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The Power of Substitution: The Great German Gas Debate in Retrospect

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"Do we knowingly want to destroy our entire economy?"

BASF CEO Martin Brudermüller, 31 March 2022[2]

The Russian attack on Ukraine in February 2022 laid bare Germany's dependence on Russian energy imports and ignited a heated debate on the costs of a cut-off from Russian gas. While one side predicted economic collapse, the other side (ours) predicted "substantial but manageable" economic costs due to households and firms adapting to the shock. Using the empirical evidence now at hand, this paper studies the adjustment of the German economy after Russia weaponized gas exports by cutting Germany off from gas supplies in the summer of 2022. We document two key margins of adjustment. First, Germany was able to replace substantial amounts of Russian gas with imports from third countries underscoring the insurance provided by openness to international trade. Second, the German economy reduced gas consumption by about 20%, driven mostly by industry (26%) and households (17%). The economic costs of demand reduction were manageable with the economy as a whole only experiencing a technical mini-recession in the winter of 2022/23. Overall industrial production "de-coupled" from production in energy-intensive sectors (which did see large drops) and declined only slightly. We draw a number of key lessons from this important case study about the insurance offered by access to global markets and the power of substitution, specifically that supply shocks have dramatically smaller costs when elasticities of substitution are very low (but non-zero) compared to a truly zero elasticity.

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[2] Frankfurter Allgemeine Zeitung (2022). German company BASF is the largest chemical producer in the world and was heavily reliant on Russian gas until Russia cut off gas supplies to Germany in the summer of 2022. In the same interview Brudermüller also warned that a cut-off from Russian gas "could bring the German economy into its worst crisis since the end of World War II and destroy our prosperity."

On March 7, 2022, less than two weeks after the Russian invasion of Ukraine, we published, jointly with a group of coauthors, a paper that addressed a seemingly simple question: what if the German economy was cut off from Russian gas? At that point, Germany imported about 55% of its gas consumption from Russia, and relied on Russia for close to one third of its total energy consumption (Bachmann et al, 2022a). The "What if" question was intentionally framed in a way that allowed the cut-off to be the result of a German embargo, or the result of an end to gas supplies initiated by Russia. The aim of the paper was to provide a compass for policy-makers facing momentous decisions. How would the German economy cope with a sudden stop of energy imports from Russia? Would the likely result be a severe recession like during the Global Financial Crisis or perhaps even a massive collapse in output and spiking unemployment comparable in its severity to the Great Depression of the 1930s? Or should we expect the economic costs to be more muted, i.e., a more ordinary recession of the kind that the German economy had dealt with in the past and was well-equipped to deal with in terms of the available policy space to cushion its impact?

Our answer at the time, based on key statistics about the German economy, relevant empirical estimates and applied macroeconomic theory, was that an immediate emancipation from Russian energy was feasible and would entail "substantial but manageable" economic cost for the German economy. Our analysis foresaw an output cost in the first year following such a cut-off in the range of 1-3% relative to a no-cut-off baseline scenario, in line with previous recessionary episodes that the country had successfully dealt with. This prediction was highly controversial at the time and triggered an intense public debate that culminated in the German chancellor warning of the "irresponsible use of mathematical models" for policy-making on the main prime-time talk show.[3] Fearing catastrophic economic consequences of an end to Russian gas, the German government decided to keep importing rather than sanctioning it. Moreover, partly because of the fear of Russia retaliating by cutting off gas supplies, the German government was widely perceived to have taken a softer stance in offering support to the Ukrainian government and imposing other sanctions on Russia.

The Russian gas soon stopped flowing nevertheless. But it was Russia, not Germany or the European Union, that made the decision. Starting in June 2022, Russia drastically reduced gas supplies to Europe, in particular through the important Nord Stream 1 pipeline running directly from Russia to Germany in the Baltic Sea. Russia halted Nord Stream 1 flows completely at the end of August 2022 and the pipeline was destroyed by underwater explosions four weeks later resulting in a complete severance of Russian supplies to Germany.

One and a half years after the initial debate and a year after the final cut-off, this paper takes stock of what we have learned since then. We briefly review the original argument and the controversy it caused, but mainly focus on how the German economy coped with the actual severance of Russian gas supplies.

[3] Anne Will Show with Chancellor Scholz on 27 March 2022. See https://benjaminmoll.com/Scholz/ for a full transcript and English translation of Chancellor Scholz's comments as well as a linked video recording. Key excerpt: "But they get it wrong! And it's honestly irresponsible to calculate around with some mathematical models that then don't really work."

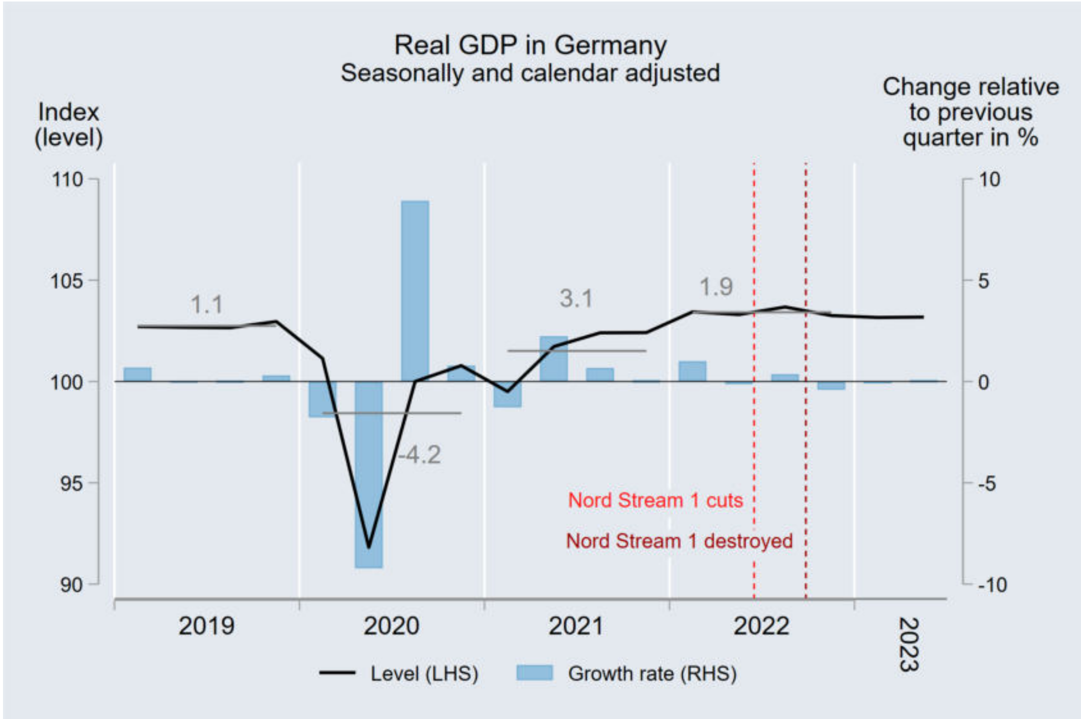

Figure 1: Real GDP in Germany

Notes: the GDP data are from table 81000-0002 of the German National Accounts available through the German statistical agency Destatis at https://www-genesis.destatis.de/. The GDP level (left axis) is normalized to 100 in 2020Q3, the quarter after the 2020 pandemic recession. Russia cut gas deliveries through the Nord Stream 1 pipeline substantially starting in mid June 2022 (first to 40% then 20%, "Nord Stream 1 cuts") and halted flows completely on 31 August 2022. The pipeline was destroyed on 26 September 2022 ("Nord Stream 1 destroyed").

Prima facie, the evidence seems to support the original argument of the "What if" paper. Germany was partially cut off from Russian gas in June 2022 and completely in August 2022, but did not go into a deep depression. As shown in Figure 1, German GDP expanded by close to 2% for the entire year 2022 despite a circa 20% drop in gas consumption. In the fourth quarter of 2022 and the first quarter of 2023, during the peak of the winter's heating season, Germany entered a mini-recession with GDP in these two consecutive first contracting by 0.4% and then by 0.1%.[4] This outcome must be compared to estimates in studies financed by trade-unions and business associations that foresaw output losses between 6% and 12%, with the most apocalyptic estimates due to Krebs (2022) and Prognos (2022) that both predicted an output collapse of 12%,[5] as well as Hüther (2022) who warned of "2.5 or 3 million additional

[4] Of course, the observed evolution of German GDP is not directly comparable to a counterfactual prediction like ours that was relative to a no-cut-off baseline scenario holding other factors constant.

[5] See IMK (2022), Krebs (2022) and Prognos (2022). Even though counterfactual GDP predictions and the GDP time series are not directly comparable, it is clear that these dramatic counterfactual estimates between 6% and 12% have not come true. For example, given that GDP growth was close to zero over the 2022/23 period, in order to believe a 12% GDP drop relative to a no-cut-off baseline scenario, one would have to believe that GDP would have grown at around 12% in the absence of a gas import stop which is clearly absurd. For context, IMK is a union-financed think tank, the Krebs study was paid for by

unemployed".[6] Overall, while the German economy is stagnating and faces substantial long-run headwinds, the direct economic costs of the end of Russian energy imports proved moderate and manageable, in line with the results of the original "What if" study.

In this paper, we have four main ambitions. First, we lay out the basic theoretical considerations regarding the economy's ability to adapt. One important and non-obvious point is that even very low elasticities of substitution are a powerful force for reducing the impact of a large input supply shock like the gas cut-off. While a Leontief production structure (i.e., the case in which elasticities are truly zero) implies drastic economic costs, specifically that production falls one-for-one with gas, even moderate substitutability mutes these costs considerably. The simplest illustration of this result uses a calibrated aggregate production function with an elasticity of substitution σ between gas and other inputs: in the Leontief case $\sigma = 0$, a 20% drop in gas supplies implies a 20% drop in production; however, when $\sigma = 0.05$, the corresponding output losses are only 2.7%, i.e. going from $\sigma = 0$ to $\sigma = 0.05$ reduces the output loss by almost a factor of ten. The underlying logic is considerably more general, however, and extends to richer multi-sector models of supply chains like the model of Baqaee and Farhi (2021) used by Bachmann et al. (2022a) to explore the importance of "cascading effects" in production (see below). Intuitively, because the share of gas in production is small, even a small amount of substitutability is sufficient to overcome the gas input's bottleneck property. In the more complicated models, additionally, international trade plays an important role, specifically substitution of gas-intensive products via imports.

Second, we show how the German economy adapted to the end of Russian gas supplies. We track the consumption response of households and industries on the demand side, and discuss the additional supply that replaced Russian gas. On the supply side, Germany was able to replace substantial amounts of Russian gas with imports from third countries, often taking advantage of the integrated European gas market, for example by importing U.S. liquified natural gas (LNG) via LNG terminals in the Netherlands. On the demand side, the German economy reduced overall gas consumption by about 20% in the period July 2022 to March 2023 relative to previous years.[7] The largest contribution came from industry which reduced its gas consumption by a striking 26% whereas household gas consumption fell by a smaller but still impressive 17%. An online appendix complements these statistics by describing 36 concrete cases of substitution and adaptation by German firms and households.

We pay particular attention to the adjustment of the industrial sector to the gas cut-off. Much of the German debate in February and March 2022 centered around "cascading effects" in production, the idea that a cut-off from Russian gas would not only affect energy-intensive

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the German trade union federation DGB, and the Prognos study was paid for by a business association. See Bachmann et al. (2022b) and Moll (2022b) for a summary of studies conducted by other entities.

[6] For comparison, the German labor force was around 47 million people in 2022 so 2.5-3 million additional unemployed would have corresponded to an increase in the unemployment rate of more than 5%. Hüther is the head of industry-financed think tank IW Köln.

[7] The 20% overall demand reduction that we document is somewhat below other estimates in the literature, for example Ruhnau et al. (2023) who find that gas consumption during the second half of 2022 was 23% below the temperature-adjusted baseline.

upstream sectors but then take down and “destroy” the entire industrial sector and economy with it – the quote by the BASF chemicals executive at the beginning of our paper is a good example of this line of argument. We therefore ask what sectors were most affected by the gas cut-off and whether and to what extent it resulted in such cascading effects. While production in energy-intensive sectors like chemicals and glass production did see substantial cuts of up to 20%, we find no evidence of substantive cascading effects. To the contrary, we find that overall industrial production displayed a substantial “de-coupling” from production in these energy-intensive sectors and was hardly affected. In an open economy with substitution possibilities, sharp declines in output in some upstream sectors do not necessarily lead to large contractions in downstream industries. At each point in the production network substitution possibilities exist.

Third, we ask if Germany could have also withstood an earlier cut-off from Russian gas, as early as the end of March 2022, as advocated by some and hotly contested by others. A prominent line of thinking among the skeptics is that the additional five months from April to August, during which Germany continued to import and stockpile Russian gas, was decisive as it allowed the country to purchase enough Russian gas to increase storage capacity sufficiently to get through the following winter. By contrast, an immediate severance from Russian energy at the end of March 2022, would have resulted in storages running out in the middle of the winter as well as shortages and rationing and an ensuing economic catastrophe.

We revisit this argument and show that Germany exited the 2022/23 heating period with gas reserves that exceeded imports from Russia from April to August 2022. In other words, even in the scenario of a Russian supply cut-off at the end of March 2022, Germany would have had enough gas to make it through the following winter (assuming identical consumption). While actual observed gas storage levels were around 65% at the end of the 2022/23 heating period, they would have still been around 25% even in the counterfactual scenario of an immediate cut-off. Moreover, as the March cut-off would have coincided with the end of the 2021/22 heating period, the combination of gas imports from other countries and pre-existing storage would have been sufficient to satisfy both industrial and household gas demand at any point in time. There would never have been a gas shortage at any point throughout the year and German gas storage levels would have instead always exceeded a safety margin of around 25%. In other words, on the basis of this simple calculation, Germany would have been able to cope with an earlier embargo on Russian gas imports. The country’s leaders likely overestimated the geoeconomic dependency on Russia and arguably opted for a more cautious policy towards Russia than was necessary.

Lastly, we briefly discuss the political economy of policy consulting and the role domestic lobbies have played in the process. We also look back critically and argue that Germany could have done more to help Ukraine at an earlier stage, and that there are important lessons for related cases in the future such as China and Taiwan. Market economies have a tremendous ability to adapt that we should not underestimate again.

