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DISCUSSION PAPER

// TOM KREBS

# Economic Consequences of a Sudden Stop of Energy Imports: The Case of Natural Gas in Germany

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**Summary**
This policy paper studies the effects of a sudden stop of natural gas imports from Russia on the German economy. The analysis focuses on the supply-side effects that arise when a gas shortage affects production in the gas-intensive manufacturing sectors, with a corresponding production disruption that propagates along the value chain and through the entire economy. In a baseline scenario, a hypothetical gas embargo implemented in May 2022 leads to a short-run decline in aggregate output between 3.2 percent and 8 percent of GDP. In an alternative scenario, in which Germany can easily replace Russian gas imports by alternative imports, the short-run decline in aggregate output following the embargo is between 1.2 percent and 3 percent of GDP. In addition to the supply-side effects, an embargo causes a reduction in output via the demand-side channel. According to recent simulation studies, the demand-side effects of an energy embargo (coal, oil, natural gas) reduce GDP between 2 percent and 4 percent in the short run. These results underscore the high degree of uncertainty regarding the economic consequences of a sudden stop of Russian gas imports in the short run. Finally, an immediate gas embargo also causes permanent economic damage and has significant social implications. In policy terms, the results show the need for the German government to act as swiftly as possible to ensure independence from Russian energy imports. In addition, Germany's future energy system needs to be more resilient to macroeconomic and geopolitical shocks.



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## 1. Introduction

In the wake of the Russian invasion of Ukraine on February 24, 2022, European leaders debated whether the European Union (EU) should immediately stop all energy imports from Russia.[2] However, several EU countries resisted this type of "cold-turkey" approach and opted for a more gradual policy. For example, in April 2022 the German government decided against an immediate embargo and instead announced a plan to gradually phase out Russian energy imports (BMWK, 2022a,b). Specifically, Germany decided to wean itself off Russian coal and oil by the end of 2022 and to stop Russian gas imports by the end of 2024.

In this paper, I discuss the possible economic consequences for Germany if the EU had decided to impose an immediate import stop on natural gas from Russia in April or May 2022.[3] To answer this question, I draw on various sources and existing results. I also highlight how different assumptions lead to starkly different conclusions, which partly explains the wide range of predictions that have arisen from different model simulations.

I proceed with the analysis in four steps. In a first step, I compute the expected short-run decline in natural gas supply in Germany after a sudden stop of Russian gas imports. To do this, I draw on a range of studies of the natural gas market that all come to the same conclusion: without Russian gas supply, Germany and the EU face a binding physical constraint on overall gas supply in case of an immediate embargo. In other words, the short-run gas supply function becomes inelastic at a point that is economically relevant. Assuming Germany, respectively the EU, will import gas from non-Russian countries up to the point of inelastic supply, I can compute the negative gas supply shock that would hit the German economy in case of a gas embargo. In a baseline scenario, in which Germany and the EU fulfil their – already ambitious -- plans to replace Russian natural gas in 2022, this gas shock amounts to a reduction in annual gas consumption by 290 TWh or 32 percent of 2021 consumption. In an alternative scenario, in which these plans will be over-fulfilled and more natural gas can be imported from non-Russian countries in the short run, annual gas consumption in Germany would have to be reduced by 240 TWh or 27 percent of gas consumption in 2021.

In a second step, I compute how the gas supply shock is distributed among the three sectors that use natural gas in Germany: building, energy and industry. According to current calculations, the energy sector can save or replace up to 105 TWh of natural gas in the short term without endangering the electricity supply (mainly by fuel shifting in power generation

[2] In March and April 2022, the demand for an immediate and complete energy embargo was an integral part of the public debate. See, for example, the New York Times column by Paul Krugman "Can Germany break up with Russian gas?" (Krugman, 2022) and the call to action "Let's stop financing the war — Immediate import ban on Russian oil and gas!" initiated by Ralf Fuecks and signed by many German public intellectuals (Fuecks, 2022).

[3] Clearly, the economic consequences would be the same if Russia had decided to stop delivering natural gas to Germany, respectively the EU, in April or May 2022. Indeed, since June 14, 2022, gas delivery to Germany/Europe from Russian have been substantially reduced and on June 23, 2022, the German government activated the second of three levels of the gas emergency plans (BMWi, 2019, BMWK,c). The negative economic effects of this gradual reduction of Russian gas deliveries are similar to the effects described here, but the likelihood that a severe gas shortage in the manufacturing sector will occur – the baseline scenario in the current report – is now smaller than it was in April 2022, when the first version of this report was written (Krebs, 2022).

from gas to coal/oil). In the building sector, gas consumption can decrease by around 55 TWh if private households substantially reduce their room temperature in the winter, improve operating settings (e.g., water-saving/heating fittings) and invest in heat pumps. This leaves a supply "deficit" of 130 TWh in the baseline scenario and 80 TWh in the alternative scenario, which needs to be offset by a reduction in natural gas use in the industrial sector. In other words, gas supply available to the industrial sector would decrease by 130 TWh, respectively 80 TWh, in case of an embargo.[4] This amounts to a required reduction in gas use by 53 percent, respectively 33 percent, of industrial gas use in 2021.

In a third step, I compute the short-run decline in industrial production in response to the shortage of natural gas supply. In Germany, there are six manufacturing sectors that heavily rely on natural gas as an energy input: chemical, metal, glass/ceramics, food, paper, and mechanical engineering. For many companies belonging to one of these six sectors, natural gas is an essential input factor in the production process that is difficult to replace in the short run. In other words, the production function is of the Leontief-type with a limited switching opportunity.[5] In the baseline scenario, an embargo leads to a production loss in gas-intensive manufacturing that reduces the annual gross domestic product (GDP) by 1.6 percent. In the alternative scenario, the production loss in gas-intensive manufacturing amounts to 0.6 percent of annual GDP. This figure defines the first-round economic effect of a gas embargo.

In a fourth and final step, I calculate the macroeconomic consequences of an immediate halt to Russian gas imports by considering how the short-run decline in production in the gas-intensive industries (first-round effect) propagates and amplifies through the entire economy via production linkages (second-round effect). In Germany, the gas-intensive industry produces specialized intermediate goods that cannot easily be replaced by imports in the short-run and that provide an input into a complex supply chain. A sudden drop in the production of basic chemical or metal products would lead to interruptions in production chains via so-called “network effects”, and thus spill over into the entire economy. The network multiplier (Acemoglu et al., 2016) summarizes to what extent this second-round effect reduces aggregate production. I survey the existing evidence on the size of this network multiplier in the short run and conclude that a range between 2 (lower bound) and 5 (upper bound) appears reasonable for the case of a sudden drop in production in the gas-intensive industry in Germany. Thus, aggregate output would drop in the short run by 3.2 to 8 percent in the baseline scenario and by 1.2 to 3 percent in the alternative scenario, in which the industrial sector barely experiences any gas shortage. These results are in line with recent work on the supply-side effects of a sudden of stop of gas imports (Bundesbank, 2022a,b, and GD, 2022a,b).

In this report, I focus on the question of how a sudden stop of gas imports from Russia in April or May 2022 would have affected the German economy via the supply-side channel. However, an embargo also influences aggregate demand due to rising energy prices and

[4] In case of a complete embargo in April or May 2022, the German government would have activated the gas emergency plan (BMWi, 2019) immediately and the Federal Network Agency (Bundesnetzagentur) would have been in charge of the gas allocation mechanism; see Section 2.2 for details.
[5] See the discussion in Section 3 for details.

increasing uncertainty. Several papers have used simulation analysis based on large-scale macroeconomic models to assess the importance of this demand-side channel and conclude that this channel would cause German GDP to decline by 2 percent to 4 percent in the short run (Bundesbank, 2022a,b, GD, 2022a,b,c, IMK, 2022, SVR, 2022a). Clearly, in the case of an energy embargo, both economic channels will cause a decline in aggregate production, but the interaction of the two channels is complex and depends on several factors. If we assume that to a first-order approximation the total GDP effect is the simple sum of the two effects (Bundesbank, 2022a,b, SVR, 2022a),[6] then the short-run impact of an immediate embargo would be a drop in aggregate production, between 5.2 and 12 percent in the baseline scenario and 3.2 percent and 7 percent in the alternative scenario.[7]

The wide range of results demonstrates the high degree of uncertainty regarding the economic consequences of a sudden gas embargo. One reason for this uncertainty is that the economic effects strongly depend on the size of the gas supply shock that would hit the German economy in case of an embargo, which in turn depends on the extent to which Russian gas can be replaced by alternative imports in the short run (baseline scenario vs alternative scenario). Another reason is that current business cycle models – and, in particular, the large-scale macroeconomic models used by central banks and international organizations – have not fully incorporated the type of supply-side channel that arises when complex production networks are disrupted. Moreover, there is limited empirical evidence regarding the macroeconomic consequences of the sudden disruption of production networks. In this sense, economics is currently in a situation similar to that before the 2008/2009 global financial crisis (GFC), when most economists and business cycle models underestimated the real economic impact of the Lehman-Brothers bankruptcy.

Despite this uncertainty, a few general lessons can be drawn from the analysis. Specifically, an immediate and complete halt of Russian natural gas imports in April or May 2022 – in combination with a coal and oil embargo – would probably have led to a short-run drop in German GDP comparable to the decline in 2009 during the GFC or in 2020 during the COVID-19 crisis. Clearly, this would also have caused a steep recession in Europe with corresponding implications for the world economy. In a best-case scenario, Germany might “only” experience a “regular” recession, but in a worst-case scenario, a sudden gas embargo could cause the largest annual GDP loss that (West) Germany has experienced since World War II.[8] Moreover, there are at least two reasons to expect the social consequences of an embargo-caused recession in 2022/23 to be more severe than in the previous two recessions.

