is to substitute gas with other inputs in production. A higher elasticity of substitution means that firms can switch from gas to alternative resources with greater ease, meaning that a smaller increase in the price of natural gas is needed to bring about the fall in demand to clear the market, and thus with smaller implied changes in gas expenditure shares. Our sectoral production function approach is similar to the simplest model approach by Bachmann et al. (2022).

Second-round impact

The production function equation (1) formalized the idea that firms in industry k will need to use goods produced by other industries as intermediate inputs for production and coefficients α_{jk} summarize the input-output linkages across sectors. To derive the second-round effects, we will leverage the property of the Cobb-Douglas production function that sectoral expenditure share on intermediate goods is unchanged and invariant to the realization of supply shocks. It implies changes in intermediate inputs from sector j in production of sector k are equal to the changes in output of sector j[42,43]

$$d\ln X_{jk} = d\ln Y_j,$$

and equation (5) can be rewritten as

$$d\ln Y_k \approx \alpha_{E_k} d\ln E_k + \sum_j \alpha_{jk} d\ln Y_j.$$

Then, we have

$$\overrightarrow{d\ln Y^s} = (I - A')^{-1}\alpha_E \overrightarrow{d\ln E} = (I - A')^{-1} \overrightarrow{d\ln Y^d}$$

where $A = [a_{jk}]$ is the input-output matrix and the coefficient α_{jk} summarizes the amount of inputs from sector j required for one unit of output k, which is equivalent to the sector k's expenditure share on inputs from sector j. The corresponding Leontief inverse matrix is denoted as $L = (I - A)^{-1} = \sum_{i=0}^{\infty} A^i$. The relationship between the sectoral direct and second-round effects is given by

$$\overrightarrow{d\ln Y^s} = (I - A')^{-1}\overrightarrow{d\ln Y^d},$$

in terms of sectoral level direct impact and the production network. The Leontief inverse associated with input-output matrix A is denoted as $L = (I - A)^{-1} = \sum_{i=0}^{\infty} A^i$, where the (j,k) element of the Leontief inverse $l_{jk} = a_{jk} + \sum_r a_{jr}a_{rk} + \cdots$.The sectoral second-round impacts of gas shock on sector j can be rewritten as

$$d\ln Y_k^s = \sum_j l_{jk}\, d\ln Y_j^d = \sum_j \left(a_{jk} + \sum_r a_{jr}a_{rk} + \cdots\right) d\ln Y_j^d$$

The second-round impact of the gas shock on sector k will propagate through the input linkages directly from the input suppliers and indirectly through the downstream suppliers. Given that it takes time for the higher-order effects to materialize, the analysis will focus on the second-round impact of gas shocks, which is captured by $\sum_j a_{jk} d\ln Y_j^d$. Over time, intermediate inputs will become more substitutable, and the supply bottleneck incurred by the gas shock will ease. As a result, the higher-order propagation through the input-output linkages will become less critical.

Aggregation

Given that

$$dlnGDP = \sum_k dlnVA_k$$

[42] Given that the gross national output is a CES aggregation of the gross sectoral production, the relative sectoral output share is fixed.

[43] Note that these are log changes, rather than percentage changes. These are similar at small values, but as the percentage change approaches -100%, the log change approaches $-\infty$. One practical implication of this is that, if gas shortages cause the production of components like steel and rubber (almost) to cease, then production of cars would (almost) cease as well, even if the expenditure share (α_{jk}) of the auto industry on steel or rubber is small.

and assuming that changes in value added is the same as changes in output at sectoral level,[44] the aggregate changes in direct and second-round impacts can then be calculated as

$$dlnGDP^{d} = \sum_{k} \lambda_{k} \, d\ln Y_{k}^{d},$$

and

$$dlnGDP^{s} = \sum_{k} \lambda_{k} \, d\ln Y_{k}^{s},$$

where $\lambda_k = \frac{V_k}{\sum_k V_k}$ is the value-added share of sector k, calibrated from the input-output table.

[44] This assumption implicitly assumes the sectoral labor and capital shares will be invariant to the gas shocks, which is in line with our Cobb-Douglas production function specification. For simplicity, our approach does not explicitly specify factor input, such as labor and capital.

References

Ahir, Hites, Nicholas Bloom, and Davide Furceri. 2022. The world uncertainty index. National Bureau of Economic Research Working Paper No. 29763.

Albrizio, Silvia, John Bluedorn, Christoffer Koch, Andrea Pescatori and Martin Stuermer, forthcoming. Market Size and the Impact of Sanctions:Sharing the Pain from a Potential Russian Gas Shut-off to the European Union. IMF Working Paper.

Andersen, Trude Berg, Odd Bjarte Nilsen, and Ragnar Tveteras, 2011. How is demand for natural gas determined across European industrial sectors? *Energy Policy* 39(9), pp. 5499-5508.

Arif, Rabia and Benjamin Steven, 2022. German steel market expects significant decrease in inventory, output: survey. S&P Global Commodity Insights. April 4.

Bachmann, Ruediger, David Baqaee, Christian Bayer, Moritz Kuhn, Andreas Löschel, Benjamin Moll, Andreas Peichl, Karen Pittel, and Moritz Schularick, 2022. "What if? The economic effects for Germany of a stop of energy imports from Russia." ECONtribute Policy Brief 28/2022.

Baqaee, David, and Emmanuel Farhi. Networks, barriers, and trade. 2019. National Bureau of Economic Research Working Paper No. 26108.