The structure of this paper is as follows. We start with a short exposition of Germany’s dependence on Russian gas before the Russian invasion of Ukraine and the events leading up to the eventual cut-off. Section 2 recaps the argument of the “What if” paper, specifically that substitution would be a powerful force toward lowering the costs of a gas cut-off. Section 3 discusses the adjustment that has taken place over the past year and benchmarks the development to the prediction of the model. Section 4 asks whether an immediate disruption in April 2022 would have had much more severe consequences. Section 5 considers the role of “luck”, specifically whether the 2022/23 winter was particularly mild, as well as various other factors in global energy markets. Section 6 discusses the main lessons from the debate for policy consulting and similar future episodes. Section 7 concludes.

1. Background: Germany’s dependence on Russian gas and the 2022 gas cut-off

Long ignored by German politicians, Germany’s dependence on gas imports from Russia was exposed dramatically after the Russian aggression. How Germany became so dependent on Russian gas even though the Russian government had weaponized its gas export in the past (in particular against eastern European countries like Ukraine), is a fascinating question for political scientists. A recent book by Bingener and Wehner (2023) provides an excellent analysis of the mix of political economy problems, industrial lobbying, naЇvete, and outright corruption that led to this dependence. After Russia’s attack on Ukraine, the question of economic dependence became one of acute geoeconomic relevance: to what extent were Germany’s options to support Ukraine and take a tough stance on Russia compromised by the country’s dependence on Russian gas?

Yet the European gas crisis started well before the Russian attack on Ukraine. Already in summer 2021, gas storages in Europe were not being refilled at the usual pace. Specifically Russia’s gas monopolist Gazprom controlled a number of storage facilities at the time, including Germany’s largest one (Rehden), and purposely kept it almost empty. Russia gradually reduced gas supplies, withholding almost 20% of the usual pipeline flows it delivered to Europe in previous years. This led to sharply increasing gas prices from below 20 € per megawatt-hour (MWh) at the beginning of 2021 to a first peak of close to 100 €/MWh in October and another one of close to 150 €/MWh in December 2021. This gradual Russian withholding of volumes went largely unnoticed by the media and public debate, likely partly due to the difficult access to gas-flow data. Some commentators and “experts” circulated various theories on technical, commercial and legal reasons for the reduced flows, thereby preventing a sense of urgency among the policy-makers and the public.

The start of the war had little direct impact on prices and volumes. However, when it became clear that Kyiv would not be taken in a few weeks and a coalition of Western countries formed that supported Ukraine and put substantial sanctions on Russia, Russia soon started further weaponizing its gas exports. To begin, Russian President Putin decreed on 31 March 2022 that Gazprom would only receive payments for gas in Russian Rubles. Even though this contradicted agreed contract terms and risked undermining financial sanctions, European policy-makers were reluctant to offer clear guidance to their companies on this issue, likely due to the perceived importance of Russian gas imports for the functioning of Europe’s economy. Subsequently, Gazprom stopped gas deliveries to Poland and Bulgaria for refusing to pay in

Rubles. Moreover, flows through the Yamal pipeline (that passes Poland towards Germany) were also stopped by Russia based on claims of Polish sanctions against the pipeline company. In June 2022, Russia unilaterally limited gas flows through the Nord Stream 1 pipeline to 40%, then reduced them further to around 20% and eventually halted flows completely on 31 August 2022.

These politically tense months between February and September 2022 were characterized by a Russian strategy to divide European unity, for example by selectively cutting gas supplies to specific countries while at the same time offering to Germany to open the newly built Nord Stream 2 pipeline so as to avoid the much-feared gas crisis.

Finally, on 26 September 2022, the two branches of Nord Stream 1 and one of the two branches of Nord Stream 2 were destroyed by underwater explosions in the Baltic sea (with the actors unknown at the time of writing). The destruction of the Nord Stream pipelines ended this phase of uncertainty by substantially cutting Russian gas flows to Europe (routes via Turkey and Ukraine remained operational), in particular ending direct pipeline flows from Russia to Germany for good. While Germany imported more than half of its gas from Russia in 2021, and this was expected to further increase with the planned opening of Nord Stream 2 at the beginning of 2022, the share of Russian gas fell to 0% by September 2022. Figure 2 is reproduced from Gil Tertre (2023) and shows the key events over time.

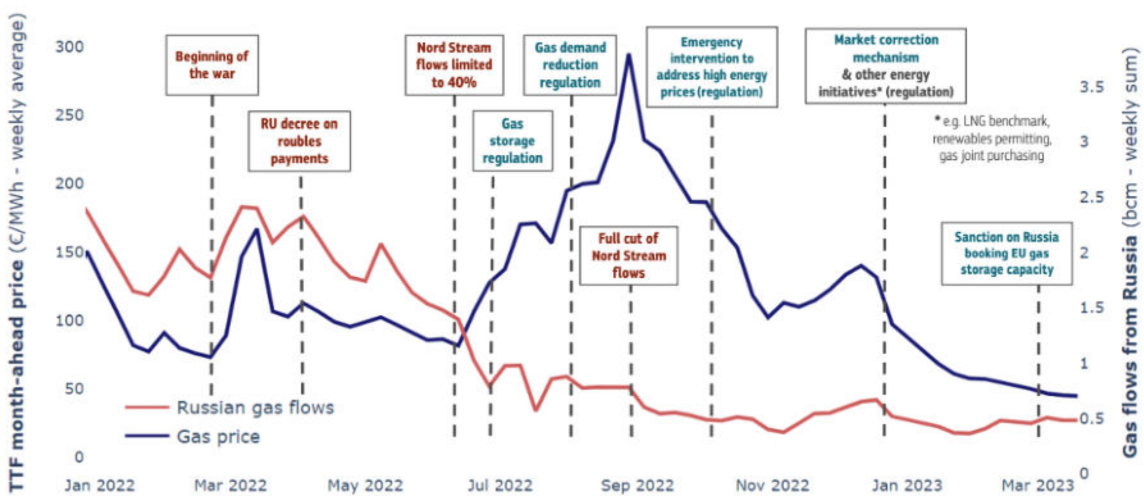

Figure 2: Russian weaponization of gas supplies and gas prices (reproduced from Gil Tertre, 2023)

The starting point of our “what if” paper was a summary of Germany's dependence on Russian energy at the beginning of the war in Ukraine (Table 1, reproduced from Bachmann et al, 2022a). One energy input stood out: natural gas. In particular data from 2021 showed that Germany imported more than half (55%) of its gas from Russia. Furthermore Germany was much more dependent on natural gas than many other countries, with natural gas accounting for almost a third of the overall energy mix.

	Oil	Natural gas	Coal (Lignite and Hard Coal)	Nuclear	Renew-ables	Others	Total
TWh	1077	905	606	209	545	45	3387
%	31.8	26.7	17.9	6.2	16.1	1.3	100
of which Russia	34%	55%§	26%	0%	0%	0%	30%

Notes: §in 2020 – already lower in 2021 and 2022.
Source: Agora Energiewende (2022); Eckert, and Abnett (2022).

Table 1: German primary energy usage 2021 (reproduced from Bachmann et al., 2022a)

In contrast to the other energy imports from Russia (oil and coal), it was also clear that Russian gas would be considerably harder to substitute with imports from third countries (like Norway or the Netherlands). This is due to German gas imports having been pipeline-bound, in particular from Russia via the Northstream and Yamal pipelines, and Germany at the time not having even a single terminal for importing liquified natural gas (LNG). The combination of Germany's large dependence on Russian gas and the difficulty in substituting this Russian gas with imports from other countries meant that we focussed our analysis on the economic costs of a cut-off from Russian gas.

2. The core argument: the power of substitution

The core theoretical argument of the “What if” paper was that German firms and households would adapt to a cut-off of Russian gas supplies in ways that would ultimately reduce the economic impact. Producers would switch to other fuels or fuel suppliers and import products with high energy content while households would cut their gas demand by turning down their thermostats. Importantly, elasticities of substitution that are very low, but non-zero, translate into much smaller economic losses than in the case of literally zero substitutability (i.e., Leontief production). Substitution along the supply chain and across producers would mean that macro elasticities are larger than micro elasticities. “Cascading effects” along the supply chain would be muted as opposed to “destroying” the economy's entire industrial sector.

Using the approaches we outline below, we argued that even in the case of a “cold turkey” import stop of Russian gas in March or April 2022, the economic costs would “be substantial but manageable.” Our analysis foresaw GDP and Gross National Expenditure (GNE) losses in the first year after such a cut-off in the range of 1-3% relative to a no-cut-off baseline scenario.

2.1. An aggregate production function

To illustrate the power of substitution in a transparent fashion, we start by considering an extremely simple and purposely stylized setup. We assume that Germany produces output Y using natural gas G (which it imports from Russia) as well as other inputs X (like labor and capital) according to a constant-elasticity of substitution (CES) aggregate production function

$$Y = \left(\alpha^{\frac{1}{\sigma}} G^{\frac{\sigma-1}{\sigma}} + (1 - \alpha)^{\frac{1}{\sigma}} X^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}}, \quad (1)$$

where $\alpha > 0$ parameterizes the importance of brown energy in production and $\sigma \in [0, \infty)$ is the elasticity of substitution between gas and other inputs. The goal is to assess the effect of a drop in gas supply G on production Y and how this depends on the features of the aggregate production function. The setup is, of course, extremely simplistic in that it only features two factors of production, no input-output linkages, and so on. However, as we discuss below, such an analysis can be a good approximation even in a much richer environment like the multi-sector model of Baqaee and Farhi (2021) used further below.

The following special cases show that, depending on the value of σ, the macroeconomic effects of a drop in gas supplies G are extremely different. The examples are complemented by Figure 3 which plots production Y as a function of natural gas G for different values of the elasticity σ for a calibration described in Bachmann et al (2022a) in which the share parameter α equals 1%[8].

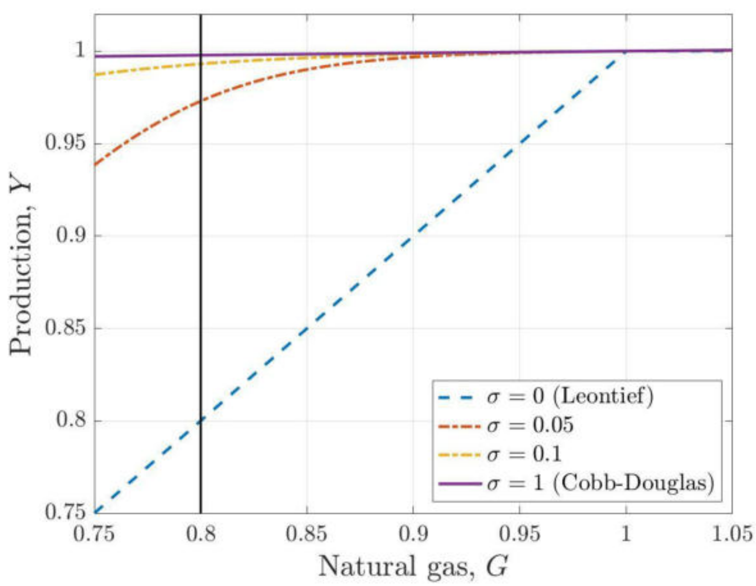

Figure 3: Output losses following a fall in gas supply for different elasticities of substitution

[8] Bachmann et al. (2022a) document that the share of natural gas imports in German Gross National Expenditure (GNE) is roughly 1%.

A particularly useful special case is that of Leontief production, i.e. exactly zero substitutability $\sigma = 0$, in which case (1) becomes $Y = \min\{G/\alpha, X/(1 - \alpha)\}$. Starting from an initial optimum, a reduction in G implies that $Y = G/\alpha$ and hence $\Delta \log Y = \Delta \log G$. Therefore, if the elasticity of substitution is exactly zero, production Y drops one-for-one with gas supply G. This is illustrated by the dashed blue line in Figure 3 which plots production Y as a function of energy G for the Leontief case. For example, a drop in gas supply of $\Delta \log G = -20\%$ implies a drop in production of $\Delta \log Y = -20\%$. Intuitively, the Leontief assumption means that, despite its small input share, gas is an extreme bottleneck in production: when energy supply falls by 20%, the same fraction 20% of the other factors of production X lose all their value (their marginal product drops to zero) and hence production Y falls by 20%. Note that this output loss is completely independent of the input share α: with Leontief production even a tiny input becomes an extreme bottleneck and takes down the economy one-for-one. That zero substitutability predicts that production falls one-for-one with gas is much more general and is also true in multi-sector models with complex supply chains.

On the other extreme, the special case of Cobb-Douglas production with an unrealistically high elasticity of substitution of $\sigma = 1$ implies very small output losses. When $Y = G^{\alpha} X^{1-\alpha}$ we have $\Delta \log Y = \alpha \times \Delta \log G$ so that a 20% gas drop implies an output loss of only 0.2% ($1\% \times (-20\%) = -0.2\%$).

The most important conclusion however concerns intermediate cases with low but non-zero substitutability like $\sigma = 0.05$. The red dash-dotted line in Figure 3 plots the output losses for this case. It shows that the case with moderate but non-zero substitutability $\sigma = 0.05$ is very different from the Leontief case with literally zero substitutability $\sigma = 0$, for example, a 20% gas supply drop leads to an output loss of 2.7% rather than 20%, i.e. going from $\sigma = 0$ to $\sigma = 0.05$ reduces the output loss by almost a factor of ten. More generally, and somewhat surprisingly, Figure 3 shows that the case $\sigma = 0.05$ is much more similar to the Cobb-Douglas case $\sigma = 1$ than to the Leontief case $\sigma = 1$. Intuitively, because the input share $\alpha = 1\%$ is small, even a small amount of substitutability is sufficient to overcome the gas input's bottleneck property. In summary, while a Leontief production function predicts that production falls one-for-one with gas, even moderate substitutability implies much smaller losses.