First, a steep recession in 2022 or 2023 caused by a sudden stop of gas imports from Russia would most likely have more severe labor market consequences than the previous two recessions in Germany. A recession due to gas shortages would directly impact the industrial sector, which constitutes the backbone of the German economy, with high value-added production and a large number of well-paying jobs. In addition, after two years of the COVID-19 crisis and global supply chain problems, many companies with an inherently viable

[6] See the discussion in Section 4 for details.

[7]This has to be subtracted from the trend to arrive at the actual output loss.

[8] In 2009, real GDP dropped by 5,6 percent and in 2020 by 4,9 percent. These are the largest one-year drops in German GDP since WWII.

business model might go bankrupt in a new recession or relocate their production to (non-European) foreign countries. In general, recessions often cause lasting damage; this is the so-called "hysteresis effect" of recessions. The rapid recovery of the German economy after the GFC of 2008/2009 is therefore not the rule, and there is much to suggest that an energy-related economic crisis would be less short-lived than the financial crisis in Germany.

Second, a steep recession in 2022 or 2023 would take place against the backdrop of high inflation. A sudden stop of gas imports leads to a negative aggregate supply shock and would push the already high inflation rate in Germany even higher. Inflation is inherently a social problem since it affects lower- and middle-income households disproportionally. Moreover, the ability to use expansionary monetary policy in a supply-side recession is limited. Finally, fiscal policy also needs to act cautiously in order to avoid fuelling inflation even if there is plenty of fiscal space. From a policy perspective, negative aggregate supply shocks are always a complex challenge for which there is no truly satisfactory solution. In this sense, large negative supply shocks that cause a severe economic crisis are an economic policy disaster.

In summary, the available evidence suggests that a sudden stop of Russian energy imports could have far-reaching economic and social consequences. Two policy conclusions follow from this result. First, the gains from taking immediate action to reduce gas consumption and to replace Russian gas imports are significant. While the German government has been quite decisive in securing additional gas imports from non-Russian countries, it has so far not been able to implement a coherent plan that would lead to the necessary reduction in domestic gas consumption. This must be one of the policy priorities in the months to come.[9] Second, Germany's energy system has to become more resilient to macroeconomic and geopolitical shocks. The issue of resilience has many dimensions (Brunnermeier, 2021), and will most certainly play a key role in the construction of a future energy system that is based on renewable energy.

## 2. Supply and allocation of natural gas after the embargo

### 2.1 Gas supply shock hitting the German economy

I consider the following scenario. In April 2022, the EU decides to impose an energy embargo that would completely stop the import of natural gas from Russia by the beginning of May 2022. The supply freeze lasts for at least one year (until April 2023); this defines the "short-run period" in this report.

Compared to oil and coal, natural gas is the energy source that is most difficult to replace in the short run. Germany and Europe have little additional production capacities and cannot buy natural gas on the "world market" in unlimited quantities because the transportation

[9] In other words, the reduction in gas consumption discussed in Section 2 is best achieved using the right policy instruments. See, for example, Grimm et al. (2022) and Neuhoff et al. (2022) for a discussion of some concrete policy measures that could lead to a substantial reduction in gas consumption. Starting in June 2022, the German government began a national campaign for less natural gas consumption and on June 23, 2022, the German government activated the second level of the gas emergency plan (BMWK, 2022c).

capacities for liquefied natural gas (LNG) are limited in the short run (Neuhoff, 2022). Thus, there are short-run capacity constraints that any economic analysis must take into account. In other words, the short-run gas supply curve becomes inelastic at an economic relevant point. Moreover, the transportation of natural gas within Europe uses pipelines and the pipeline system is a European network, which means that decisions regarding the distribution of gas among the EU countries after an embargo have to be taken at the European level.[10]

In 2021, natural gas consumption in Germany was 912 terawatt hours (TWh), of which almost half (430 TWh) was imported from Russia (Agora, 2022).[11] Some portion of the 430 TWh of imports from Russia can be replaced by imports from other countries. Based on the plans of the EU Commission (EU, 2022) and the analysis of the International Energy Agency (IEA, 2022), the study by Agora (2022) estimates that EU member countries could increase production and imports of natural gas by about 500 TWh in the short run. Assuming that Germany would receive about one-third of this additional gas, Agora (2022) computes an extra gas supply of 140 TWh for Germany (15 percent of Germany's annual consumption in 2021). This scenario is the baseline scenario in my analysis. It assumes that the EU fully implements its plans, and that Germany receives about one-third of the additional gas that EU countries can secure. This seems ambitious, but, in principle, possible. Moreover, the additional gas imported or produced has to be delivered to Germany via the existing pipeline network; this seems possible according to recent calculations (Holz et al., 2022).

In the baseline scenario, in Germany a gas embargo leads to a loss of Russian gas imports of 430 TWh and an increase of imports of 140 TWh from other countries. This leaves a "deficit" of about 290 TWh of natural gas or 32 percent of German gas consumption in 2021. Such a deficit defines the necessary reduction in gas consumption after the embargo and amounts to one-third of gas use in 2021. In other words, there is a short-run capacity constraint that tightens and binds after the gas embargo. From an economic point of view, the short-run gas supply function shifts to the left, whereby the inelastic part of this supply function shifts by 290 TWh.[12]

The limited possibilities of replacing natural gas imports from Russia in the short run do not contradict the plans of the German government to become independent of Russian gas imports by 2024 (BMWK, 2022a,b). Here, the timeframe is important. Regarding natural gas, there is a substantial difference between an adjustment period of a few months to a maximum of one year (the short run in this report), with a three-year adjustment period. This is true both in terms of the possibilities to replace Russian natural gas imports with imports from other countries and in terms of the possibilities to replace natural gas with alternative energy sources (oil, coal, electricity) in production. A gradual approach to phasing

[10] For example, almost half of the natural gas that Germany buys from Russia is transported through the pipeline system to other European countries. It is therefore not surprising that several EU countries resist a gas embargo, even though a coal embargo was imposed as part of the fifth package of EU-sanctions and a (partial) oil embargo as part of the sixth package of EU sanctions.

[11] The figures always refer to TWh Hu.

[12] The existence of a capacity constraint (inelastic supply) for natural gas in the short run is one reason why calculations based on the assumption of competitive gas markets are not applicable or at least generate misleading results: see Section 5 for details.

out Russian gas imports is costly, but most likely manageable, whereas a cold-turkey approach might generate large economic and social costs.

### 2.2 Gas allocation mechanism after the embargo

In the baseline scenario, there is a shortfall of around 290 TWh or 32 percent of gas use in 2021 after a gas embargo. This determines the expected reduction in gas supply after an embargo, assuming that without the embargo the expected gas consumption in the period May 2022 to April 2023 would amount to 912 TWh. The next question is which sectors of the economy would reduce their gas consumption and by what amount; that is, how would the reduction of gas supply by 290 TWh and the corresponding gas shortage be allocated after the embargo?

In Germany, the consumption of natural gas is concentrated among three sectors (Agora, 2022): first, buildings and construction (340 TWh, mainly private households); second, the energy sector, including the conversion sector (278 TWh, private and some public companies); and third, manufacturing (245 TWh, private companies). In case of a sudden stop of Russian natural gas imports in May 2022, the emergency plan for a natural gas supply (BMWi, 2019) would have to come into force immediately and would stay in place until 2023 or longer. This means that the distribution of the available gas would be partially based on central planning. In other words, the government would have to activate the gas emergency plan immediately after the embargo and the Federal Network Agency (Bundesnetzagentur) would take charge of large parts of gas allocation. This would have to happen immediately after the embargo in May 2022, even though gas consumption is relatively low in Germany during the summer months.[13] There are two reasons for this.

First, the sufficient supply of natural gas in every region of the country cannot be ensured, even if the aggregate gas supply is sufficient to meet aggregate gas demands in the summer months. The reason is that natural gas is transported to users via pipeline networks and, due to technical reasons, the additional gas coming from Norway or the Netherlands cannot immediately replace the lack of natural gas from Russia. This problem could probably be solved after an initial period of chaos, although nobody knows for sure how long the adjustment period would be. Second, and more importantly, the natural gas storage facilities need to be replenished in the summer to ensure that there is sufficient gas for the protected customers in the winter, such as private households as they have priority over business customers. However, without Russian gas imports, this requires that the supply of natural gas for companies in the energy and manufacturing sector is already restricted in summer 2022.

The exact dynamics of the distribution of the reduction in natural gas consumption over the course of the year following the sudden stop of Russian gas imports is highly uncertain. However, the final outcome has to be a reduction in annual gas consumption by 290 TWh. In

[13] Monthly natural gas consumption usually falls sharply in the months of June, July and August since there is no need for heating and little use of air conditioning in Germany. Indeed, on June 23, 2022, the German government activated the second of three levels of the gas emergency plans in response to a reduction in Russian gas imports thereby increasing the possibilities of the Federal Network Agency (Bundesnetzagentur) to intervene in the gas allocation mechanism (BMWK, 2022d).

addition, the degree of supply shortages (respectively, forced gas saving) in the energy and manufacturing sectors would be determined by the Federal Network Agency to a large extent. In contrast, any reduction in gas consumption in the building sector would have to be achieved by mainly using price signals and appeals: private households are protected customers and therefore have priority over business customers.[14] Thus, the allocation of natural gas following an embargo is not well described by models that assume perfect competition and imply an efficient gas allocation. Put differently, a simple supply-demand analysis based on historical gas demand elasticities is unlikely to yield useful results.