Barrot, Jean-Noël, and Julien Sauvagnat. "Input specificity and the propagation of idiosyncratic shocks in production networks." *The Quarterly Journal of Economics* 131, no. 3 (2016), pp. 1543-1592.

BDEW, 2022. Facts and arguments: Short-term substitution and savings potential natural gas in Germany. March 17. Berlin.

Bloom, Nicholas, 2014. Fluctuations in uncertainty. *Journal of Economic Perspectives* 28(2), pp. 153-76.

Bloom, Nicholas, Max Floetotto, Nir Jaimovich, Itay Saporta-Eksten, and Stephen J. Terry, 2018. Really uncertain business cycles. *Econometrica* 86(3), pp. 1031-1065.

Bundesbank, 2022a. “Additional disruptions to the German economy in the event of an energy embargo.” Monthly Report, April. Frankfurt.

Bundesbank, 2022b. “Possible development of the German economy in an adverse risk scenario.” Monthly Report, June. Frankfurt.

Carvalho, Vasco M., Makoto Nirei, Yukiko U. Saito, and Alireza Tahbaz-Salehi, 2021. Supply chain disruptions: Evidence from the great east Japan earthquake. *The Quarterly Journal of Economics* 136(2), pp. 1255-1321.

Choi, Sangyup, Davide Furceri, Prakash Loungani, Saurabh Mishra, and Marcos Poplawski-Ribeiro, 2018. Oil prices and inflation dynamics: Evidence from advanced and developing economies. *Journal of International Money and Finance* 82, pp. 71-96.

Chen, Shiu-Sheng, 2009. Oil price pass-through into inflation. *Energy Economics* 31(1), pp. 126-133.

Grimme, Christian, and Marc Stöckli, 2018. Measuring macroeconomic uncertainty in Germany. In CESifo Forum, 19(1), pp. 46-50. München: ifo Institut-Leibniz-Institut für Wirtschaftsforschung an der Universität München.

Di Bella, Gabriel, Mark Flanagan, Karim Foda, Svitlana Maslova, Alex Pienkowski, Martin Stuermer and Frederik Toscani, forthcoming. Natural Gas in Europe: Stress Testing a Disruption to Supply. IMF Working Paper.

Holz, Franziska, Robin Sogalla, Christian von Hirschhausen, and Claudia Kemfert, 2022. DIW current, No. 83: Special issues on the war in Ukraine, 9 pages. Berlin, March.

ENTSOG, 2022. Summer Supply Outlook, April 11.

European Central Bank, 2022. "Natural gas dependence and risks to euro area activity." Box 4, Economic Bulletin, Issue 1/2022. Prepared by Vanessa Gunnella, Valerie Jarvis, Richard Morris and Máté Tóth.

Federal Network Agency, 2022a. Determination of the grid reserve requirement for the winter of 2022/2023 and the observation period from April 2023 to March 2024. Bonn, April 29.

Federal Network Agency, 2022b. Load sharing gas - options for action, weighing decision, action depending on the situation: as of May 17, 2022. Bonn.

German Council of Economic Experts, 2022. Effects of a possible end to energy supplies from Russia on energy security and economic output. Economic Outlook, March. Wiesbaden.

Habermeier, Karl, Inci Otker-Robe, Luis I. Jácome, Alessandro Giustiniani, Kotaro Ishi, David Vávra, Turgut Kisinbay, and Francisco Vazquez, 2009. Inflation pressures and monetary policy options in emerging and developing countries—A cross regional perspective. IMF Working Papers WP/09/01, pp. 1–78.

Hamilton, James D., 2003. What is an oil shock? *Journal of Econometrics*, 113(2), pp.363-398.

Hamilton, James D., 2018. Why you should never use the Hodrick-Prescott filter. *Review of Economics and Statistics*, 100(5), pp.831-843.

Joint Economic Forecast, 2022. "From Pandemic to Energy Crisis: Economy and Politics under Permanent Stress." Spring Joint Economic Forecast No. 1-2022. Prepared by the German Institute for Economic Research (DIW Berlin), the ifo Institute (Munich), the Kiel Institute for the World Economy (IfW Kiel), the Halle Institute for Economic Research (IWH), and RWI (Essen).

Jurado, Kyle, Sydney C. Ludvigson, and Serena Ng, 2015. Measuring Uncertainty. *American Economic Review* 105, pp. 1177–1216.

International Monetary Fund, forthcoming. Germany: 2022 Article IV Consultation Staff Report. IMF Country Report, July. Washington, DC.

Kmenta, Jan, 1967. On estimation of the CES production function. *International Economic Review* 8(2), pp. 180-189.

Labandeira, Xavier, José M. Labeaga, and Xiral López-Otero, 2017. A meta-analysis on the price elasticity of energy demand. *Energy policy* 102, pp. 549-568.

OECD, 2022. "Economic and Social Impacts and Policy Implications of the War in Ukraine." OECD Economic Outlook, Interim Report, March.

Schnittker, Christian, Shirley Feng, Alexandre Stott, 2022. "The Impact of Gas Shortages on the European Economy", Goldman Sachs Economics Research.

Steinbuks, Jevgenijs, 2012. Interfuel substitution and energy use in the UK manufacturing sector. *The Energy Journal* 33(1).

UNDP and World Bank, 2005. Implementing Power Rationing in a Sensible Way: Lessons Learned and International Best Practices. Energy Sector Management Assistance Program Report 305/05. August.

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