Finally, it is worth noting that Bachmann et al. (2022a) evaluated the effects of a gas cut-off not just on GDP but also on Gross National Expenditure (GNE). GNE, also known as “domestic absorption,” is the economy's total expenditure defined as the sum of household expenditure, government expenditure and investment, that is $GNE = C + I + G$ in the GDP accounting identity $GDP = C + I + G + (X - M)$. GNE (rather than GDP) is the welfare-relevant quantity in many macroeconomic and trade models including the Baqaee-Farhi model. One reason for focussing on GNE rather than GDP is that GDP may not pick up the terms-of-trade effect through which German consumers become poorer when the price of natural gas (an imported good) rises (e.g. Obstfeld and Rogoff, 1995; Mendoza, 1995).[9] Sinn (2022) misguidedly criticized the analysis of Bachmann et al. (2022a) for missing this effect even though GNE is not subject to this criticism.[10]

2.2. Macro elasticities are larger than micro elasticities

The question under consideration in the Great Gas Debate was the potential impact of a cut-off from Russian gas on the German *macro*economy. However, many arguments focussed on very *micro* physical production processes, with industry leaders claiming that substitutability of Russian gas was very close to zero. Bachmann et al. (2022a) argued that this "micro" or "engineering view" of substitution is too narrow and misses important mechanisms through which the macroeconomy would adapt to an import stop.

Macro elasticities of substitution are larger than the corresponding micro elasticities. That is, even if substitution is completely impossible at the very micro level this does not necessarily mean that there is no substitution in the aggregate economy. Technically, single production processes may be very close to displaying a zero elasticity of substitution (Leontief); but they may still aggregate up to an economy with a positive and potentially much higher elasticity of substitution. The observation that zero or low substitution at the micro level does not necessarily imply low substitution at the macro level goes back to a classic paper by Houthakker (1955) who showed that an economy in which individual firms that have Leontief production technologies (i.e. individual elasticities of substitution of zero) can aggregate up to a Cobb-Douglas aggregate production function (i.e. an aggregate elasticity of substitution of one). More generally, it is a classic result in macroeconomic theory that the elasticity of substitution increases with the level of aggregation (e.g. Jones, 2005; Raval and Oberfield, 2021).

The apparent lack of substitutability is thus a classic "micro-to-macro fallacy" (of which there are a number in economics). It also provides a straightforward explanation for why many industry representatives seem to believe that the world is one of little substitution (a "Leontief world"): they are actually right at the micro-micro level and this "engineering viewpoint" biases them to also view the macroeconomy in this fashion. (Of course, the alternative explanation for the apparent belief is simply industrial lobbying, a point we return to later.)

[9] Theoretically the effect is easiest to see in a small open endowment economy with an exogenously given relative price of exports to imports p (which is the country's terms of trade). Real GDP is given by the endowment and therefore not affected by fluctuations in the terms of trade p. However, consumption and welfare decline when the terms of trade p declines, an effect not picked up by real GDP.

[10] Sinn writes "Many have called for an embargo on European imports of Russian gas, arguing that this would [come] at minimal cost to Europe in terms of lost GDP [including a hyperlink to Bachmann et al. (2022a)]. A new study exposes this argument for the fantasy that it is. [...] Due to the terms-of-trade effect, the welfare of consumers of gas and gas-intensive goods would decline as the price of these now-imported items increases [an effect missed by considering real GDP]." That GNE=C+I+G is not subject to this criticism is easiest to see in models without investment or a government in which it just equals welfare-relevant consumption C. A possible reason for Sinn's misguided criticism is that he did not read Bachmann et al.'s paper past the executive summary, thus missing the analysis in terms of GNE.

2.3. The importance of time: the Le Chatelier principle and seasonality of gas demand

Another important observation about elasticities of substitution is that they increase with the time horizon over which the substitution ought to take place. Switching a glass melting furnace from gas to fuel oil from one day to the next is probably impossible but, given enough time, such a switch may well be feasible.[11] The idea that elasticities increase with time has become known as the "Le Chatelier principle" (Samuelson, 1961; Milgrom and Roberts, 1996).[12] It is also well-known that gas demand is strongly seasonal, with demand being about three times higher in winter than in summer, primarily due to households using gas for heating (see e.g. Figure 2 in Bachmann et al. 2022b).

The le Chatelier principle in combination with the seasonality of gas demand was one important reason why Bachmann et al. (2022a) argued that an immediate "cold turkey" import stop in April 2022 would not entail much larger economic costs than an import stop in the summer or early fall. Because a cut-off at the beginning of April would have coincided with the end of the previous heating period and a drop-off in household demand, gas supplies would have been sufficient at any point in time to satisfy both industrial and household gas demand and to avoid shortages.

In particular, also in the case of an April 2022 import stop, industry would have had time until the following winter to conserve and substitute gas. While a "cold turkey" import stop would have resulted in less gas imports from Russia and thus a larger required demand reduction, it would have arguably also sent the signal to industry to start substituting and adapting at full speed already from April rather than only later in the summer and thus longer adjustment times until the next winter (i.e. larger elasticities of substitution by the le Chatelier principle). See Section 4 for a detailed analysis of the importance of gas imports from Russia from April to August 2022.

2.4. Modeling supply chains and international trade: "cascading effects" and substitution via imports

Much of the German debate in February and March 2022 centered around "cascading effects" in production, the idea that a cut-off from Russian gas would not only affect energy-intensive upstream sectors but then "take down" the entire supply chain and industrial sector with it. For example, a drop in gas supply would lead to a drop in glass production (a very gas-intensive product), which would then lead to a drop in the production of bottles, which would lead to a drop in the production of medicine, which would affect the ability to provide hospital care, and so on. Theoretically, if production were Leontief and elasticities of substitution were zero everywhere along the supply chain, then a 20% drop in gas supplies, would lead to a 20% drop

[11] Switching glass melting furnaces from gas to fuel oil is not a hypothetical example but actually happened, see example 13 in the collection of 36 substitution examples in Appendix E.

[12] Atkeson and Kehoe (1999) build models of energy use that rationalize the Le Chatelier principle.

in glass production, the production of bottles and so on, and ultimately a 20% drop in economy-wide industrial production.

To take the possibility of knock-on effects along the supply-chain seriously, Bachmann et al. (2022a) modeled such supply chains using the Baqaee and Farhi (2021) model. The Baqaee-Farhi model is a multi-sector model with rich input-output linkages and in which energy is a critical input in production. The model is *designed* to address questions in which supply chains or production networks play a key role, specifically how a shock to an upstream product (e.g. an energy input) propagates downstream along the supply chain, i.e. the "cascading effects" discussed above. The model features 40 countries as well as a "rest-of-the-world" composite country, and 30 sectors with interlinkages that are disciplined with empirical input-output matrices from the World Input-Output Database (Timmer et al., 2015). Each entry of the World Input-Output matrix represents a country-sector pair, e.g. we use data on the expenditure of the German "Chemicals and Chemical Products" sector on "Electricity, Gas and Water Supply" and how much of this expenditure goes to different countries, say how much goes to Germany itself and how much to Russia. The model features a nested CES structure.

The idea that input–output linkages can serve as a propagation mechanism for such shocks is well established in the literature. See Carvalho and Tahbaz-Salehi (2019) for a review of this literature and Carvalho et al. (2021) for a prominent example studying the propagation of the 2011 Japan earthquake that destroyed the Fukushima nuclear plant.

As just mentioned, the Baqaee-Farhi model features not only multiple sectors but also multiple countries and thus international trade. The analysis using this type of model points to one margin of substitution that turned out to be important in practice: substitution of gas-intensive products via imports. Intuitively, it is not necessary for German producers to substitute gas itself; instead, they can substitute the energy-intensive inputs they use in production like ammonia, and they can do so via trade by importing those goods from another country. In this way, producers effectively import gas "embodied in" these inputs. Of course, this type of substitution via imports comes with some loss in production in the importing country (in this case Germany). However, these losses may be small and, on the flip side, this substitution stops the notorious cascading effects discussed above.

Finally, it is worth noting that an empirically-disciplined multi-sector model like the Baqaee-Farhi model reflects an important feature of modern advanced economies: manufacturing typically accounts for a moderate share of aggregate economic activity. This is true even for Germany which is often viewed as an industrial powerhouse: German manufacturing accounts for "only" about 23% of total employment and 25% of value added.[13] This is a natural consequence of the structural transformation process during which manufacturing activity is replaced by the service sector. Put differently, some observers seem to be under the mistaken impression that the structure of the German economy is still that of earlier time periods like the 1970s during which energy shocks had large negative effects.

[13] See the appendix of Bachmann et al. (2022a) who document these numbers using Eurostat data.

2.5. A useful tool: the Baqaee-Farhi sufficient statistics approach

In a number of papers Baqaee and Farhi have popularized the use of second-order approximations to obtain analytical results in complex multi-sector models. Bachmann et al. (2022a) use a variant of this approach to obtain a useful "sufficient statistics" formula which allows for quick back-of-the-envelope calculations.

The key idea of the approach is that the extent to which the upstream energy supply shock propagates through the production chain shows up in a sufficient statistic, namely, the *change* of the energy expenditure share in GNE induced by an import stop. Intuitively, when there are important bottlenecks along the supply chain and elasticities of substitution are low, energy prices skyrocket when energy supply falls which implies that the energy expenditure share rises strongly.

It is relatively easy to verify that this insight is correct in the context of the simple aggregate production function (1) -- see appendix A. Perhaps surprisingly, Bachmann et al. (2022a) show that it is also true in the much more complex multisector environment of Baqaee and Farhi (2021). Denoting gas imports by m_G and their price by p_G so that the gas expenditure share in GNE is given by $p_G m_G / GNE$, the effect of a shock to gas imports $\Delta \log m_G$ approximately equals

$$\Delta \log GNE \approx \frac{p_G m_G}{GNE} \times \Delta \log m_G + \frac{1}{2} \times \Delta \left(\frac{p_G m_G}{GNE} \right) \times \Delta \log m_G. \quad (2)$$

The intuition for the second term is the one we already discussed: the change in the GNE share of gas imports $\Delta \frac{p_G m_G}{GNE}$ summarizes in a succinct fashion the substitutability implied by model choices about elasticities, the input-output structure, and so on.

The formula can be used for back-of-the-envelope calculations as follows. Consider for example a drop in gas imports by 30% so that $\Delta \log m_G = \log(0.7)$. The share of gas expenditure in GNE $p_G m_G / GNE$ equals about 1.2%. The second-order approximation also requires a number for the *change* in the expenditure share $\Delta \frac{p_G m_G}{GNE}$, a number that was not yet available in the data at the time of writing the Bachmann et al. (2022a). In one of their calculations, Bachmann et al. assumed that this share would quadruple to 4.8%. Using these numbers, the GNE losses are given by

$$\Delta \log GNE \approx 1.2\% \times \log(0.7) + \frac{1}{2} \times (4.8\% - 1.2\%) \times \log(0.7) \approx -1\%. \quad (3)$$

More generally, formula (2) can be used to bound the GNE loss from the shock: above a certain GNE-loss-number, the strong complementarities and "cascading effects" required to get there, would imply an unreasonably large increase in the gas expenditure share, say to 20% of GNE. It is worth noting that this logic applies not just to the Baqaee-Farhi model but also to a much wider class of general equilibrium models. Other analyses of import supply shocks should therefore always examine their model's predictions for changes in expenditure shares for their reasonableness. See also Berger et al. (2022) who put the sufficient statistics approach based on (2) to good use.

2.6. Additional arguments and omissions from the analysis

Less than two weeks after the release of our original paper, we added a detailed appendix to the paper with a number of historical real-world examples that show how firms and households have found ways to substitute in adversity.[14] These include the Chinese rare earths embargo against Japan, the shutdown of the Druzhba pipeline, and various examples from World Wars I and II. There is one particularly relevant case study we were not aware of at the time, namely the case of Chile getting cut off from Argentinean gas in 2007 – see the illuminating discussion by Velasco and Tokman (2022) who were the Chilean finance and energy ministers at the time.

As the “what if” paper was clear to emphasize, our analysis used a real model with no further business cycle amplification and therefore omitted some of the channels through which a large energy supply shock may affect the economy. In particular, our model omitted standard Keynesian demand-side effects in the presence of nominal rigidities as well as amplification effects due to financial frictions. To be clear, our flexible-price model did include what many lay people would call “demand side effects”, namely that skyrocketing relative prices of energy erode purchasing power and consumer welfare. But it omitted the feedback from the drop in aggregate consumption to production and employment that is operational in Keynesian models with nominal rigidities and high marginal propensities to consume. To acknowledge such missing mechanisms, we added a “safety margin” to the results of their model simulations. In particular, our largest number was a GNE loss of 2.3% (see Table 2) which we rounded up to 3% when presenting our headline numbers (see the paper’s abstract). Perhaps reassuringly, work by our co-author Bayer published a few weeks after “what if” (Bayer et al., 2022) as well as Pieroni (2023) used quantitative HANK models to take into account such Keynesian multiplier effects and largely confirmed our original results.[15]

The main reason for these omissions was not that we deemed these effects unimportant. Instead, it was simply that we wrote “what if” in a rush (ten days) and therefore, given time constraints, had to make choices about what channels to include in our analysis and what to leave out. We will revisit these points in section 3.6 when we discuss which of these omissions were important with the benefit of hindsight and lessons for future analyses of similar scenarios.

[14] See “Supplement to ‘What If? …’: Real-World Examples of Substitution and Substitution in the Macroeconomy” available at https://benjaminmoll.com/RussianGas_Substitution/.

[15] Bayer et al. (2022) and Pieroni (2023) modeled exactly the same gas supply shock as we did in our original work but in HANK models. Bayer et al. (2022) found that the upper bound of economic costs stayed below 3% of GDP, i.e. below the “safety margin” we left ourselves whereas Pieroni found that they could reach up to 3.4%, i.e. just outside our upper bound.

3. How the adjustment happened: adaptation and substitution by German industry and households

A year after the final cut-off from Russian gas, we can take stock of what happened to the German economy. The most recent GDP numbers for the German economy, also covering the winter 2022/23, have been published at the end of July 2023. Prima facie, the evidence seems to support the original argument of the “What if” paper. Germany was partially cut off from Russian gas in June 2022 and completely in August 2022, but did not go into a deep depression. Moreover, as shown in Figure 1, German GDP did not only not collapse, but actually expanded by close to 2% for the entire year 2022.