**2.3 Gas supply shock hitting the manufacturing sector**

In this report, I use the results found by Agora (2022), who conducts a detailed sector analysis based on a wide range of studies, to assess the maximal degree of reduction in gas consumption in the building and energy sectors that would be possible. In conjunction with the necessary total gas reduction of 290 TWh, this provides my estimate of the required reduction in gas use by manufacturing companies; that is, the negative gas supply shock that would hit the manufacturing sector in case of an embargo.

Agora (2022) examines these savings potentials in the energy industry and concludes that 105 TWh of natural gas can be saved or replaced in the short term in an optimistic scenario (level 2), by changing the use of some power plants, expanding renewable energies, and using heating oil in individual natural gas power plants. In this scenario, natural gas consumption in the energy industry is thus reduced by more than one-third in the first year after the supply freeze, without the energy supply being severely affected, which is certainly an ambitious plan.

In the building sector, Agora (2022) calculates that approximately 55 TWh can be saved in the first year after the gas embargo through behavioural changes (e.g., lowering the room temperature), improve operating settings (e.g., water-saving/heating fittings) and investment measures (e.g., heat pumps).[15] This corresponds to a 17 percent decrease in natural gas consumption in the building sector and is the “optimistic scenario” or the “ambitious scenario” in the Agora study (level 2). It assumes, among other things, that 50 percent of private households reduce their room temperature by an average of 1.5 degrees Celsius and 50 percent of households by one degree. This requires significant behavioural adjustments for many households, given that some households – in particular, high-income households – will not react at all to price increases by reducing their room temperature. The targeted average reduction in room temperature can therefore only be achieved if a

[14] For example, the Federal Network Agency would have to intervene in valid supply contracts between companies and energy suppliers if it wanted to achieve a significant reduction in gas consumption by manufacturing companies as early as summer 2022. Of course, the Federal Network Agency could use auctions to introduce some element of a price mechanism to allocate scarce gas resources. It would also have to acquire stakes in energy companies (e.g., Uniper) in order to support them financially. Indeed, as part of the activation of the second gas emergency plan in June (BMWK, 2022c), the government explicitly mentions the possibility of an intervention is valid contracts and the possibility of auctions. Further, by the end of June the energy supplier “Uniper” asked the government for financial assistance including an injection of equity capital (Handelsblatt, 2022a).

[15] Agora (2022) calculates 56 TWh, which is rounded down here to 55 TWh.

substantial fraction of households reduces their average room temperature in the winter by at least 2 degrees Celsius.

These considerations show that in the baseline scenario, which is already quite optimistic in parts, the expected natural gas consumption in the building and energy sectors taken together could fall by 160 TWh in the first year after the embargo. This value is most likely an upper bound for the planning of the Federal Network Agency, whose task it is to ensure the security of gas supply for protected (priority) customers. With a decline in natural gas availability of 290 TWh, this leaves a "deficit" of 130 TWh that must be absorbed by the manufacturing sector through a corresponding reduction in gas consumption.

In 2021, the manufacturing sector (without the conversion sector) consumed approximately 245 TWh of natural gas (Agora, 2022). This means that in the baseline scenario, the manufacturing sector needs to reduce its natural gas consumption by around 130/245 = 53 percent. This defines the size of the exogenous natural gas shock that would hit the manufacturing sector industry in the event of a gas embargo.

There have been frequent calls by economists to use the price mechanism to provide private households and companies with the right incentives to save energy or to replace natural gas (Bayer et al., 2022). In a certain sense, the current analysis assumes that price signals are used wherever possible and that the Federal Network Agency only intervenes when the energy supply is at risk, or the market solution leads to an inefficient outcome. Otherwise, it would hardly be possible to reduce natural gas consumption in the energy sector by one-third in the short term without significant production losses, as assumed here. In addition, gas savings in the building sector assumed here are only feasible if private households make strong behavioural adjustments. Additional savings in the building sector only seem possible if private households lose their legal status as priority costumers and the manufacturing business gets priority over private individuals, which would require a change in the law and has no political support.[16]

### 2.4 Alternative scenario

Five economic research institutes (DIW, IfW, Ifo, IWH and RWE) have analysed the economic consequences of a sudden stop of Russian gas imports to Germany (GD, 2022a,b); see Section 5 for a detailed discussion. In their "median scenario", they assume that the loss of Russian gas imports can be more easily replaced by imports from non-Russian countries than assumed in the baseline scenario. Specifically, the current paper follows Agora (2022) and IEA (2022), which implies that about 140 TWh of lost gas imports from Russia can be replaced by alternative gas imports, leading to a reduction in net gas supply by 290 TWh (32 percent of total consumption in 2021). In contrast, in the median scenario GD (2022a,b) follow Holz et al. (2022), who calculate in a "realistic scenario" that about 190 TWh can be replaced by alternative imports, leading to a reduction in net gas supply by 240 TWh.[17]

[16] See also the statement of the head of the Federal Network Agency in an interview (Handelsblatt, 2022b).

[17] Holz et al. (2022) examine to what extent additional gas produced in Europe (or imported to Europe) can be delivered to customers in Germany through the existing pipeline network. For a "realistic scenario", they calculate that the existing infrastructure allows the transport of 190 TWh of additional German gas imports

To establish comparability with GD (2022a,b) and to determine the importance of the size of the gas supply shock following an embargo, I also consider an alternative scenario in which 190 TWh of the lost Russian natural gas imports can be replaced by other gas imports. Thus, in the alterative scenario, the reduction in net gas supply in Germany in the year following the embargo amounts to 240 TWh or 26 percent of the natural gas consumption in 2021.[18] The assumptions regarding the savings potentials in the building and energy sectors remain unchanged: the gas saving potential in these two sectors is still 160 TWh. Thus, in the alternative scenario, the manufacturing sector must decrease its natural gas consumption by 240 - 160 = 80 TWh, which amounts to 89/245 = 33 percent of its own consumption in 2021.[19]

Table 1 summarizes the main results in the two scenarios:

**Table 1. Gas Supply-shock due to the Embargo**

| | Gas Supply-shock Hitting German Economy | Gas Supply-shock Less Import Substitution | Reduction in Gas used in Building and Energy Sector | Gas Supply-shock Hitting Manufacturing |
|---|---|---|---|---|
| **Base scenario** | 430 TWh [47%] | 290 TWh [32%] | 160 TWh [18%] | 130 TWh [53%] |
| **Alternative scenario** | 430 TWh [47%] | 240 TWh [27%] | 160 TWh [18%] | 80 TWh [33%] |

**Note:** Percentages in the first three columns refer to the total consumption of 912 TWh in 2021. Percentages in the fourth column refer to the industry consumption of 245 TWh in 2021.

### 3. Production effect in the gas-intensive manufacturing sectors

In the baseline scenario, a gas embargo would reduce gas supply by around 290 TWh or 32 percent of total consumption in the short run. The building and energy sector could maximally reduce gas consumption by 160 TWh, so that gas use in manufacturing would have to be reduced by 130 TWh or 53 percent of own consumption in 2021 (Table 1). In this

from Norway, the Netherlands and non-European countries (LNG gas via the Netherlands, Belgium and France). However, this does not resolve the issue that European production is already close to full short-run capacity and that the worldwide supply of LNG gas that Europe has access to is limited (Neuhoff, 2022). Once this additional constraint is taken into account, the baseline scenario in the current paper becomes the "realistic scenario".

[18] The analysis in GD (2022a,b,c) assumes similar gas savings potential in the building and energy sector as in the current paper. Specifically, GD (2022a,b,c) assumes, based on the work of BNDE (2022) and Holz et al. (2022), that 15 percent of gas consumption can be saved in the residential sector and 30 percent savings are possible in the energy sector. Furthermore, in line with the current paper, GD (2022a,b,c) assumes that these reductions in gas use have no effect on production via the supply-side channel.

[19] The reduction in gas consumption of 33% in the manufacturing sector in this „alternative scenario" is substantially larger than the corresponding gas reduction in the median scenario of GD (2022a,b). Indeed, in the median scenario of GD (2022a,b), there is only a gas shortage of less than 10 percent of annual gas consumption.

section, I analyse how such a sudden reduction in gas supply would affect production in the gas-intensive manufacturing sectors. This determines the first-round economic effect of a gas embargo.

### 3.1 Gas-intensive manufacturing sectors

In Germany, the use of gas by manufacturing companies is concentrated in six industrial sectors: first, basic chemicals and other chemicals (using 59 TWh in 2021); second, metal production and processing, as well as metal foundry (using 36 TWh); third, glass and ceramics together with the processing of stones and earth (using 29 TWh); fourth, food and tobacco production (using 27 TWh); fifth, the paper industry (using 19 TWh); and last, mechanical and vehicle engineering (using 14 TWh) (see Agora, 2022; Fraunhofer, 2021).[20] In these six gas-intensive manufacturing sectors, all production requires natural gas, and this input factor cannot easily be replaced by alternative energy inputs in the short run. In other words, the short-run production function of many companies or production processes is a Leontief production function, with natural gas as an input factor.[21] In addition to the assumption of a Leontief production function, I assume that output produced by individual plants is proportional to their gross value added.

Not every production process in the six gas-intensive industrial sectors requires natural gas. Therefore, in a first step, I determine the share of production processes in the six gas-intensive sectors for which natural gas is an essential input factor. Given the assumed proportionality of production and gross value added, this approach also yields an estimate of the share of gross value added that is lost if gas use decreases.

The gross value added of the three industrial sectors "chemicals", "metals" and "glass and ceramics together with the processing of stones and earth" amounts to approximately 5 percent of GDP in 2021 (Destatis, 2022). In the basic chemicals industry, the metals industry (excluding steel), and the glass and ceramics industry, together with the processing of stones and earth, the production processes are almost entirely dependent on natural gas as an input factor.[22] Overall, I find that the three mentioned sectors produce about 3 percent of GDP using natural gas as an essential input factor.

Production in the two sectors "food and paper" creates a gross value added of around 2 percent of GDP (Destatis, 2022). In these industries, around half of the production processes require natural gas as an essential input factor. This results in a gross value added of 1 percent of GDP, which could not be generated without natural gas. Finally, it is necessary to take into account the mechanical engineering and vehicle manufacturing sectors, which together have a gross value added of more than 7 percent, with many companies within this

[20] See Agora (2022), Table 3. The remaining natural gas consumption of 17 TWh is in other sectors, which include the manufacturing of rubber and plastic goods.

[21] More formally, I assume that the production possibilities of an individual plant i are represented by the Leontief production function $y_i = z_i \min \{e_i, \lambda_i \cdot x_i\}$, where $y_i$ denotes production, $z_i$ denotes a productivity parameter, $e_i$ denotes the quantity of natural gas used, $x_i$ denotes a vector of quantities of other inputs used, and $\lambda_i$ denotes a vector of weights. Components of the vector my are all inputs into the production process beyond natural gas, which might include energy inputs, such as coal or oil.

[22] See Navigant (2020) for a discussion of the production structure in basic chemicals and BMWK (2022c) for a discussion of the metals industry.

sector unable to operate without natural gas. For this sector, it is assumed that a gross value added of 1 percent of GDP is based on production processes that are not possible without natural gas.

These considerations show that in the six gas-intensive industrial sectors output (gross value added) of about 5 percent of GDP would be lost if no natural gas were available. This defines the share of production in natural gas-intensive industries in which natural gas is used as an essential input factor.

Bundesbank (2022a,b) and five economic research institutes have conducted an analysis (GD, 2022a,b,c), in which they use a somewhat more formal method to estimate the gross value added of production that requires natural gas as an essential input factor. Specifically, in GD (2022a,b,c), the gross value added of the gas-intensive industry sectors is multiplied by a weight that is determined according to the gas intensity of the sector, and then the weighted sum of the gross value added of the sectors is calculated; see GD (2022b) for details. Bundesbank (2022a,b) uses a similar approach, and both methods are very similar to the one used here. Not surprisingly, the results are also similar, though the estimate of gross value added of production that requires natural gas as an essential input factor in GD (2022a,b,c) is somewhat larger than the 5 percent of GDP obtained here. The reason for this discrepancy is that in GD (2022a,b,c), the "coal mining and extraction of crude oil and natural gas" sector is included and considered to be a gas-intensive sector (see Table 2 in GD, 2022b).[23]

### 3.2 Substitution possibilities of the gas-intensive manufacturing sectors

A gas embargo would directly affect plants in six gas-intensive industrial sectors using natural gas as an essential input factor and producing output (gross value added) of around 5 percent of GDP. For these plants, there is a limited possibility to replace natural gas with alternative energy sources in the short run without suffering significant production losses. Formally, this means that for part of the production process, one Leontief production function with gas as an input factor is replaced by an alternative Leontief production function without gas as an input factor. Three studies have estimated the proportion of production processes in which such a substitution is possible in the short run.

BDEW (2022) calculates the short-run substitution possibilities for gas-intensive manufacturing ranging from 4 percent to 13 percent, where the basic chemical industry has the lowest substitution possibility with 4 percent and food production has the highest substitution possibility with 13 percent. Agora (2022) estimates a slightly higher average value of 15 percent for all gas-intensive sectors taken together, but they do not calculate separate values for individual sectors. In an alternative scenario (level 2), Agora (2022) estimates a substitution potential of up to 33 percent, but in this scenario, substantial and time-consuming investments in plant technology are assumed, which would lead to a significant and longer decline in production. In addition, it should be noted that the substitution potential of 33 percent (respectively 15 percent), in Agora (2022) refers to the

[23] In addition, in GD (2022b), the sectors "machinery and motor vehicles" have a larger weight than in the current paper, and the sectors “chemicals and metals” have a slightly smaller weight.

use of natural gas for process heat and does not apply to the gas use as a material input, where it is much more difficult to replace. A final study by Holz et al. (2022) also considers two scenarios, which are essentially taken from the two scenarios in Agora (2022). In the first scenario (medium saving), substitution possibilities are estimated in 15 percent of cases and in the second scenario (maximum saving), a value of 33 percent is assumed.

Given the available evidence on the substitution possibilities in the gas-intensive manufacturing sector in Germany, I assume that natural gas can be replaced by alternative energy sources in 20 percent of the cases without a reduction in production in the short run. This is a rather optimistic assumption, as only substitution options or smaller investments are considered that can be made within the framework of the regular production cycle and thus do not lead to a significant production decline. Formally, this is a substitution of oil or coal for natural gas, as implicitly assumed in economic analyses when a factor substitution without adjustment costs is considered. For comparison: in GD (2022a,b), it is assumed on the basis of the results of BDEW (2022) that natural gas can be replaced by alternative energy sources in the short term and without significant production losses in 10 percent of cases.

A short-run substitution possibility in 20 percent of the production processes means that around 245 x 0.2 = 49 TWh of natural gas can be saved without significant production losses. For the remaining production processes, there are no corresponding substitution possibilities in the short run. These remaining production technologies use 245 - 49 = 196 TWh of natural gas. In the case of an embargo, they must reduce production to save the remaining deficit of 130 - 49 = 81 TWh of gas.

It is important to note that energy disruption does not always lead to production losses; often there are ways of increasing the efficiency of using an energy input or switching energy inputs without significant investment. For example, Carvalho et al. (2021) find that the post-earthquake performance of energy-disrupted firms was very similar to non-energy disrupted firms. In other words, Japanese firms were — perhaps surprisingly — good at adapting in the short run to capacity constraints imposed on half of Japan's electricity grid. This result does not contradict the current analysis since the overall electricity constraints in Japan were much less severe than the gas shortage that would occur in the baseline scenario. Put differently, the baseline scenario already assumes that a reduction of gas supply to the manufacturing sector by 20 percent would not lead to any production loss because companies will switch to alternative energy sources.

Assuming switching from one Leontief production function to an alternative Leontief production function is formally equivalent to a substitution for a given CES production function with a corresponding elasticity of substitution. Indeed, under ideal conditions, which are not approximately fulfilled in the present case, such switching of Leontief production functions leads to an aggregate Cobb-Douglas production function (Houthakker, 1956; Jones, 2005). However, little is known about the short-run substitution elasticity for energy-intensive manufacturing, except that it could be quite small and close to Leontief if the time-frame is only a few months (up to a year).[24] Given that economic results are highly sensitive to small variations in the relevant elasticities when these elasticities are small, the approach taken in this paper seems to be more useful since it allows a transparent and intuitive discussion of the underlying assumptions.

### 3.3 Production decline in the gas-intensive manufacturing sectors

In the six gas-intensive manufacturing sectors, output (gross value added) of 0.8 x 5 = 4 percent of GDP is produced with natural gas as an essential input factor and no substitution possibility in the short run. In these production sectors, natural gas consumption must be reduced by 81/196 = 0.41 or about 41 percent. Using a Leontief production function, a 41 percent decrease in natural gas consumption causes a 41 percent decrease in production. Thus, an embargo implies an output loss of 1.6 percent of GDP in the six gas-intensive industrial sectors. This short-run decline in industrial production over the period April 1, 2022 to March 31, 2023 is a direct consequence of the sudden stop of gas imports from Russia. It is the first-round economic effect of a natural gas embargo in the baseline scenario.

The analysis has not taken into account that the reduction in gas consumption is not necessarily be distributed evenly among the individual production plants of the six gas-intensive sectors. In principle, one can imagine an allocation of gas that ensures that only production plants with low productivity experience a gas shortage, which might imply that the production loss is substantially reduced. Note that this contradicts the assumption of a Leontief production function at the plant level, since a good allocation mechanism can exploit the differences of productivity levels to minimize the industry-wide production loss caused by a decline in the supply of natural gas.

The allocation of natural gas can take place either through markets or through a state agency. As explained above, in case of an embargo, the Federal Network Agency (a state agency) would have to take charge to manage the expected gas shortages. It could use auctions to allocate some of the natural gas, but it is questionable whether it would use this instrument, especially during the first weeks after the embargo, when the situation would likely be highly chaotic. Besides practical considerations, there are good theoretical reasons why gas allocation via the market mechanism (auctions included) would not lead to a desirable allocation. In other words, the price mechanism might not lead to either an efficient allocation in the narrower sense (i.e., GDP-maximising) or a desirable allocation for society as a whole (i.e., welfare-maximising).

There are several reasons why one should not expect markets or auctions to work well. Efficiency in the narrower sense is most likely not achieved because of non-competitive behaviour (market power) and financial frictions, which are particularly pronounced in an economic crisis.[25] From the perspective of society as a whole, additional criteria, such as the security of supply, must be taken into account (see Section 2). For example, should

[24] For example, Barrot and Sauvagnat (2016) and Boehm et al. (2019) find that in the case of supply chain interruptions, there is almost no substitution of specific inputs in the short run.
[25] Moreover, network effects can lead to inefficient allocations. However, the quantitative network literature has predominantly considered network models in which the market outcome leads to an efficient allocation.

companies in the basic chemical industry, that produce products at the beginning of a complex value chain be supplied with natural gas first, or should companies in the food industry that produce fertiliser for agriculture be supplied first? None of this means that the price mechanism should be completely suspended in the event of a natural gas embargo, but it does show that designing an allocation mechanism that is desirable for society as a whole is a complex, multidimensional problem that is unlikely to be very successful in the short run.