Even in the fourth quarter of 2022 and the first quarter of 2023, during the peak of the winter’s heating season, Germany only experienced a mini-recession with GDP according to preliminary estimates, first contracting by 0.5% and then by 0.1%, i.e., registering two consecutive quarters of negative growth, but by the smallest of all possible margins.[16]

Using the empirical evidence now at hand, this section documents how the adjustment actually played out. As we see now in greater detail in the rear-view mirror, the economy showed a tremendous ability to adapt that was widely underestimated. Producers partly switched to other fuels and imported products with high gas content, while households adjusted their consumption patterns. Overall industrial production “de-coupled” from production in energy-intensive sectors (which did see large drops) and was hardly affected. To lend some color to the statistics of this section, online Appendix E collects 36 concrete cases of substitution and adaptation that shows how German firms and households weaned themselves off Russian gas.

3.1. Germany’s changing “gas balance”: large adjustments on both the demand and supply side

The end of Russian gas imports left a large gap in German gas supplies. How did the country adjust to close this gap? Was the adjustment primarily on the demand side, i.e. lower gas consumption, or supply side, i.e. increased imports from third countries? Figure 4 shows the change of the German “gas balance” for the period July 2022 (when Russia cut gas supplies substantially, see section 1) to March 2023 (the end of the heating period) compared to the preceding three years.

[16] Also other European countries withstood Russia’s weaponization of natural gas remarkably well. According to the most recent Eurostat GDP flash estimates for 2023Q2 (Eurostat, 2023), both the European Union and the Euro area expanded in the first two quarters of 2023, and only a handful of individual member countries like Czechia and Estonia have experienced (shallow) recessions (defined as two consecutive quarters of negative GDP growth) since the beginning of 2022. The exception is Hungary which has seen four consecutive quarters of negative GDP growth since 2022Q3.

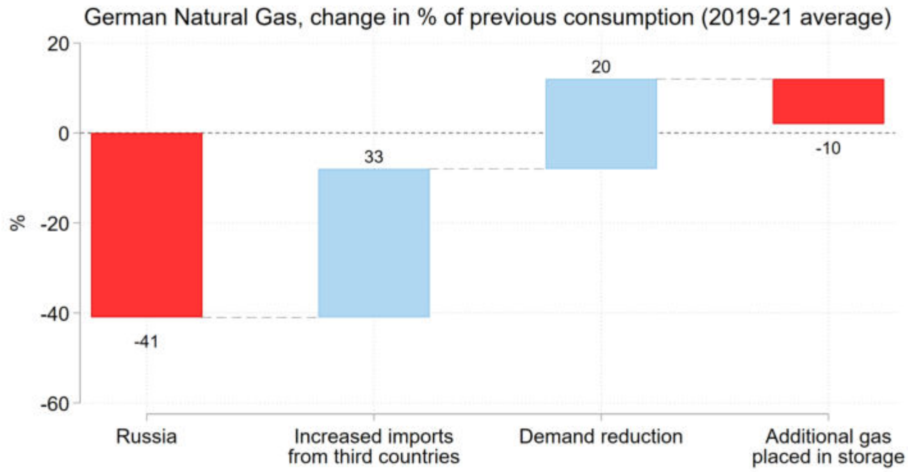

Figure 4: Germany's changing gas balance

Notes: The figure compares German natural gas imports, consumption, and storage change for the period July 2022 - March 2023, to the corresponding average from 2019 to 2021 using data from Eurostat (database code nrg_ti_gasm), McWilliams and Zachmann (2023), and AGSI. On the supply side, we take into account not only direct imports to Germany but also indirect imports via third countries as well as re-exports within Europe. More details, including on sources, are in appendix B.

The cut-off from Russian gas reduced supply by 41% of total consumption in previous years. This gap was filled by large adjustments on both the demand and supply sides. Additional supplies from third countries (like Norway, Algeria, and the U.S.) accounted for 34% of the gap while gas demand in 2022/23 was about 20% lower compared to the 2019-21 average.[17] Finally, an additional 10% of annual consumption was used to increase storage levels, in part necessary because some storage facilities were Russian-owned and had been purposely kept empty. We postpone further discussion of the supply side to section 3.5 where we break down the sources of the new gas supplies and highlight the insurance function played by European and global market integration.

Zooming in on the demand side, Table 2 breaks down the 20% demand reduction into its key components using data from McWilliams and Zachman (2023). With the exception of electricity generation where gas demand for power generation fell only by a small single digit amount, industrial demand fell by 26% and household demand by about 17%.

These numbers are not far off the adjustment path described in our second paper ahead of the gas cut-off (Bachmann et al., 2022b) in which we counted on a 26% demand reduction by industry and 16% by households. However, we substantially overestimated the potential for gas savings in electricity generation. As we will discuss later, this had a lot to do with specific elements of "bad luck" in electricity generation (the shortfall in French nuclear energy production

[17] On the supply side, we take into account not only direct imports to Germany but also indirect imports via third countries as well as re-exports within the EU. For comparison Appendix Figure B.2 plots the direct flows.

and the drought in Europe that reduced available hydropower substantially). The demand reduction was supported by good incentives for savings for households emanating from the proposals of an expert commission, as we will discuss below.

	2022/23 consumption	Baseline consumption	Reduction rel. to baseline	Percentage reduction	Bachmann et al. (August 2022)
Total	642 TWh	799 TWh	157 TWh	20%	25%
Industry	276 TWh	373 TWh	98 TWh	26%	26%
Households	281 TWh	339 TWh	58 TWh	17%	16%
Power	85 TWh	87 TWh	1 TWh	2%	45%

Table 2: Large demand reduction by industry and households

Notes: The table summarizes gas consumption over the period July 2022 to March 2023 ("2022/23 consumption") and compares it to average consumption in the same months in the years 2019 to 2021 ("baseline consumption"). The column "Bachmann et al. (August 2022)" refers to predictions about a hypothetical adjustment path we made in Bachmann et al. (2022b) in early August 2022 ahead of the gas cut-off. Data for gas demand are taken from McWilliams and Zachmann (2022b). The source provides a more detailed methodology for the calculation of demand, but the key assumptions are as follows. Gas consumption is measured separately for so-called RLM meters (large consumers directly connected to the transmission grid) and SLP meters (small consumers). "Households" refers to small consumers (SLP) and therefore also includes commerce and small businesses. "Power" refers to gas used in electricity generation which we calculate from power output of gas-fired power plants and assuming a plant efficiency of 50%. Consumption by "industry" is calculated by removing gas used for power-generation from RLM consumption. That the numbers in the last row seemingly do not add up is due to rounding, i.e. the unrounded numbers do add up.

Section 2.5 emphasized a key sufficient statistic, the change in Germany's gas expenditure share. While our original analysis was forced to speculate about the future evolution of this statistic, Appendix Figure B.3 plots this expenditure share using the evidence now at hand. Before the 2021/22 winter, natural gas accounted for around 1% of Germany's total expenditure (GNE). As Russia weaponized and restricted gas supplies, skyrocketing prices meant that this expenditure share increased sharply to around 4% of GNE. This quadrupling of the gas expenditure share turned out to be in line with the experiment we already described in section 2.5 and for which the Baqaee-Farhi sufficient statistics approach predicted a 1% GNE loss.

3.2. Industry

Taking a closer look at the 20% aggregate demand reduction over the past heating period, the evolution of gas consumption and output in the industrial sector is of particular interest as much of the original arguments on the effects of the cut-off focussed on short-run substitutability of gas in industrial production. We already know that in the aggregate industrial gas usage decreased by 26% relative to previous years (Table 2). Importantly, this sharp reduction in gas usage was not accompanied by large output drops, as many had feared.

Figure 5 plots industrial production and gas consumption in Germany and six other European countries. As a benchmark, recall from section 2 the key prediction that a Leontief zero-substitutability production structure implies that production falls one-for-one with gas consumption. That is, if elasticities of substitution in industry had been truly zero, Germany should have seen overall industrial production fall by around 26% as the drop in industrial gas usage would have cascaded through the entire supply chain. Figure 5 demonstrates that in Germany, but also across the rest of Europe industrial production looks nothing like in this Leontief case. In Germany, industrial production did not fall meaningfully and even rose compared to the previous year depending on the month of comparison. On the European level, hardly any correlation can be observed between reductions in gas consumption and manufacturing output. In the Netherlands, for instance, gas consumption fell by almost 30% while industrial output overall increased significantly.

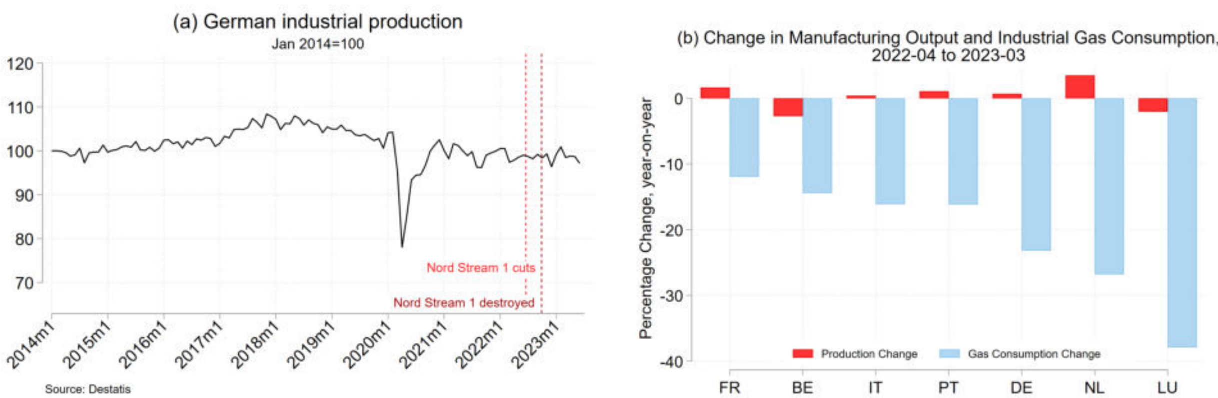

Figure 5: Industrial production in Germany and Europe looks nothing like Leontief

Notes: the industrial production data in figure 5a are from table 42153-0001 of the German economic sectors statistics available through the German statistical agency Destatis at https://www-genesis.destatis.de/. The index is normalized to 100 in 2014M1. Figure 5b compiles gas demand data for industries from McWilliams and Zachmann (2023), industrial output data is from Eurostat, database code: sts_inpr_m.

We next ask what sectors were most affected by the gas cut-off and whether and to what extent there were knock-on effects along the supply chain. Unfortunately, the German Statistical Agency will only release detailed data for 2022 gas usage by industry sector in October 2023. However, we can use pre-existing classifications of industries into more and less energy-intensive sectors to gain a better understanding of the actual adjustment processes.

We find clear indications that production in energy-intensive sectors was strongly affected. Figure 6 displays the time path for production in energy-intensive industries using the classification of the German Statistical Agency alongside production in other industries. As can be seen from the graph, production in energy-intensive sectors dropped by close to 20%.[18] However, industrial production of other sectors declined only slightly. Importantly, this observed “decoupling” between energy-intensive production and production of other sectors is the polar opposite of the much-feared “cascading effects” discussed earlier. Figure 6 (along with the results in figures 7 and 8 below) shows that in an open economy with substitution possibilities, sharp declines in output in some upstream sectors do not necessarily lead to large contractions in downstream industries. At each point in the production network substitution possibilities exist.

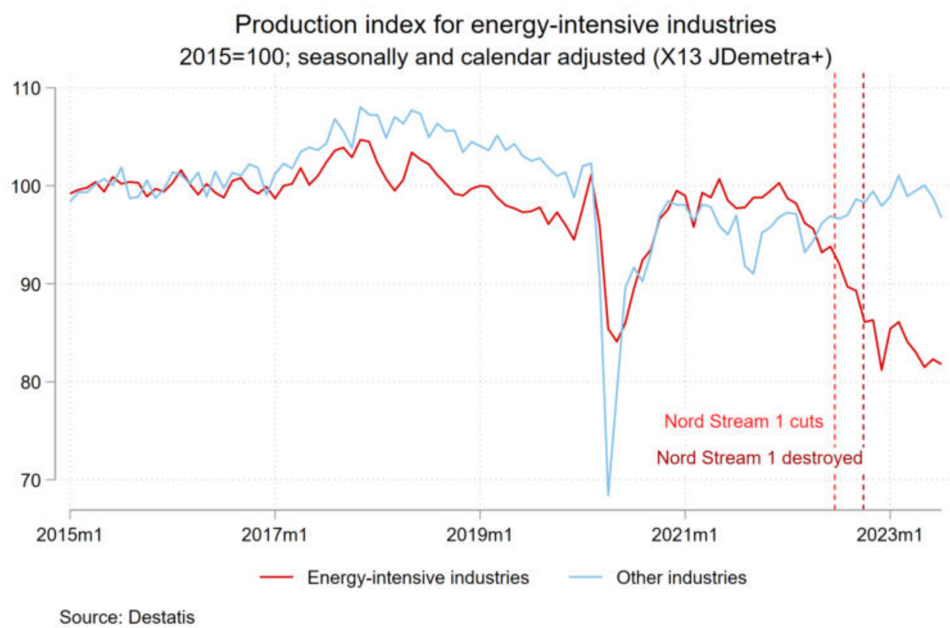

Figure 6: Decoupling of overall industrial production from energy-intensive sectors

Notes: data are from Destatis (2023a, Figure 5) and Vogel et al. (2023). Energy-intensive industries are: (i) paper and paper products, (ii) coke and refined petroleum products, (iii) chemicals and chemical products, (iv) basic metals, and (v) other non-metallic mineral products, which together account for a total of 16.4% of overall industrial production in the base year 2015 (Vogel et al, 2023). We back out the index for “other industries” by using that the index for overall

[18] An interesting question is how close this large production drop in energy-intensive sectors was to the Leontief benchmark of a one-for-one drop with gas consumption. Since data on gas usage by sector has not been released yet, we cannot answer this question yet. A natural conjecture is that gas usage in these sectors dropped by more than the 26% reduction for industry as a whole, which would imply that not even production in those sectors behaved like in the Leontief case.

industrial production is a weighted average of that for energy-intensive industries and that of other industries with weights 16.4% and 83.6%.