Currently, there are no studies that provide reliable estimates of the extent to which a particular allocation mechanism can dampen the production loss in the German manufacturing sector in case of a gas shortage. In line with Bundesbank (2022a,b) and GD (2022a,b,c), I assume that the gas supply is randomly allocated across production plants.

### 3.4 Production decline in the gas-intensive manufacturing sectors: alternative scenario

In the alternative scenario, gas consumption in the six gas-intensive manufacturing sectors only needs to decrease by 80 TWh (see Table 1). Assuming the same short-run substitution possibilities as in the baseline scenario, 49 TWh of natural gas can be saved without a significant drop in production. This leaves a deficit of 80 - 49 = 31 TWh, which defines the necessary reduction of gas consumption by production plants without substitution possibilities.

A reduction of gas consumption by 31 TWh amounts to a decrease in natural gas use by 31/196 = 0.16 or 16 percent for plants in the manufacturing industry that rely on gas as an input factor and that cannot replace it in the short run without reducing production. These plants produced an output of about 4 percent of GDP in 2021. Thus, a 16 percent reduction of natural gas use in this part of the manufacturing sector generates an output loss of 0.6 percent of GDP. This decline in short-run production in the six gas-intensive manufacturing sectors is the first-round economic effect in the alternative scenario.

## 4. Aggregate production effects

A sudden stop of Russian gas imports would lead to a drop in production in the gas-intensive manufacturing sectors by 1.6 percent of GDP in the baseline scenario and 0.8 percent in the alternative scenario (see Section 3). This production decline is concentrated in six sectors that mainly produce intermediate goods (for example, chemicals) that are used as inputs in a complex production chain. A sudden decline in production in these six industrial sectors propagates through the entire economy through production linkages, thereby amplifying the initial production loss. These are the “second-round effects” of a natural gas embargo due to the disruption of production and supply chains and the economic interdependencies in a modern economy.

In the following, I address the question of how a sudden drop in production in the six gas-intensive manufacturing sectors (“production shock”) propagates through the economy and amplifies via so-called “network effects”. I continue to consider short-run effects defined as the economic adjustment in the time span May 2022 until April 2023 following the embargo.[26]

### 4.1 Network multiplier

A useful method for calculating the second-round effects of a gas embargo is the simulation analysis using a model economy that is grounded in economic theory and has been validated by empirical evidence. This approach to answering economic questions is roughly comparable to the analyses of epidemiologists who use a model-based simulation analysis to investigate the effects of a lockdown on the incidence of infection. Of course, the choice of model and the meaning of the phrase "theory-based and validated by empirical evidence" always depends on the context and the research question.

The class of network models as developed in Acemoglu et al. (2012a) is a natural starting point for an analysis of the propagation and amplification of production shocks along the value/supply chains. These models can be calibrated using input-output tables of the national accounts in order provide a realistic representation of the production linkages in the economy under consideration (empirical foundation). The underlying concept of this method can be traced back to the work of Leontief (Leontief, 1941). See, for example, Carvalho and Tahbaz-Salehi (2019) for a summary of the literature.

Acemoglu et al. (2016) use such a model-based approach in combination with input-output tables to quantify the extent to which small shocks are amplified and propagated throughout the economy. To this end, they develop a theoretical framework and use data from the Bureau of Economic Analysis on the input-output linkages of 392 US industries. They consider four different types of shocks and summarize the amplification effect through production linkages by the "network multiplier", defined as the ratio of the size of the initial shocks (production loss in one industry) to the size of the aggregate output loss.[27] They calculate multipliers that are quite large and range from 6.6 to 15.6, where the very high multiplier of 15.6 reflects the small size of the initial shock to a certain extent. The authors draw the following conclusion: "Overall, we interpret our results as suggesting that network-based propagation, particularly but not exclusively through input-output linkages, might be playing a sizable role in macroeconomic fluctuations, and certainly a more important one than typically presumed in modern macroeconomics".

For Germany, Bundesbank (2022a,b), GD (2022a,b,c), and Prognos compute the amplification effect when the gas-intensive industry abruptly reduces production. Bundesbank (2022a,b) finds a production (network) multiplier somewhat larger than 2. GD (2022a,b) do not report the supply-side effect separately. However, GD (2022c) explicitly reports the first-round and second-round effects of the manufacturing sector, and they find a multiplier effect somewhat above 3 for propagation that is confined to the manufacturing sector. Of course, the multiplier

[26] Clearly, the long-term adjustment and substitution possibilities for companies are much greater than the short-term possibilities, so that the short-term amplification effect is much more pronounced than the long-term effect. This means, among other things, that the empirical evidence mainly relevant to the current discussion is evidence that refers to a timeframe of, at most, one year. This criterion is satisfied by the empirical work discussed in this section.

[27] Note that a multiplier of 1 corresponds to a situation in which there is no propagation of the initial production shock.

effect for the aggregate economy is larger than the one that only applies to the manufacturing sector, but GD (2022c) only reports production losses in the manufacturing sector. Computation results not reported in GD (2022c) suggest a multiplier effect that exceeds 4 when the propagation through the entire economy, not only the manufacturing sector, is taken into account. Prognos (2022) conduct a very detailed industry using a method in line with Bundesbank (2022a,b) and GD (2022a,b,c). They find a first-round production loss of 3,2 percent of GDP and an aggregate production loss of 12,7 percent of GDP implying a multiplier of 4.

Bundesbank (2022a,b) and GD (2022a,b,c) use input-output tables to estimate production linkages, but they do not use a model-based (structural) approach, as in Acemoglu et al. (2016).[28] Specifically, they assume that the production loss through the interruption of production linkages is proportional to the value share of the intermediate goods. Clearly, this approach does not fully capture possible production losses due to the breakdown of supply chains and therefore underestimates the network multiplier.[29] For example, this approach would incorrectly assign almost no economic significance to missing semiconductor chips or wiring harnesses in the automotive industry (Tyborski, 2022), even though the recent experience of the German car industry tells a very different story (Wollmershaeuser, 2021).[30]

None of the above papers provides direct empirical evidence that could validate the computed multiplier effects. Carvalho et al. (2021) provide this type of evidence. Specifically, Carvalho et al. (2021) use the earthquake in Japan in 2011 (which also led to the Fukushima nuclear accident) as a “natural experiment” to estimate how a sudden production loss in one part of the economy propagates through the entire economy, leading to an amplification effect. In line with Acemoglu et al. (2016), they use a model-based approach to identify the production loss that is due to the disruption of supply chain linkages (network effects).[31] Carvalho et al. (2021) estimate that companies in regions directly affected by the Fukushima accident suffered an economic loss of 0.1 percent of GDP and that this production shock was amplified by sectoral production linkages summing up to a total economic loss of 0.47 percent of GDP. Thus, this evidence suggest a short-run network multiplier of almost 5.[32]

[28] In the application of the network models to the case considered here, the decline in production in the gas-intensive manufacturing sectors computed in Section 3 amounts to an exogenous productivity shock (in combination with the endogenous labor response) in Acemoglu et al. (2016).

[29] See also Bundesbank (2022a), footnote 40, for a similar point.

[30] Wollmershäuser et al. (2021) estimate that supply disruptions of semiconductors in Spring 2021 caused a production loss in the German car industry of over one percent of GDP, even though the "market value" of the undelivered intermediate goods was negligible.

[31] In the model used by Carvalho et al. (2021), the Fukushima accident is represented as a negative productivity shock (respectively, a capital shock) for the directly affected firms. To apply their finding to the case considered here, the decline in production in the gas-intensive manufacturing sectors computed in Section 3 amounts to the exogenous productivity (capital) shock -- in combination with the endogenous labor response – as in Carvalho et al. (2021). See also footnote 25.

[32] Barrot and Sauvagnat (2016) study the economic impact of natural disasters in the US and find that a $1 decrease in sales due to a disaster in a firm that manufactures intermediate goods leads to a $2.4 decrease in sales to the firm's customers (direct and indirect). This result highlights the strong complementarity of the value chain in the short run. However, the empirical analysis does not fully capture the economy-wide amplification effect and underestimates the aggregate network multiplier.

Carvalho et al. (2021) provide a second type of computation based on the estimated model economy that suggest a smaller multiplier. Specifically, they consider two economies, one with input-output linkages and production parameters estimated from the Japanese data and one that is identical to the first economy except that there are no input-output linkages between disaster-area firms and firms in the rest of the economy. They find that in the model economy without input-output linkages, the disaster shocks causes a production decline of 0.21 of GDP, whereas in the model economy with input-put linkages, the economic impact is a production loss 0.47 of GDP. This points towards a multiplier effect of 2.2. Note that this approach to computing the network-multiplier is different from the approach taken by Acemoglu et al. (2016), who compute the network multiplier for a fixed economy, whereas in the above calculation two economies with distinct production structures are compared.

Based on the evidence above, in this paper I consider network multipliers in the range of 2 and 5 when computing the short-run macroeconomic effects of a sudden production decline in the gas-intensive industry in Germany. Note that the lower bound of 2 roughly corresponds to the result in Bundesbank (2022a,b) and the upper bound of 5 roughly corresponds to the estimate of Carvalho et al. (2022) if the first type of calculation in the paper is used. Note further that GD (2022a,b,c) compute a multiplier of somewhat above 3 for the manufacturing sector only and above 4 when the whole economy is considered, which lies at the upper end of my range. Prognos (2022) computes a multiplier of 4. Finally, the results in Acemoglu et al. (2016) suggest that network multiplier might be substantially larger than my upper bound. In this sense, the range 2 to 5 represents a conservative choice, especially if one takes into account that a sudden gas embargo in April 2022 would have directly affected gas-intensive manufacturing companies in Germany that to a large extent produce intermediate goods at the beginning of a long value chain with complex production linkages.

Clearly, the results of Carvalho et al. (2021), respectively Acemoglu et al. (2016), apply to economies with a different production structure than the German economy. In other words, estimated multipliers depend on structural parameters that in general differ across economies.[33] There are reasons to expect the "bias" to go either way, especially when the results of these studies are used to draw inferences regarding the amplification effect in relation to a shock to the gas-intensive manufacturing sector in Germany. For example, one can argue that in Germany it could be easier than in the US or Japan to replace domestically-produced intermediate goods with imports from EU countries, though these substitution possibilities are limited in the short-run and with the EU in a recession after an embargo. On the other hand, substitution might be harder in the case of an energy embargo because the gas-intensive manufacturing companies in Germany to a large extent produce intermediate goods at the beginning of a long value chain with complex production linkages. Moreover, the size of the initial shock considered here is substantially larger than the shocks considered

[33] Of course, a similar issue arises when, as in Bachmann et al. (2022), the substitution elasticity of the German manufacturing sector is calibrated with reference to estimates of the substitution elasticity for the UK manufacturing sector.

in Acemoglu et al. (2016) and Carvalho et al. (2021), which might increase or decrease the associated network multiplier.

### 4.2 Results

In the baseline scenario, a gas embargo leads to a production decline of 1.6 percent of GDP in gas-intensive manufacturing in the first year (see Section 3, first-round effect). Taking into account the economic impact of the disruption of production linkages, the aggregate effect is an output loss of between 3.2 percent of GDP (multiplier of 2) and 8 percent of GDP (multiplier of 5). These short-run aggregate production losses include the first- and second-round effects.

In the alternative scenario, the first-round effect of a gas embargo corresponds to an output loss of only 0.6 percent of GDP. If the strength of the second-round effect remains unchanged, then the aggregate output decline in the alternative scenario is 1.2 percent, with an output multiplier of 2, and 3 percent, with an output multiplier of 5.

The propagation and amplification of shocks through network linkages along the value chain can be dampened through the import of intermediate goods. Thus, for a given first-round effect, import possibilities mitigate second-round effects, since imports might substitute for domestic inputs to downstream manufacturing sectors. However, these substitution possibilities are often limited in the short run (Barrot and Sauvagnat, 2016; Boehm and Oberfield, 2019). Moreover, the network multiplier is estimated in Carvalho et al. (2021) by taking into account these substitution possibilities, as the Japanese economy is also an open economy.

Table 2 summarizes the results.

**Table 2. Short-run Output Losses due to a Gas Embargo**

| | Gas Supply-shock in Manufacturing | Gas Supply-shock including Substitution in Manufacturing | Output Loss in Gas-intensive Manufacturing | Aggregate Output Loss |
|---|---|---|---|---|
| **Baseline Scenario** | 130 TWh [53%] | 81 TWh [41%] | 57 billion [1,6%] | 114 billion - 286 billion [3,2% - 8%] |
| **Alternative Scenario** | 80 TWh [33%] | 31 TWh [16%] | 21 billion [0,6%] | 43 billion - 107 billion [1,2% - 3%] |

**Note:** The GDP loss in the third and fourth columns refers to the decline in gross value added in the one-year period following the complete gas embargo implemented in May 2022 relative to a situation without a gas embargo. Euro figures are inflation-adjusted changes relative to a gross domestic product of €3,571 billion (2021 value). Percentages in the first and second columns refer to industry gas use of 245 TWh in 2021.

Table 2 shows that the output effect of a sudden gas embargo varies widely. There are two reasons for the considerable variation. First, the economic effects strongly depend on the size of the gas supply shock that would hit the German economy in case of an embargo, which, in turn, depends on the extent to which Russian gas can be replaced by alternative imports in the short run; this is shown by the comparison of the baseline scenario with the alternative scenario. Second, there is considerable uncertainty regarding the size of the multiplier effect that would arise should the German gas-intensive industry suddenly decrease production.

The results shown in Table 2 are in line with the results reported in Bundesbank (2022a,b) and GD (2022a,b,c). Section 5 contains a detailed discussion of the various results.

**4.3 Permanent output effects and social consequences**

Recessions generate economic and social costs because economic growth and employment decline in the short run. This short-run output effect of a gas embargo is depicted in Table 2. However, recessions also cause long-lasting damage to the economy and society and represent additional costs of a crisis that persist even after economic recovery has taken place.

In the economics literature, the long-run scarring effect of recessions is known as the "hysteresis effect" of recessions (Blanchard and Summers, 1986). For example, Ball (2014) and Cerra and Saxena (2008) use a macroeconomic time series analysis to show that recessions have a permanent, negative effect on aggregate output. In other words, short-run fluctuations in aggregate activity affect potential output. Moreover, empirical studies have found a strong link between cyclical fiscal policy and potential output (see, for example, Fatas and Summers, 2018, and Gechert et al. 2019).

There are various economic explanations for the relationship between recessions and potential output. One economic channel has attracted particular attention in the literature; that is, the loss of human capital. Specifically, unemployment is often associated with the loss of firm- or sector- or occupation-specific human capital, and in a recession, the probability and duration of unemployment increases. This effect is not only theoretically sound, but also empirically plausible. For example, empirical studies show that job loss leads to permanent income loss, and this permanent income loss is particularly impactful for workers who lost their jobs during a recession (Davis and Wachter, 2011). Further, parts of the physical capital stock may be destroyed during the crisis and building up new production structures after the crisis takes time and investment.[34]

Clearly, the extent of the hysteresis effect is not the same for all recessions and countries. Specifically, it mainly depends on three factors: first, the structural weaknesses or strengths of the economy before the recession; second, the size and persistence of the exogenous shock that led to the recession; and third, policy decisions during the recession that determined the severity of the recession and the extent of the long-run damage. The effect of these influencing factors becomes clear when comparing developments in Germany and the US during the GFC of 2008/2009.

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[34] Benigno and Fornaro (2018) discuss another channel of impact: The long-run output losses from a crisis-induced decline in private investment in new technologies. Of course, there is also the cleansing effect of recessions (Caballero and Hammour, 1994) that tends to lead to long-run productivity gains due to recessions.

The German labor market and economy recovered very rapidly after the GFC of 2008/2009, whereas in the US, recovery in the labor market was sluggish and output losses persisted (Ball, 2014). This difference in outcome can be attributed to three factors: first, the German economy entered the crisis in a position of relative strength, whereas in the US, the labor market already showed signs of considerable weaknesses before the crisis; second, in contrast to Germany, the US has a weak welfare state and therefore lacks automatic stabilizers. Moreover, with the expansion of short-term working benefits, German policymakers provided an effective policy response that, in terms of stabilization impact, likely exceeded the fiscal measures taken in the US; and third, the exogenous shock in the US was larger and more lasting than in Germany. Specifically, the financial crisis originated in the US and hit the core of the US economy; that is, the financial sector. In contrast, the GFC in Germany was mainly a short-term demand shock that was very quickly offset by rising export demand from China.

These considerations suggest that a deep recession in Germany caused by a gas embargo would create a strong hysteresis effect in contrast to the German experience of the GFC of 2008/2009. This type of energy shock would directly hit the core of the German economy (that is, the industrial manufacturing sector), and would therefore weaken potential output. Moreover, large parts of the German manufacturing sector have been weakened after two years of the COVID-19 health crisis and global supply chain problems, so an energy shock could force many companies into bankruptcy or provide incentives to relocate their production lines to (non-European) foreign countries. Finally, monetary policy has its hands tied due to high inflation rates, and fiscal policy would also very quickly reach its limits.

Recessions also have negative social consequences. Specifically, income losses associated with recessions are not evenly distributed among households. In other words, who loses how much in an economic crisis? The available evidence suggests the following conclusions.

First, crises are events in which not only the average income falls, but also many people lose a considerable amount. In other words, the evidence shows that the probability and magnitude of permanent income losses – (personal disasters, in other words) rises sharply during crises (Guvenen et al., 2014). This implies, among other things, that the negative impact of crises on people's well-being is much larger than a simple GDP view would suggest. This hypothesis is supported by empirical work that examines the long-run impact of job displacement on earned income. Job loss due to redundancy is often associated with permanent income losses, and these permanent income losses are particularly high for workers who have lost their jobs during a recession (see Schmieder et al., 2010 for Germany, and Davis/Wachter, 2011 for the US). The situation is similar for students graduating in a recession: those who have to look for their first job during a recession have a harder time in the short term and in the long term. Put succinctly, students graduating during recessions experience permanent income losses; recessions leave permanent scars (Oreopoulos et al., 2012).

Second, low-income workers suffer greater income losses than average-income workers in percentage terms. Since many of these workers live close to the subsistence level and have no savings, the crisis hits this group particularly hard. In this sense, the economically worseoff lose the most during an economic crisis. For example, during the COVID-19 crisis, the self-employed reduced their working hours to a much greater extent than employees due to the loss of orders (Bünning et al., 2020). Further, among white-collar workers, those with a high income and higher education take advantage of the opportunity to continue working in a home office, while workers with less education are much more likely to be employed on a part-time basis.

## 5. Overview of the literature

In this section, I survey the literature on network models of production. I also discuss the recent work by Bachmann et al. (2022), Bundesbank (2022a,b), GD (2022a,b,c) and Prognos regarding the  supply-side effects on the German economy of a gas embargo and the work on the demand-side effect (Bundesbank, 2022a,b; IMK, 2022).