Figure 7 conducts a more granular analysis using our own measure of gas intensity at the sectoral level, with gas intensity defined as an industry's past gas consumption relative to its turnover. As expected there is a clear negative correlation between changes in industrial production and gas intensity, with the most gas intensive sectors seeing the largest drops in industrial production. However, not just the slope of the relationship is interesting but also the level. In particular, while energy-intensive sectors like chemicals, paper, or fertilizer did see sharp drops in production (presumably because they also saw substantial drops in gas consumption), many other sectors saw no drops or even increases in production. Instead, in a "cascading-effects view" of the world, industrial production should have fallen in all sectors regardless of how energy-intensive they are because the initial negative gas supply shock to gas-intensive sectors should have "taken down" the entire supply chain. Figure 7 thus again shows no evidence of cascading effects and instead shows more of the de-coupling already evident in Figure 6.

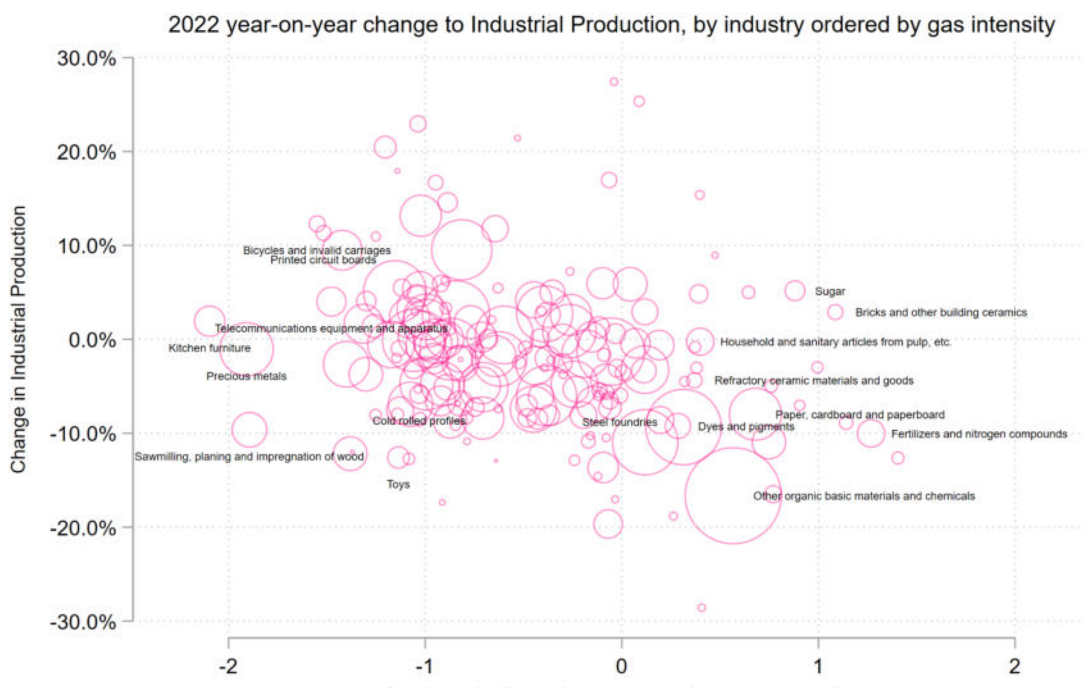

Figure 7: Sectoral output change and energy-intensity of industrial sectors

Notes: the data are from DeStatis industry level databases, industrial production and energy consumption data are merged according to WZ codes.

When the German Statistical Agency will release 2022 gas usage by industrial sector in October 2023, it will be interesting to correlate the drops in industrial production in Figure 7 with the drops in gas usage. Such a sectoral version of Figure 5(b) will provide the sharpest test of the extent of substitution along the supply chain by answering the question whether production only fell in particular gas-intensive sectors with large drops in gas usage or whether these production drops "cascaded" further downstream and even affected sectors that do not consume any gas or experienced no drops in gas usage.

Figure 8 provides some illustrative examples for the substitution via imports emphasized in Section 2.4 by plotting output change and import growth for a number of selected energy-intensive industrial sectors like rubber, plastics, and aluminium production. We observe substantial increases in net imports of energy-intensive products. While the correlation with the reduction of output on the industry level is less close, substitution via imports was likely an important channel through which gas savings could be realized with small effects on the overall economy.

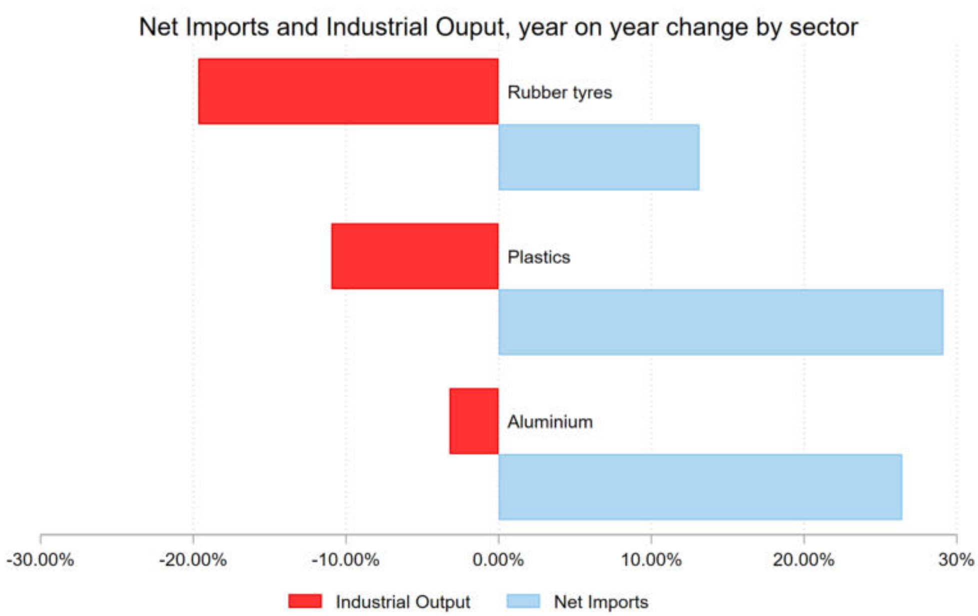

Figure 8: Illustrative examples of substitution via imports

Notes: DeStatis industry level data for industrial production are mapped to trade data from Eurostat, database code: DS-045409. For "Rubber tyres" (full name "new pneumatic tyres, of rubber") WZ code is: 2211, and HS code: 4011. For "Plastics" (full name "Plastics and Articles Thereof"), WZ code is: 2016, and HS code: 39. For "Aluminium" (full name "Aluminium and ArticlesThereof"), WZ code is: 2442, and HS code is: 76.

A study by Mertens and Müller (2022) provides additional support for the hypothesis that substitution via imports was likely important in practice. Using a more fine-grained product-level analysis, they show that only 300 specific products account for about 90% of industrial gas consumption in Germany. They then argue that these products are heavily traded on the world market and therefore likely more easily substitutable via imports.

As already noted, appendix E collects 36 concrete cases of substitution of gas and gas-intensive products by German firms and households. One of these is worth re-stating here because it illustrates well the substitution via imports just discussed: when gas prices skyrocketed in Germany and Europe, chemicals giant BASF drastically reduced the production of ammonia (a very gas-intensive product) at its Ludwigshafen site; BASF then switched to producing ammonia in its other plants around the world, including in the U.S. where gas prices were much lower, and more generally to importing ammonia from other countries with a newspaper article noting that “this substitution via the world market [is] relatively easy.”[19] What is worth noting here is that substitution via imports can sometimes even happen *within* the same firm. It is also worth contrasting BASF’s apparent substitution prowess with its chief executive’s statement about the destruction of the entire economy quoted at the beginning of our paper.

Finally, there is some high-level and suggestive evidence that lower industrial gas demand was, at least in part, due to skyrocketing gas prices. See Ruhnau et al. (2023), in particular the downward-sloping time-series relationship between monthly prices and quantities in their Figure 5(b). The endogeneity of both prices and quantities as well as the complexity of the gas market mean that this evidence should not be interpreted as causal. But it is nevertheless worth highlighting that high prices were associated with reductions in industrial gas demand.

3.3. Households

Consumption by households and other small consumers represents around 41% of overall gas consumption.[20] Because households use gas overwhelmingly for heating, their demand is both highly seasonal and influenced by weather variations (see section 5). Overall, German households consumed 17% less gas in the period July 2022-March 2023 than in the same period in the three preceding years (Table 2).

Appendix figure B.4 shows that demand reduction by households was significant even when controlling for temperature. While temperature-controlled household demand in January and February 2022 was above average, from March 2022, i.e. after the war started, it increasingly fell below average. This indicates that households actively reduced their gas consumption. A lot of this saving might have been behavioral - i.e., reducing room temperature or heating less rooms. But over time we might see more and more structural savings based on investments, ranging from light-touch investments in insulating drafty doors and windows to substantial capital spending on replacing gas boilers by heat-pumps.

Disentangling the causes of these quite significant household gas demand reductions will provide important lessons for policy makers and the energy industry. The early demand reductions in March 2022 - when high wholesale prices had not yet translated into increasing

[19] See cases 2 and 15 in Appendix E as well as Neue Zürcher Zeitung (2022).
[20] As already noted in the note to table 2, what we term household gas consumption is consumption by SLP consumers (small consumers not directly connected to the transmission grid) and therefore also includes not just households but also some commerce and small businesses.

retail prices indicate that the shock of the crisis, discussions about emptying gas storages and public appeals had some effect on household behavior. There was, however, only a very limited federal level gas saving campaign. It had only a budget of 40 million Euros - i.e., 50 cent per German citizen - and was targeted at energy switching[21] not at energy saving, and it was not evaluated. This was maybe over worries that a hard savings-campaign will rather upset the population (Deutscher Bundestag, 2022). More importantly, there was no federal public program to support demand-side investments into gas savings, while at the same time billions were spent on the supply side. On the regional-state and local level, campaigns have been run by administrations and/or gas suppliers.

In general, German retail prices are sticky and billing often only happens once a year (for a cumulative volume). Assessing the impact of retail prices on household gas consumption is also only starting and remains held back by a lack of public granular data. Such granular data will be key, as the situations of households differed quite widely depending on the region they were living in, their gas supplier, their gas consumption pattern and most importantly the supply contract they were on. As the wholesale price explosion was very differently passed-through to different customers - also the demand reduction patterns might differ.

Still, over time an increasing share of consumers saw their gas prices go up significantly. As all new/renewed retail gas contracts since March featured significantly higher prices, over time more and more consumers (anyone that had to enter a new contract) became also affected by increasing prices. Already before, some gas suppliers offered saving-bonuses to those households that reduced their demand - thereby overcoming the issue that incumbent retail tariffs did not signal the high cost of gas on the wholesale market. And by autumn 2022 the number of contract-renewals, or their announcement has confronted a substantial share of consumers with the drastically increased prices. This visibly impacted demand. Gas prices across countries and changes in gas prices correlate with gas demand reductions during the crisis[22]. That is, countries with the highest increase in household gas prices saw the strongest reduction in gas demand in the EU.

This also shifted the political dynamics for the state to intervene. In October the federal government set up an expert commission to discuss sensible policies to help consumers without increasing demand (see section 3.4), while at the same time temporarily reducing VAT for natural gas from 19% to 7%, muting the price-signal for consumers at the expense of German tax-payers.

Analogously to the case of industrial gas demand, there is some high-level and suggestive evidence that high prices were associated with household demand reductions. See Ruhnau et al. (2023), in particular the downward-sloping relationship between monthly prices and quantities in their Figure 5(a), though with the same caveats as in the case of industrial gas demand (see the discussion above).

[21] The campaign was called www.energiewechsel.de - which means “energy switch.”
[22] See McWilliams et al. (2022)

3.4. Policy choices matter: Germany's alternative to a price cap

Skyrocketing gas prices in the summer and fall of 2022 put substantial strains on the finances of both households and firms, leading to calls for policy intervention to support households and firms. In contrast to policymakers in many other European countries, German policymakers refrained from imposing a price cap on natural gas and instead opted for lump-sum transfers based on households' and firms' historical gas consumption. We here briefly review this scheme. We do so for two reasons. First, the scheme is interesting from an economic perspective in that it provides relief by aiming to target the income effect of higher gas prices while leaving substitution effects intact, akin to what Mas-Colell et al. (1995) term "Hicks compensation." Second, the scheme is an interesting blueprint for future government interventions to alleviate the hardship in the face of rising commodity prices.

The policy was based on the proposal of a commission composed of various stakeholders (like union and industry leaders) as well as a number of economists including our co-authors Christian Bayer and Karen Pittel (German gas commission, 2022). Precursors of this scheme were proposed by Christian Bayer in Bachmann et al. (2022a, 2002b). As has been widely discussed, the official name of the German policy scheme, "gas price break", is a misnomer and "gas cost break" may instead have been a more accurate name. This is because the scheme caps a household's or firm's total expenditure rather than the marginal price of an extra kWh of gas which remains equal to the pre-intervention market price. See Bayer et al. (2023) and Bundesregierung (2023) for summaries and preliminary evaluations of the scheme.

Figure 9(a) graphically illustrates the German scheme using a numerical example. The x-axis plots a household's current gas consumption as a percentage of its historical consumption which is assumed to be 10,000 kilowatt-hours (kWh). The y-axis plots the household's gas bill in Euros as a function of its gas consumption under a number of scenarios of gas prices and policy interventions. Initially the gas price paid by households is at 5 cents per kWh resulting in a gas bill of 500 Euros (black dashed line). Now gas prices skyrocket by a factor of 5 to 25 cents/kWh so that the gas bill of a household consuming 10,000 kWh of gas is not 500 Euros but 2500 (blue dashed line). What are the effects of various policies to support households? One option is a price cap, say at 12 cents per kWh (green dashed lines). As desired, this brings down the gas bill from 2500 to 1200 Euros. But it also comes with a problem: it strongly reduces the household's incentive to reduce gas consumption relative to the high price (the green line is flatter than the blue line).

The German policy is instead represented by the red solid line. Households receive a transfer (credit on their gas bill) equal to 80% of their historical consumption times the difference between the current market price 12 cents per kWh (an estimated long-run "new normal" gas price).[23] The key observation is that, in contrast to a price cap, this transfer is not directly tied to current gas consumption (i.e. it is a lump-sum transfer) and thus preserves incentives for reducing gas consumption. Graphically the red line has the same slope as the blue dashed line

[23] The transfer is capped at the total bill amount, i.e. it is not possible to "make money." Graphically the red line equals zero when gas consumption drops below about 40% of historical consumption.