### 5.1 Supply-side effects – general

The degree of substitution of factors of production is a classic topic in economics and also played an important role in the famous Cambridge-Cambridge controversy. The economic theory of economic growth has usually assumed a Cobb-Douglas production function with capital and labor as input factors, which amounts to the assumption of a high degree of substitution (elasticity of substitution of 1). Moreover, CES functions are often used to aggregate different types of human capital (Acemoglu, 2009). The macroeconomic literature on optimal climate policy, in which the substitutability of different energy sources plays a central role, has usually assumed substantial substitution possibilities in the tradition of the Nordhaus model (Golosov et al., 2012), but there are also alternative approaches in the macroeconomic literature (Acemoglu et al., 2012b).

Substitution possibilities are generally more limited in the short run more than in the long run, and the definition of "short run" always depends on the context. It is therefore not surprising that the Leontief production function (Putty-Clay approach) has been used in particular to describe the short-run phenomena, such as business cycle movements (Atkeson and Kehoe, 1999; Gilchrist and Williams, 2000). Hence, the modern macroeconomic literature has paid attention to the issue of limited short-run substitution possibilities, even though in public discussion there seems to be a tendency by economists to overestimate short-run substitution possibilities.

The modern literature on network effects (Acemoglu et al., 2012a) has analysed how a fall in output (production shock) in one sector of the economy propagates and amplifies throughout the economy via the disruption of supply chains. These basic ideas date back to the work of Leontief on input-output tables. They also play an important role in some of the early work on the real business cycle (King and Plosser, 1983). Recent literature on network effects in production chains has led, however, to a certain revival of these themes; see, for example, Carvalho and Tahbaz-Salehi (2019) for a survey of the literature.

## 5.2 Supply-side effects: Bundesbank (2022a,b) and GD (2022,a,b,c)

In independent work, the German central bank (Bundesbank, 2022a,b) and five German economic institutes (DIW, IfW, Ifo, IWH and RWE in GD, 2022a,b,c) compute the first-round supply-side effect of a sudden stop of Russian gas imports using the method outlined in Sections 2 and 3. Bundesbank (2022a,b) considers one scenario that roughly corresponds to the baseline scenario defined in Section 2 and finds a short-run production loss of 1.5 percent of GDP in the gas-intensive manufacturing sectors (first-round effect). These results show that the short-run, first-round effects of a gas embargo calculated in Bundesbank (2022a,b) is very much in line with the results in the current paper.

GD (2022a,b,c) consider different scenarios regarding the size of the gas supply shock that would hit the German economy in case of an embargo, but only report the economic effects for one scenario. GD (2022a,b) does not report the supply-side effect without the demand-side effect separately, so that a direct comparison with the results in Table1 and 2 is difficult. However, GD (2022c) report the first-round effect that is somewhat larger than the one computed in Bundesbank (2022a,b) and in the current report assuming a comparable degree of gas shortage. Prognos (2022) computes a first-round effect of 3.2 percent of GDP, about twice the effect in Bundesbank (2022a,b) and the current report.

Bundesbank (2022a,b) and GD (2022a,b,c) also compute the second-round effect of a gas embargo; that is, they analyse how the production interruption in the gas-intensive industry propagates throughout the economy via supply-side linkages and amplify the initial production shock. To this end, these studies use the input-output tables to estimate production linkages, but they do not use a model-based (structural) approach, as in Acemoglu et al. (2016) and Carvelho et al. (2021). Specifically, they assume that the production loss through the interruption of production linkages is proportional to the value share of the intermediate goods.

As discussed in Section 4, Bundesbank (2022a,b) computes a network multiplier above 2 and close to 2.5 (Bundesbank, 2022b). The total supply-side effect in Bundesbank (2022a,b) amounts to a GDP loss of more than 3 percent. GD (2022a,b) does not report the supply-side effects separately from the demand-side effects. However, GD (2022c) explicitly reports the supply-side effects for different scenarios regarding the size of the gas supply shock, but the only consider the manufacturing sector. GD (2022c) find a multiplier effect somewhat above 3 for the manufacturing sector. Of course, the multiplier effect for the aggregate economy is substantially larger than the one that only applies to the manufacturing sector and computations not reported in GD (2022c) suggest a multiplier above 4. Overall, GD (2022c) finds that in one scenario, in which the gas supply shock hitting the gas-intensive manufacturing sectors would amount to more than half of 2021 gas consumption (160 TWh). The production loss in the manufacturing sector in 2023 would amount to 9,9 percent of GDP. Finally, Prognos (2022) also considers a scenario with a severe gas shortage and finds an aggregate production loss of 12.7 percent of GDP.

Bundesbank (2022a,b) considers a scenario that is close to the baseline scenario in Tables 1 and 2, whereas GD (2022a,b) assumes that the "median scenario" is a scenario close to the alternative scenario in Tables 1 and 2. This begs the question as to which scenario is the most realistic one. The following argument suggests that the baseline scenario in Table 1 would have been the most likely scenario in case of an immediate and complete gas embargo in April or May 2022, though by July 2022 with gas storage tanks filled to 60 percent of full capacity this scenario has become less likely.

In the current study, the baseline scenario assumes a net reduction in gas supply of 32 percent after the embargo; see Table 2. This scenario is derived from the studies of Agora (2022) and the IEA (2022). The scenario describes a situation in which the plans of the EU and the German government for replacing Russian gas imports by the non-Russian gas imports are realized and, in addition, substantial gas savings are achieved. In contrast, the scenario called the "median scenario" in GD (2022, a,b) assumes that Germany (respectively, the EU) can replace even more of the Russian gas imports by non-Russian gas imports than in this baseline scenario. GD (2022a,b) bases their assumptions of a median scenario on the study by Holz et al. (2022). However, the study by Holz et al. (2022) only considers the physical capacity of the European pipeline system to transport the additional gas imports to its users but does not analyse whether or not the additional amount of LNG gas is available in the short run. The results reported in Neuhoff (2022) cast doubt on the assumption that Germany (respectively, the EU) can acquire more LNG-gas than assumed in the baseline scenario of the current paper in the short run.

Two further assumptions made in GD (2022a,b) are worth mentioning. First, the study assumes that the Federal Network Agency will not replenish the gas storage until the fall. Thus, the gas rationing in the manufacturing sector only occurs in the four months of January to April 2023, and the corresponding economic consequences are only felt in Q1 2023 in their median scenario. As discussed in Section 2, it is unlikely that the Federal Network Agency or the Federal Government would pursue this strategy because, without Russian gas imports, the rationing of gas used in Germany would begin in the summer months to ensure a sufficient gas supply for the protected customers (households) in the winter. This is also the line of reasoning in Bundesbank (2022a,b). The assumption does not change the total amount of natural gas available for the time period May 2022 to April 2023, but it does change the timing of the gas shortages and the dynamics of the implied economic losses.

Second, the simulation analysed in both GD (2022a,b) and Bundesbank (2022a,b) underestimate the permanent economic costs of recessions because the underlying models neglect the hysteresis effects. Specifically, a short-term economic collapse can lead to permanent damage; see Section 4. This hysteresis effect of recessions, which should be particularly pronounced in the case of a deep recession caused by gas shortages, is not adequately represented in the underlying model framework of Bundesbank (2022a,b) or GD (2022a,b), and the long-run output losses are therefore underestimated.

### 5.3 Supply-side effects: Bachmann et al. (2022)

In a well-known study, Bachmann et al. (2022) use a model-based simulation analysis to calculate the economic consequences of an energy embargo. They use a network-model that in principle allows for the amplification of small production shocks through the disruption of production linkages. Specifically, their work is based on a quantitative application of the general model of international trade developed in Baqaee and Farhi (2021), that considers a world economy with 40 countries (and "the rest of the world"); one of which is Germany.[35] Bachmann et al. (2022) calculate that an embargo on Russian energy imports would lead to a one-year output loss in Germany of 0.3 percent of GDP. In addition, Bachmann et al. (2022) use an approximation formula that allows them to express output losses as a function of the market value of gas imports and the change in this market value, independent of the input-output linkages among sectors (sufficient statistics).[36] Using this approach, they find a one-year output loss of 2.3 percent of GDP.[37]

In comparison to Bundesbank (2022a,b), GD (2022a,b,c), and the current paper, the implied output losses in Bachmann et al. (2022) appear relatively modest.[38] There are two factors that potentially explain the differences.

First, Bachmann et al. (2022) do not allow for a gas shortage after the embargo, in the sense that they assume that firms and households can always buy additional gas in unlimited quantities in a perfect market at the prevailing market price (where the market price is equal to the (social) marginal product). In other words, they disregard the possibility that the short-run gas supply function is inelastic in the economically relevant region after the embargo. Of course, the fully inelastic supply function is only the limiting case of a sequence of elastic supply functions, but the importance of this limiting case is downplayed in Bachmann et al. (2022). For example, with an inelastic gas supply function, the sufficient-statistics approach used in Bachmann et al. (2022) becomes meaningless because the market value of the reaming gas might become arbitrarily high.

Second, the study of Bachmann et al. (2022) does not contain an analysis of the gas-intensive manufacturing sectors in Germany, along the lines discussed in Section 3. Specifically, they do not separately analyse the short-run substitution possibilities of the gas-intensive industry in Germany. Instead, they assume that the substitution elasticity is common across all production sectors. They use values for the elasticity from empirical studies that might have limited relevance when it comes to the short-run effect of a sudden stop of gas supply on the gas-intensive German manufacturing sectors. The lack of a proper industry analysis in Bachmann et al. (2022) also means that their calculation will most likely understate the amplification effect (network multiplier), since the analysis does not fully capture the (complex) production linkages of the gas-intensive manufacturing industry in Germany. In other words, a proper analysis of the production linkages that matter the most in the case of a sudden gas embargo has to focus on input-output links of the gas-intensive industrial sectors with the other production sectors in the German economy.

The second point might be summarized as follows: Bachmann et al. (2022) neglect important heterogeneities and thus underestimate the short-run economic consequences of a sudden

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[35] See section 8 of Baqaee and Farhi (2021) entitled "quantitative examples".
[36] SVR (2022b) also provide calculations based on this approach.
[37] The model is a static model and the timeframe therefore depends on the application. Bachmann et al. (2022) adopt a short-run interpretation and implied output losses are interpreted as one-year losses.
[38] Indeed, many economists used the results of Bachmann et al. (2022) in the public debate to argue that an immediate and complete gas embargo in April 2022 would have been "manageable". See, for example, Krugman (2022) and Rachel and Schularick (2022).

stop of Russian gas imports. Neglecting relevant heterogeneities has often led to misleading conclusions in the macroeconomic literature. For example, in a highly influential paper, Lucas (2003) argues that the costs of business cycles or recessions are relatively small and that the benefits of macroeconomic stabilization policies are correspondingly small. However, his calculations are based on the assumption of a representative household, and subsequent research has shown that with empirically plausible heterogeneity in income losses during recessions, the costs of business cycles or recessions are substantial (Krebs, 2007). Yet another example is the literature on market power in the goods markets. Empirically documented heterogeneity in profit rates and adjustment costs are important conditions for adequately capturing the dramatic increase in market power in the US (De Loecker, 2020).

Differences in assumed substitution possibilities is another way of summarizing the difference between Bachmann et al. (2022) and the analysis conducted in Bundesbank (2022a,b), GD (2022a,b,c), and the current study. Specifically, Bachmann et al. (2022) assume that: first, Germany can relatively easily substitute Russian gas imports with imports from non-Russian countries; second, companies in the gas-intensive manufacturing sectors can relatively easily substitute gas with alternative energy sources; and third, companies using the intermediate goods produced in the gas-intensive industry can relatively easily substitute these inputs with inputs from alternative sources. Clearly, these assumptions seem plausible for the German gas-intensive manufacturing sectors in the long-run when there is sufficient time and opportunity for adjustment, which is precisely the goal of the gradual embargo policy adopted by the German government.[39] In contrast, these assumptions appear much less plausible in the short-run, which would be the case if the cold-turkey approach of a sudden stop of Russian gas imports had been adopted in April 2022.[40]

The assumption of common substitution elasticity for firms is not unusual in the applied network literature and also made, for example, in Acemoglu et al. (2016) and Carvalho et al. (2021). Clearly, this does not automatically invalidate the results in these papers, and in particular Carvalho et al. (2021) use direct empirical evidence to discipline their model analysis. In other words, the assumption of a common substitution elasticity does not necessarily lead to an underestimate of the economic impact of the disruption of production linkages. However, in the case of a sudden stop of German gas imports from Russia, the results in Bundesbank (2022a,b), GD (2022a,b,c) and the current paper strongly suggest that this type of heterogeneity plays an important role.

### 5.4 Demand-side effects

The focus of the present analysis is on the supply-side effect of a gas embargo through the disruption of production networks, but an embargo also affects aggregate economic activity

[39] Of course, in this case the model-implied output losses should be interpreted as permanent output losses, in which case an output loss of 2 percent of GDP is relatively large.

[40] Clearly, the authors of Bachmann et al. (2022) are aware of this issue, but argue that by picking a value of the substitution elasticity that they consider relatively low, they capture the short-run issues adequately. However, the results in Bundesbank (2022a,b), GD (2022a,b,c), and the current study cast doubt on the claim that this type of short-cut analysis is an adequate substitute for an in-depth industry analysis.

through the demand side. Specifically, rising energy prices due to an embargo reduce the income of households and therefore the demand for goods and services, which leads to a short-run reduction in aggregate production. In addition, an embargo would also affect financial market conditions and raise uncertainty, and this can lead to further reduction in aggregate demand and output.

A number of studies have calculated the short-run impact on output of a gas embargo due to the demand-side channel using simulation analysis based on large-scale macroeconomic models. Depending on the assumed increase in gas prices following the embargo, these studies find annual output losses of 2 percent to 4 percent of GDP due to the demand-side effects of rising energy prices (Bundesbank, 2022a,b; IMK, 2022).[41] These losses occur even if there are no quantity restrictions (rationing), as described in the previous sections.

In order to obtain an estimate of the overall effect of an immediate gas/energy embargo, the demand-side effect should be added to the supply-side effects computed in in Section 4, an approach also suggested in Bundesbank (2022a,b) and SVR (2022a). The total effect of a gas or energy embargo thus results approximately from the sum of the demand and supply effects. Thus, in the baseline scenario of the current paper (Table 2), a decline in aggregate output of between 5.2 percent and 12 percent is expected, while according to the alternative scenario, a decline of 3.2 to 7 percent of GDP would follow.

The separation of the economic analysis into supply-side channels and demand-side channels is a useful classification scheme, even if the separation line cannot be drawn sharply in every case. For example, Bundesbank (2022a,b) and IMK (2022) use the NiGEM model to calculate demand-driven effects. Here, an increase in energy prices has an effect on the propensity of private households to consume, on the one hand, and on the other hand, via the factor demand of companies. This then influences gross domestic product via the overall economic production function; the latter being a more supply-side approach.

It also be kept in mind that the simple addition of demand-side and supply-side effects is an approximation that, depending on the economic model, could produce misleading results. For example, general equilibrium effects usually tend to dampen the total effect, while complementarities – which should be particularly important in times of crisis – often add an amplification mechanism. Specifically, the reduction in production due to the supply-side channel reduces the available income of households, which in turn reduces aggregate demand and output: this effect is neglected when simply adding the two demand-side and supply-side effects.  These considerations should always be taken into account when interpreting the results.

### 5.5 Summary of results

Is useful to classify the various results regarding the economic effects of a gas embargo along two dimensions: first, a separation of demand-side and the supply-side channels; and second, the question of the size of the gas supply shock; that is, the availability of gas after

[41] Bundesbank (2022a,b) also shows that fiscal measures can dampen the GDP slump by about half a percentage point. A fiscal policy response is therefore important, but its effectiveness is limited.

the embargo. In a simple categorization, natural gas availability can be partitioned as follows: unproblematic (no gas shortage; the inelastic part of the gas supply function is not reached); somewhat problematic (a small amount of gas shortage; the alternative scenario in Table 2); and problematic (substantial gas shortage; the baseline scenario in Table 2). Note that GD (2022c) and Prognos (2022) consider a scenario in which the gas shortage in the manufacturing sector is somewhat more severe than in the baseline scenario in Table 1. Clearly, this type of scenario has become less likely in July 2022 than it was in April 2022 since the steady gas import from Russia until mid-June meant that gas storage tanks could be filled up to 60 percent of storage capacity.

The following table summarizes the various results.

**Table 3. Short-Run Output Losses due to a Gas Embargo**

| Study | Gas Availability | Demand Effect | Supply Effect | Supply and Demand |
|---|---|---|---|---|
| **Bachmann et al. (2022)** | Unproblematic | - | 0,3% - 2,3% | - |
| **Bundesbank (2022a)** | Problematic | 2% - 4% | 3,2% | - |
| **Bundesbank (2022b)** | Problematic | 4% | 3% | 7% |
| **GD (2022a,b)** | Somewhat problematic | - | - | 5.3% |
| **GD (2022c)** | Problematic | - | 9.9% | - |
| **IMK (2022)** | Unproblematic | 2.4% | | - |
| **Prognos (2022)** | Problematic | - | 12.7% | - |
| **This paper** | Somewhat problematic | - | 1.2% - 3% | - |
| | Problematic | - | 3.2% - 8% | - |

**Note:** Decline in annual inflation-adjusted GDP relative to a situation without an embargo. GD (2022a,b) calculates a GDP loss of 5.3 percent for 2023 with a negligible gas supply shortage. GD (2022c) computes a GDP loss of 9.9 percent in 2023 for a scenario with large gas supply shortage. Bundesbank (2022a) calculates a demand-side GDP loss of around 2 percent in 2022 and 4 percent in 2023, and the supply-side GDP loss of 3.2 percent occurs in 2022. For Bundesbank (2022b), all figures refer to the year 2023 and are rounded. Prognos (2022) computes the GDP loss for the 6-month period July to December 2022. In the current report, the output loss refers to the period from May 2022 to April 2023.

Table 3 underscores the wide range of results and the corresponding high degree of uncertainty regarding the economic consequences of a sudden gas embargo. One reason for this uncertainty is that the economic effects strongly depend on the size of the gas shock that would hit the German economy in case of an embargo, which in turn depends on the extent to which Russian gas can be replaced by alternative imports in the short run. This is shown by the strong variation of output losses depending on gas availability. Another reason is that current business cycle models – and, in particular, the large-scale macroeconomic models used by central banks and international organizations – have not fully incorporated the type of supply-side channel that arises when complex production networks are disrupted. Moreover, there is limited empirical evidence regarding the macroeconomic consequences of a sudden disruption of production networks.

Despite this uncertainty, a few general lessons can be drawn from the analysis. Specifically, an immediate and complete halt of Russian natural gas imports in April 2022, in combination with the coal and oil embargo implemented in April and May 2022, would probably have led to a short-run drop in German GDP, comparable to the decline in the global financial crisis of 2008/2009 or the 2020 Coronavirus crisis. In a best-case scenario, Germany might "only" experience a “regular” recession, but in a worst-case scenario, a sudden gas embargo could cause the largest annual GDP loss that (West) Germany has experienced since World War II. Moreover, there are reasons to expect the social consequences of an embargo-caused recession in 2022/23 to be more severe than in the previous two recessions, as discussed in Section 4.

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