(though it is everywhere below the latter).[24] By using a household's historical gas consumption as the basis for calculating the size of the transfer, the scheme is nevertheless targeted toward more affected households. Skyrocketing gas prices have both an income and a substitution effect. The income effect is undesirable because it makes households poorer; in contrast, the substitution effect is desirable because it reduces gas consumption. An appealing feature of the German scheme is that it leaves the substitution effect unaffected while alleviating the negative income effect. The scheme is thus a variant of what the literature has termed "Hicks compensation" (Mas-Colell et al., 1995). An important point is that the German scheme is not a two-tier price cap, for example a price cap for 80% of past consumption with market prices kicking in for consumption above 80%, as was proposed by some economists.[25]

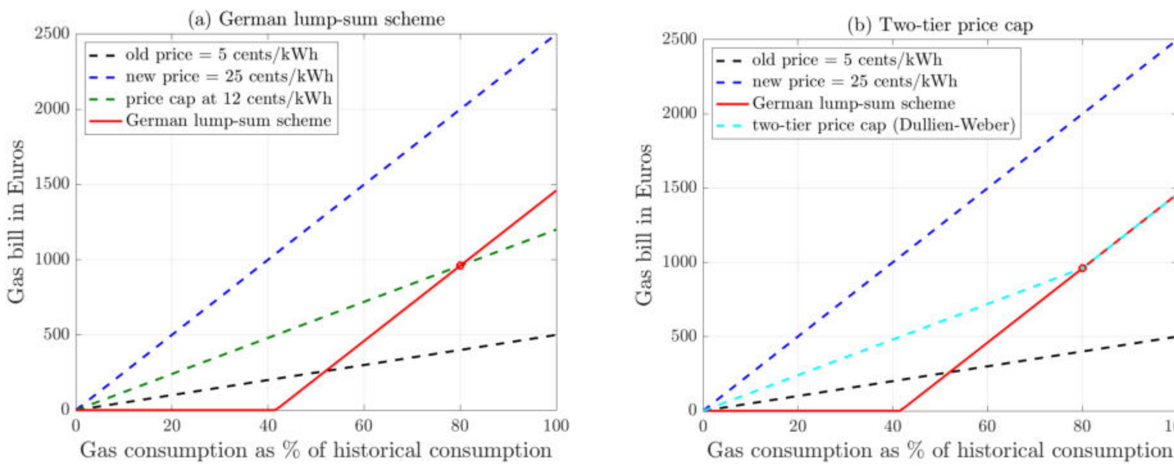

Figure 9: the German "gas price break" was a lump-sum transfer and not a price cap

Figure 9(b) contrasts the two schemes graphically, with the red line plotting the German scheme (as before) and the turquoise dashed line plotting a two-tier price cap with a price cap of 12 cents per kWh for up to 80% of past consumption. The key observation is that the schemes differ for any consumption levels below 80% of past consumption: while the German scheme preserves saving incentives for those who can save more than 20% relative to their past consumption, a two-tier price cap reduces these incentives by capping the price faced by consumers. Importantly, households reducing gas consumption by more than 20% turned out to be not just an academic curiosity: instead, during the 2022-23 winter, larger demand reductions were routinely observed.[26]

3.5. New gas supplies and the insurance value of European integration

[24] Of course there *is* a relation between the German scheme (red line) and a price cap at 12 cents per kWh (green dashed line): the point where the two lines cross is exactly 80% of past consumption. So the green dashed line for the price cap determines how much the red line is shifted down.

[25] E.g. Dullien and Weber (2022).

[26] While the average household demand reduction over the entire 2022-23 winter was less than 20% (see Table 2), demand reductions in particular weeks were considerably above 20% and often up to 40% (BNetzA, 2023). The same is presumably true for particular households or geographic areas.

As shown in Figure 4, additional supplies of non-Russian gas to Germany played an important role in getting Germany through the 2022/23 winter, with these imports increasing by around 34% relative to previous consumption. This section breaks down these imports further and highlights two main channels. First, additional gas imports into Europe made its way to Germany via the integrated European pipeline network. Second, demand reduction elsewhere in Europe freed up gas supplies that then ended up in Germany.

Considering Europe as a whole, gas imports increased significantly, with most of this increase coming from liquified natural gas (LNG) which increased by 470 TWh in the period after the Nord Stream cuts (July 2022 to March 2023) compared to the 2019-2021 average and a more moderate contribution from pipeline imports which increased by 110 TWh.[27] An important feature of the additional LNG imports was that they came at extremely high prices. Because global production capacities as well as the infrastructure for transporting LNG were constrained, LNG destined for other markets had to be re-routed to Europe by offering extremely high prices for individual cargos. The small increase in pipeline imports to Europe was similarly due to the fact that production and transportation capacity could not be ramped-up more quickly.

Turning to Germany individually, Appendix Figure B.1 plots a version of Figure 4 but with the imports from third countries broken down by ultimate source country. The largest supplier of additional non-Russian gas was Norway, contributing additional imports worth around 16% of previous consumption, i.e. almost half of the 34% overall additional supplies. LNG imports from countries like the U.S. and Qatar were also important, contributing a combined 13%. Note that, like Figure 4, the figure takes into account not only direct imports to Germany but also indirect imports via third countries as well as re-exports within the EU. This is particularly important for LNG because Germany had rejected building any LNG import infrastructure prior to the crisis and therefore had to instead rely on LNG terminals elsewhere in Europe (e.g. in Belgium, the Netherlands and France) for most of these imports. Immediately following the Russian invasion, Germany put in motion plans to finally build LNG terminals on its coast. These made a small contribution of gas imports worth around 3% of previous consumption (see Appendix Figure B.2).[28] The important role of gas imports from third countries and, specifically, via other European countries highlights the insurance benefits of global and European market integration.

While imports from outside Europe were instrumental for displacing Russian gas in Germany, another crucial factor for getting Germany through the 2022/23 winter was demand reduction elsewhere in Europe. This is because additional imports to Europe replaced only about two thirds of Russian imports so that an additional fall in demand was needed. In the European Union as a whole, gas demand declined by a substantial 18% or 630 TWh in the period July

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[27] The series for European LNG imports includes indirect imports of LNG via the UK that was then passed by pipeline onto the Netherlands and Belgium. UK pipeline flows to the Netherlands and Belgium dramatically increased to make use of extra LNG import capacity in the UK. In Europe as a whole 20% of LNG import capacity was added in 2022 Q4 and 2023 Q1.

[28] The contribution of the newly-built LNG terminals may seem small to readers familiar with the German debate given these were often touted as “game changers” by politicians and in the media. The reason their contribution to getting Germany through the 2022/23 winter was not larger is that they only came online relatively late, with the first LNG terminal (Wilhelmshaven) opening on 17 December 2022.

2022 to March 2023 compared to the 2019-21 average. Gas consumption fell substantially not only in countries that were highly dependent on Russia but also in others that were not. This freed up additional gas supplies for those countries most in need. A political commitment to reduce gas consumption by at least 15% ("Save Gas for a Safe Winter") likely contributed to this EU-wide demand reduction, specifically because it entailed a commitment to letting markets work despite the very high prices that were adversely impacting domestic industrial and household consumers alike. In summary, high prices discouraged demand all over the EU, high prices at the entry points into the European system drew international volumes into Europe, and intra-European gas price differentials pulled gas flows into the countries most in need of volumes to replace Russian supplies, specifically Germany.

3.6. Looking back and looking ahead

With the benefit of hindsight, which elements of our earlier analysis have held up well and which ones less so, i.e. where is there room for improvement? What lessons can we draw for future analyses of similar scenarios? For example, suppose that ten years from now another large energy supply shock looms and we would like to evaluate it using quantitative macroeconomic modeling. Or suppose China invades Taiwan and a similar debate arises about the economic costs of sanctioning China. Which parts of the analytical framework described earlier will come in handy and where does it have gaps?

In retrospect, probably the biggest gap in our earlier analysis was the omission of demand-side effects, in particular standard Keynesian aggregate demand amplification: rising energy prices drag down consumer spending and this feeds back into production and employment which further drags down consumption, and so on.[29] Direct empirical evidence for this type of Keynesian multiplier mechanism is hard to come by because it is concerned with general equilibrium effects and we have not come up with a convincing empirical strategy for isolating them during this particular episode.

However, there are two reasons to believe that such effects are important in practice and should be included in full-blown analyses of negative energy supply shocks. First, this mechanism is operational in standard macroeconomic models with nominal rigidities that are consistent with empirical evidence on household consumption behavior, in particular Heterogeneous Agent New Keynesian (HANK) models consistent with the large observed marginal propensities to consume. See Bayer et al. (2022, 2023), Pieroni (2023), and Auclert, Monnery, Rognlie and Straub (2023) for analyses emphasizing this mechanism.

Second, empirical analyses of past energy shocks (typically oil shocks) using time-series data have documented patterns consistent with demand-side effects, in particular that these shocks primarily affect the economy through a disruption in consumer spending on goods and services other than energy (Hamilton, 2009, 2013, 2018; Edelstein and Kilian, 2009). For example,

[29] As already noted in Section 1.5, our model did include the standard flexible-price demand-side effect that higher energy prices erode purchasing power and erode consumer welfare.

Hamilton (2009, 2013) shows that one of the key responses seen following five historical oil shocks was a decline in car purchases and argues that this accounted for a large share of the drop in GDP in the 5 quarters following the shocks. Hamilton (2013) concludes that “combining these changes in spending with traditional Keynesian multiplier effects appears to be the most plausible explanation for why oil shocks have often been followed by economic downturns.” If such demand-side amplification was important following past oil shocks, one would expect it to also have been operational following the German economy’s cut-off from Russian gas.

An interesting question is why Germany’s 2022 cut-off from Russian gas appears to have been less costly than the oil shocks of the 1970s.[30] Three candidate explanations are as follows. First, both in the 1970s and today, oil plays a more important role in the global economy than natural gas and, therefore, the oil shocks were simply larger shocks. To show this, panel (a) of Figure B.5 compares the evolution since the 1970s of world oil expenditures as a share of world GDP to those on natural gas. Despite larger fluctuations in both series, the oil expenditure share is consistently higher than the gas expenditure share, with oil expenditures of about 2% of GDP in “normal times” compared to 1% for gas. Similarly, comparing the 1970s oil and 2022 gas shocks, oil expenditure more than quadrupled from about 1.5% to 7% of world GDP in the 1970s whereas gas expenditure rose from around 1% to 3.5%, so that the oil shock’s peak impact was again twice as high as that of the gas shock (7% vs 3.5%).[31] Data for both Germany and the EU as a whole paint a similar picture – see panel (b) of Figure B.5.[32] Second, as already noted in section 2.3, structural change means that manufacturing now accounts for a smaller share (only about a quarter) of economic activity than in the past. Third, households’ use of oil and gas differ in ways that could explain why high oil prices appear to be a stronger drag on consumer spending than high gas prices. Specifically, high oil prices affect consumers primarily via high petrol prices whereas high gas prices affect heating costs. Petrol prices are much more tied to spot market prices than heating costs which are determined by relatively longer-term contracts. Petrol costs are arguably also more salient and may thus affect consumer spending and confidence more strongly.[33]

On the flip side of paying more attention to Keynesian demand amplification, future analyses should probably spend relatively less time and effort quantifying the “cascading effects” discussed in section 2.4. This is because, the data instead showed a substantial “de-coupling”

[30] It is worth noting that, during the 1970s oil shocks, Germany fared better than the United States. For example, in the aftermath of the 1973/74 oil shock, U.S. GDP contracted by 2.5% (Hamilton, 2009) whereas German GDP contracted by “only” 0.9% in 1975 (Destatis, 2023b).

[31] Note that the oil shock was also much more persistent. Consistent with our numbers, Baqaee and Farhi (2019, Figure 7) calculate that the global expenditure on crude oil as a share of world GDP was around 2% and quadrupled to 8% in the 1970s.

[32] Also recall Figure B.3 which showed an increase in Germany’s gas expenditure share in GNE from 1% to 4%. The larger impact for Germany in Figure B.3 than B.5(b) is primarily due to the use of higher frequency monthly data in Figure B.3 with monthly gas prices showing a larger peak than the yearly data in Figure B.5(b).

[33] Finally, an alternative potential explanation of a different type is that many oil shocks appear to be strongly temporally correlated with large monetary policy shocks (Hoover and Perez, 1994; Nakamura and Steinsson, 2018), implying that inference about the separate effects of either type of shock is complicated.

of overall industrial production from that in a few energy-intensive sectors like chemicals and glass, that is the polar opposite of “cascading effects.” The focus on “cascading effects” in our original paper was due to these effects being a central (or perhaps even *the* central) concern in the spring 2022 German public debate. In retrospect, this also reflected that lobbyists are skilled at shifting public debates, in particular taking advantage of the fact that the “Leontief logic” that everything drops proportionately is extremely intuitive for non-specialists. The absence of cascading effects and the strength of the observed de-coupling between energy-intensive production and the rest is interesting from an economic perspective. Once more granular data on industrial production and gas usage will become available, it will be interesting to see how exactly this decoupling played out in practice.

4. Could Germany have withstood an earlier cut-off as well?

To what extent did the timing of the cut-off matter for these benign economic outcomes? It is clear now that the cut-off from Russian gas that Germany experienced in the summer of 2022 had moderate and manageable economic consequences and that the country even exited the winter with substantial gas reserves of around 65%. But it is an open question whether Germany would have made it through the winter with an earlier cut-off, possibly as early as April 2022 that would have left only a few weeks for preparations?

A prominent line of argument is that the additional months from April to August, during which Germany continued to import and stockpile Russian gas, were decisive to fill storage capacity sufficiently to get through the winter. Without those Russian imports, the argument goes, with an immediate severance from Russian energy starting in April 2022, shortages, rationing and high economic costs would have ensued.

We here provide some simple counterfactual calculations to answer this question, taking 1 April 2022 as the hypothetical cut-off date. We ask the following simple question: in retrospect, would Germany still have had gas left in its gas storage facilities at the end of the 2022/23 winter, if the country had stopped importing Russian gas on 1 April 2022 rather than continuing to import and stockpile Russian gas until the end of August 2022? Would Germany have run out of gas in the middle of the winter?

Figure 10 presents a simple counterfactual scenario that answers this question. The blue solid line plots the actual observed storage evolution including Russian gas imports after March 2022. The black dashed line plots the counterfactual storage evolution in the event of an April import stop calculated from combining data on Russian gas imports and the observed storage evolution (see the explanation below and in the appendix). The key takeaway is that, even with a 1 April gas cut-off, Germany would still have exited the winter with gas storages that are 25% full. In other words, Germany would have been able to cope with an earlier April embargo.

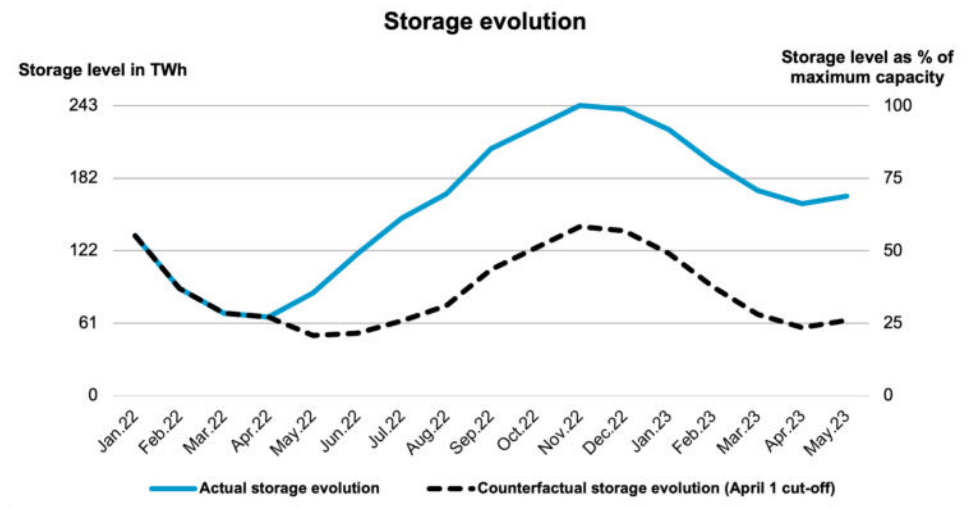

Figure 10: Counterfactual storage evolution with gas cut-off at the end of March 2022

Notes: See Appendix C for details on sources and the construction of the series for counterfactual storage evolution.

The following simple calculation explains this result. We compute the cumulative observed imports of Russian gas over the period April to August 2022 taking into account imports via third countries as well as re-exports (see appendix for details) and compare this number to the amount of gas left in German storages at the end of the 2022/23 heating period. The idea is simple: holding consumption and other gas supplies constant, if Germany exited the winter with more gas left in its storages than these cumulative imports, then Germany would not have run out of gas even with an April import stop from Russia. In contrast, if gas reserves at the end of the winter were less than these cumulative imports, Germany may have run out of gas without these imports.

Germany imported around 100 TWh (Terawatt hours) of Russian gas since April 2022 which is around 10% of the typical annual gas consumption in previous years or around 40% of maximum storage capacity.[34] On the other hand, Germany had around 160 TWh of gas left in its storage facilities which is around 16% of typical annual consumption or around 65% of storage capacity. Therefore even with a 1 April gas cut-off, Germany would still have emerged from the winter with gas storages that are 25% full (65% - 40% = 25%) which is exactly the number plotted in Figure 10 – see the data point for April 2023.

In fact, the 25% storage level implied by this simple counterfactual calculation should be viewed as a lower bound, i.e. Germany would have arguably emerged from the winter with higher gas storage levels. First, our counterfactual calculation holds constant German gas consumption,

[34] For Germany-wide maximum storage capacity we use 246 TWh based on the fact that storages were completely filled by early November 2022 with 246 TWh (AGSI, 2023). Similarly, there is a question what the minimum storage level is at which storages can still operate efficiently. The lowest historical storage filling level was only 35 TWh of working gas in March 2018 (AGSI, 2023), significantly below the 60 TWh in our counterfactual scenario, and even at 35 TWh storages still contained significant volumes of cushion gas that could have been extracted in an emergency situation.

i.e. it assumes that even with gas supplies falling much more substantially and storage levels being considerably lower before the start of the winter, consumption would have been unchanged relative to its actual time path. This assumption is unrealistic: instead, with lower supplies and storage levels, further demand reduction would likely have occurred.[35] Second, there was a time period in October and November 2022 during which German gas storages were virtually full and therefore gas imports were constrained by a lack of storage capacity to put this gas. In fact, gas storages not just in Germany but all over Europe were so full at this point that this resulted in large numbers of LNG tankers queuing off Europe's coasts unable to unload.[36] While our calculation therefore provides a lower bound on gas storage levels at the end of the 2022/23 winters, we view it as useful because of its simplicity.

To construct the full time path for counterfactual storage evolution in Figure 10, we additionally break down imports of Russian gas by month. Appendix Figure C.1 plots the results and highlights that, while Germany continued to import Russian gas through the end of August 2022, these imports were small from June onwards when Russia started weaponizing gas.[37] Using these monthly data, Figure 10 is then computed by subtracting the Russian imports for each month from the observed storage net inflows. Apart from our main argument that Germany would have not exhausted its gas reserves at the end of the 2022/23 heating period, the Figure makes another important point, namely that gas storages are also not exhausted at any other point in time after April 2022. Put differently, the combination of gas imports from other countries and pre-existing storage would have been sufficient to satisfy both industrial and household gas demand at any point in time.

In particular, contrary to the arguments of some skeptics, there was never a danger of a gas shortage immediately following an April gas cut-off. One important reason for this result is the well-known seasonality of gas demand, i.e. that gas demand is much lower in the summer. An April cut-off would have coincided with the end of the 2021/22 heating period and thus the start of the low-demand summer period meaning that even relatively low levels of pre-existing storage would have been enough to prevent shortages and rationing. That the seasonality of gas demand means that there would be no immediate gas shortages even with a cold turkey import stop was an important argument in our March 2022 paper.[38]

Although we focus on outcomes in Germany, our counterfactual scenario considers a cut-off from Russian gas for the European Union as a whole rather than just Germany. Because the

[35] This mechanisms, additional demand reduction, would have likely been a particularly powerful force towards higher storage levels. This is because German gas storages are small relative to typical gas demand: maximum gas storage capacity is 246 TWh which is only about a quarter of annual gas consumption of around 1000 TWh (Bachmann et al, 2022b). Thus even an additional demand reduction of only 2% would have reduced demand by 20 TWh and would have increased the storage filling level at the end of the winter from 60 TWh or 25% to 80 TWh or 33%.

[36] See for example Rashed and Carreño (2022), or LaRocco (2022).

[37] Thus, the skeptics' argument that the additional five months from April to August, during which Germany continued to import and stockpile Russian gas, were decisive for getting the country through the following winter is really an argument about two months alone, April and May.

[38] Of course, an earlier import stop would likely have moved gas prices by more and/or earlier. This would have likely resulted in higher economic costs. On the flip side, it would have also resulted in larger demand reduction as already discussed.

European gas market is complex and heavily interconnected, we therefore take into account not only direct imports to Germany from Russia (via the Nord Stream 1 pipeline) but also indirect imports via third countries (e.g. flows via Ukraine Transit and Czechia or Austria to Germany) as well as re-exports. See the appendix for a detailed explanation of the methodology. Thus our series for imports from Russia includes only the gas that actually entered and was consumed or stored in Germany and is therefore “missing” in the event of an earlier import stop. Our counterfactual scenario then subtracts these missing imports from total net inflows into German storages. Note that the subtracted missing imports do not include Russian gas that used to be re-exported to third countries because doing so would overstate the gas shortfall by effectively assuming that, after 1 April, Germany would have just re-exported the same amount of gas as if nothing had happened despite being cut off from Russian gas. The appendix contains details and discusses a number of additional considerations.

5. The role of luck

In any year gas supply and gas demand are driven by numerous exogenous factors whose unpredictable realization can noticeably ease or tighten the supply-demand balance. The most important factor is the weather (section 5.1), but also (typically negative) global supply shocks such as accidents, strikes and conflicts (section 5.2) as well as global demand shocks (section 5.3) can affect the availability of LNG that played an important role in displacing Russian gas in 2022.

5.1. Was the 2022/23 winter particularly warm?

Heating demand and hence ambient temperature is a main driver of gas demand in Germany. If on one cold day the average temperature falls by one degree Celsius, total gas consumption in Germany increases by about 165 GWh of daily consumption on a typical winter day for a two degrees fall in temperature consumption increases by about 330 GWh. I.e. if it is around 0°C a 1°C change corresponds to 6-7% of gas demand. Most of this temperature-sensitivity of demand is due to small and household consumers.[39]

At a very basic level, the average winter temperature for Germany in the 2022/23 winter of 2.9°C was actually slightly colder than the average temperature over the four previous winters of 3.0°C (Deutscher Wetterdienst Climate Data Center, 2023). So how can we make different years comparable: To account for the fact that when it is already warm outside, heating demand does not change much if temperatures change (e.g., from 20°C to 21°C daily average) energy economists like to use heating-degree-days (HDD). HDDs are a measure of the severity of the cold (specifically how much the outside temperature is below 18°C) and hence the need for heating over a specific time period. Figure 11 shows that monthly heating-degree days are almost perfectly correlated with monthly gas consumption.

[39] About 120 GWh higher demand per degree alone comes from small consumers in Germany on average.

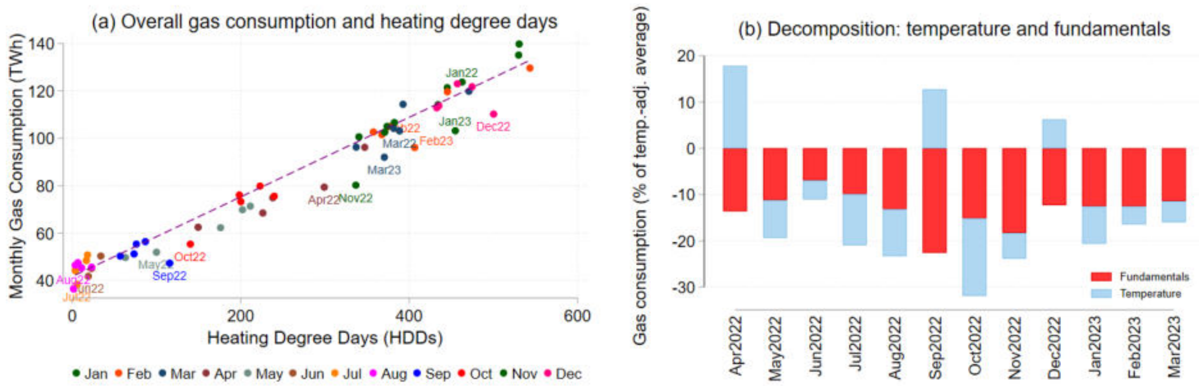

Figure 11: Temperature-adjusted gas consumption

Notes: Gas consumption data is from BNetzA. Data on heating degree days (HDDs) is from Eurostat (database code nrg_chdd_a). HDDs are a measure of the severity of the cold, specifically how much the outside temperature is below 18°C, and hence the need for heating. In Panel a, the line is fitted using data up to March 2022. In Panel b, the reduction in gas consumption compared to the pre 2022 average is decomposed into two parts. The term 'fundamental' represents the difference between actual gas consumption and its predicted value from the fitted line, while the remainder is called 'temperature'.

The figure also shows that since the Russian invasion of Ukraine (i.e. from March 2022), all monthly gas consumption has fallen below the linear trend that indicates the expected gas consumption for a month's heating degree days. For example, December 2022 was particularly cold and showed a high number of 500 heating degree days (in the previous five years, December had between 433 and 475 HDDs) that would normally imply 123 TWh of gas consumption. However, despite these cold temperatures, in December 2022 Germans consumed only 107 TWh.

Overall the year 2022 had 2736 heating degree days in Germany. This can be compared to three different baselines. Comparing it to the previous year 2021 - that with 3176 HDDs was the coldest year since 2013 - makes 2022 look like a warm year. But the outlier was actually 2021. Even the average of the previous decade of 2933 HDDs is not an actual measure of the number of HDDs that would have been expected for 2022. The reason is climate change. Using data since 1979, Appendix Figure C.1 shows that on average the number of HDDs declines by about 14 HDDs every year. Along this long-term trendline, the expected number of HDDs in 2022 was about 2850. With 2736 HDDs, the year 2022 had only 114 fewer HDDs (the year was slightly less cold as measured by HDDs). Converting these 114 HDDs into gas consumption using the correlation in Figure 11, implies a reduction in gas consumption of only 18 TWh or 1.8% of average consumption. Hence, also measured by heating degree days and the implied gas demand, Germany was not particularly lucky.[40]

[40] On the flip side, it is true that Germany was also not particularly unlucky. For example, a 2021-type very cold winter would have increased gas consumption by about 61 TWh.

A baseline year with 2850 HDDs would have implied a gas demand of 996 TWh. Compared to that, German 2022 consumption of 854 TWh implied a demand reduction of 142 TWh. Hence the 18 TWh saving from slightly milder temperatures accounted for less than 13% of the savings. These calculations confirm results by Ruhnau et al (2023) who find that substantial savings happened even after controlling for temperature effects.

And it has to be noted, that relatively warmer temperatures in October/November 2022 did contribute disproportionately little to getting Germany through the winter. The reason is that the warmer temperatures (smaller number of heating degree days) partly occurred at a time when the storages were virtually full after mid-October 2022. Hence, the higher temperatures in October/November resulted in lower gas prices that led to reduced imports and increased consumption -but not in better preparing for the winter.

5.2. Shortfalls in electricity generation prevented fuel switching

Different energy commodities show strong interaction. This is particularly true for natural gas and electricity. The two are direct substitutes for producing heat and a significant share of electricity is produced from natural gas. Their demand has many common drivers like weather and economic activity. Moreover gas and electricity demand and prices interact indirectly through other commodity markets, especially those for emission allowances and coal. Most importantly, even though gas-fired power plants are a relatively expensive and inefficient way of producing electricity, there are many hours each day during which electricity production relies on natural gas simply because cheaper options alone are insufficient to meet demand. Notably, because one needs about two megawatt-hours (MWh) of gas to produce one MWh of electricity the marginal cost and hence the hourly wholesale electricity price per MWh in these hours is about twice the gas price per MWh. Accordingly, developments in the gas market (EU: 3700 TWh, Germany:1000 TWh) spill over into the wholesale electricity market (EU: 2500 TWh, Germany: 500 TWh) that has roughly the same annual turnover.

This high degree of interaction has two relevant implications: First, the gas shock is mitigated as some of the gas savings are achieved through electricity savings or using different fuels to produce electricity (oil). Second, high gas prices have a very strong impact on electricity prices.

In 2022, however, special conditions in electricity markets meant that the first effect did not actually contribute to mitigating the gas crisis. Maintenance issues at French reactors meant that French nuclear generation in 2022 was 82 TWh (or 22%) below the already low 2021 values. Moreover, the long-planned shutdown of three German reactors at the end of 2021 reduced power generation by 32 TWh and a drought reduced hydro-generation in the European Union by 82 TWh compared to 2021. Reduced nuclear and hydro generation in 2022 meant that the EU lacked about 180 TWh (7%) of its low-cost electricity supplies (see Figure 12). Replacing this electricity-production shortfall with gas-fired generation - which is often the marginal fuel in the northwest European power market – would have required burning about 360 TWh more natural gas in power plants.[41] As a result, the European electricity system, that would normally have served as a substantial buffer to gas supply issues by switching to using more coal and reducing electricity demand, was already extremely stretched because of its very own problems. As a result, despite the largest gas crisis in recent history, Europe actually increased gas consumption in the power sector slightly from 432 TWh to 436 TWh instead of decreasing it as predicted by economic theory. These elements of "bad luck" also explain the very small contribution of power generation to demand reduction in Germany in Table 2.

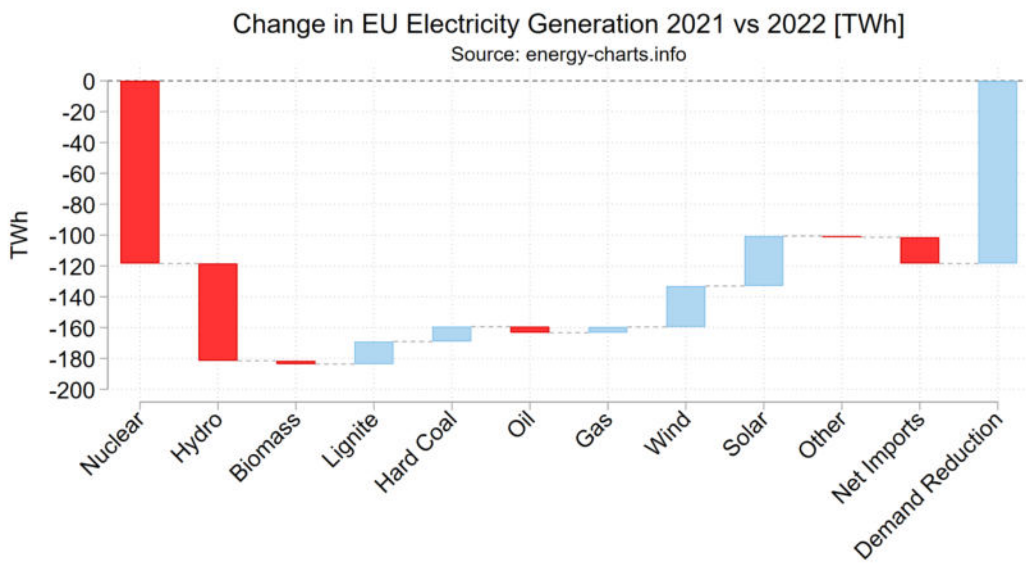

Figure 12: Reduced ability of the electricity system to alleviate the gas-scarcity

Notes: Data are from energy-charts.info based on Entso-E.

5.3. The role of LNG

The degree to which the global LNG balance in 2022 was favorable to Europe is a difficult question, as exogenous and endogenous factors overlap. It is clear that massive EU LNG imports induced higher global LNG prices and hence triggered supply-extension and demand-reduction in other markets. But the degree to which lower Asian gas demand in 2022 was driven by unexpected local factors (e.g., slower than expected post-Covid recovery) and to which degree it was a reaction to very high LNG prices is hard to pin-down in retrospect.[42]

Moreover, in June 2022, the Freeport LNG plant in the U.S., the fourth-largest LNG liquefaction plant in the world, was put out of action by a fire and only re-started loading cargoes in

[41] As gas-fired power plants have an efficiency of about 50% in transforming the heating energy of natural gas into electric energy, it takes about 400 TWh of gas to produce about 200 TWh of electricity.
[42] Asian LNG imports decreased from 1640 TWh to 1330 TWh - whereby China alone reduced by 210 bcm according to https://giignl.org/wp-content/uploads/2023/07/GIIGNL-2023-Annual-Report-July20.pdf.

mid-February 2023. It would have been able to liquify more than 100 TWh of US natural gas, had it not been dysfunctional.[43]

In conclusion, the "bad luck" elements actually exceeded the "good luck" ones over the last year. The role of "good luck" in getting Germany through the winter has been considerably overstated in the popular debate.

6. Political economy of decision making in times of crisis

Some of the most important lessons from the Great German Gas debate relate to the political economy of decision making in times of crisis. While some of these lessons are linked to specific features of the German "corporatist" model of close coordination between government, business associations, and trade unions, others likely extend beyond the narrow German context and are important to be reflected upon. In particular, the tensions between China and Taiwan could well lead to comparable developments where policy-makers might have to navigate similar trade-offs between business interests and foreign policy objectives. In the German case, the most important insights have to do with the outsized role of business leaders and their associations in times of acute crisis. One does not have to agree with Adam Smith's famous quip that congregations of business men often end in a "conspiracy against the public"[44] to conclude from the recent experience that geopolitical dynamics can bring specific incentive problems for profit-maximizing business leaders.

When the discussion about Germany's vulnerabilities began after the Russian invasion, policy-makers did not turn to academics, but to business leaders and their associations for advice. The key interlocutors were representatives of the most affected industries such as the energy and chemicals sectors, refineries and other industrial companies. This was primarily due to policy-makers' concern to understand the practical implications of a cut-off from Russian gas and what this would mean for operations "on the ground."

While understandable, this also meant that the very industries that had made large commercial bets on Russian gas became the main interlocutors, thereby blurring commercial interests and political influence once again. Business leaders had a clear incentive to talk up the dependence on Russian gas in their interaction with policy-makers in Berlin, thereby making a stronger political and military reaction by the German government less likely and indirectly increasing the chances of continued access to cheap Russian gas for their companies. Most CEOs and leaders of industry associations were outspoken that the consequences of a cut-off from Russian gas would be catastrophic. The feedback was that the dependence was extremely high and that in the short run no alternatives existed so that production cuts coupled with "cascading effects" down the production chain would be inevitable consequences of a gas cut-off. Union

[43] Freeport has a liquefaction capacity of about 20 bcm per year - hence more than 100 TWh in the 8 months of its dysfunctionality.
[44] The Wealth of Nations, Book I, Chapter X.

representatives, mainly concerned with potential job losses, were quick to support the position of business leaders.

The CEO of the German chemicals giant BASF, Martin Brudermüller, became a particularly vocal advocate of the dependency camp, predicting that a cut-off from Russian gas “could bring the German economy into its worst crisis since the end of World War II and destroy our prosperity” and asking “Do we knowingly want to destroy our entire economy?” (Frankfurter Allgemeine Zeitung, 2022).

Yet in some cases the very same businesses whose CEOs had denied any short-run possibility of gas savings or substitution announced substantial reductions in gas usage only a few weeks later, or found substitution possibilities of the very kind that had been discussed in the public debate. For instance, having warned of a shut down of its huge plant in Ludwigshafen, chemical giant BASF announced soon thereafter that its “Verbund system” would also be able to run with half the usual gas supplies and that gas-intensive ammonia production could be transferred to a BASF plant in the U.S. and imported from there.[45]

To what extent these early statements shaped Germany’s initial hesitancy to supply Ukraine with more advanced weapons quickly is a question that future historians will have to address. But it is worth highlighting that neither economic arguments on demand responses to price increases and substitution possibilities, nor empirical studies from previous interruptions of energy supplies in other countries carried enough weight to be a counterweight to the “real world knowledge” of business leaders as conflicted as they might have been. Both theoretical and empirical reasoning of economists was deemed much less relevant than the judgment of company CEOs,[46] a major reason likely being the potential political costs of going against the explicit advice of company and union leaders.

A second important lesson relates to the strategic use of think-tanks associated with business and union interests to increase the uncertainty of cost estimates.[47] In practice, individual industry and union lobbies would pay for additional studies that arrived at high cost estimates using extreme assumptions. Figure 13 contrasts the prediction of some of these studies to a May 2022 survey of academic economists about the likely effects of a Russian gas cut-off. Although the bulk of responses of academic economists were clustered in a reasonably narrow

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[45] While BASF had been publicly stating that half of its normal gas supplies would be sufficient as early as March 2022, one particularly clear version is an investor conference call presentation from July 2022 stating “Continued operation at Ludwigshafen site is ensured down to 50% of BASF’s maximum natural gas demand” (BASF, 2022, and case 18 in Appendix E). For ammonia substitution via imports, see Section 2.3 and cases 2 and 15 in Appendix E.

[46] After criticizing the use of “irresponsible use of mathematical models” on the Anne Will TV show (see introduction), chancellor Scholz added “I don’t know absolutely anyone in business who doesn’t know for sure that [entire branches of industry shutting down in the event of a gas cut-off] would be the consequences.” See the transcript and English translation available at https://benjaminmoll.com/Scholz/.

[47] Banerjee and Duflo (2019) warn against the role of “economists” representing special interests in the public debate. Two special-interest-financed think tanks stand out in Germany: the “Institut der deutschen Wirtschaft” (IW) which is financed by various industrial lobbies and the “Institut für Makroökonomie und Konjunkturforschung” (IMK) which is largely financed by the German trade union federation DGB.

range up to 5% of GDP, the studies financed by special interest groups produced much larger numbers of up to 12.7% of lost output.[48]

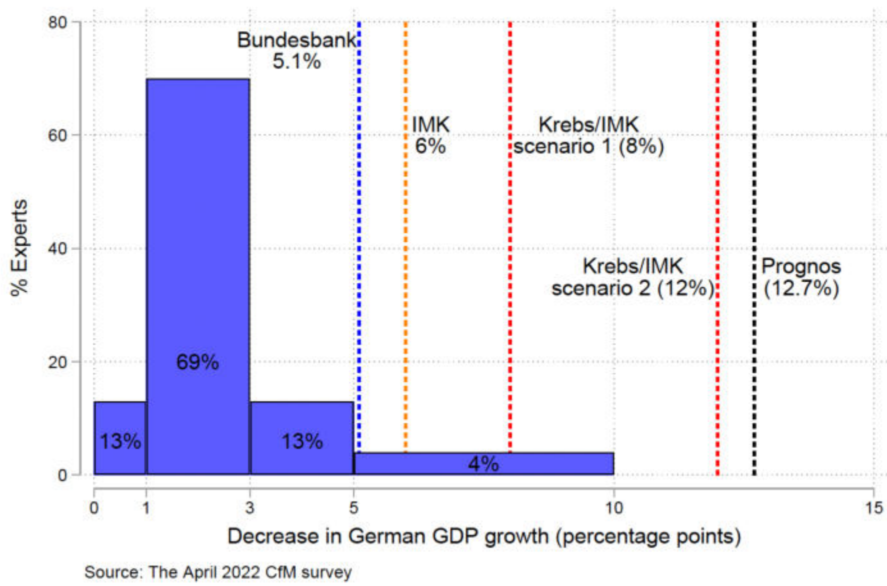

Figure 13: Studies financed by special interest groups predicted much larger GDP losses than academic economists

Notes: the blue histogram represents the answers by European academic economists to question 2 in the April 2022 CFM survey "By how much would an immediate EU-wide import ban on Russian gas reduce German GDP growth per annum in 2022-3, in percentage points (pp), if the government offset the costs with a well-targeted fiscal policy?" The dashed lines plot the estimates by Bundesbank (2022), IMK (2022), Krebs (2022) and Prognos (2022). For context, IMK is a union-financed think tank, the Krebs study was paid for by the German trade union federation DGB, and the Prognos study was paid for by a business association.

While the economic debate focused on the content of these studies and the underlying extreme assumptions, their political goal was a different one. By substantially broadening the range of potential cost estimates of a cut-off from Russian gas, they undermined public confidence in the reliability of any cost estimate and increased uncertainty about the consequences in the eye of the public. The impression remained that even experts could not agree about this matter so that the prudent thing was to conclude that we simply cannot know how bad things can possibly get – reinforcing the approach taken by policy makers. Given that uncertainty about economic estimates was so large they could be dismissed altogether and other sources of information – such as contacts with company leaders – could be considered reliable.

[48] For reference the figure also plots the largest cost estimate not financed by a special interest group, a 5.1% GDP drop predicted by Bundesbank (2022). It is worth pointing out that Bundesbank cost estimates significantly exceeded those of other comparable institutions. For example, three IMF studies (Sher et al., 2022; Pescatori et al., 2022; and Di Bella et al., 2022) predicted more moderate economic losses of up to 3% of GDP.

Ultimately, the main effect of these academically questionable studies that arrived at extremely high economic costs was to create the impression of uncertainty, allowing policy makers to dismiss academic advice as too uncertain. A good example for this is captured in the following quote by Jörg Kukies, the Head of the Economics Division in the Chancellor Office in Berlin: “We will never ever be able to determine whether this has a 2% or 10% GDP impact. [...] "We are simply trying to take the pragmatic middle course because we do not know and cannot know [what the effect would be of] such an abrupt termination.”[49]

7. Conclusion

It was primarily the economy’s ability to adapt in combination with the insurance offered by trade and (some) good economic policy making that blunted Putin’s energy weapon: as prices rose, German producers and households reduced demand and substituted away from natural gas, the country quickly sourced alternative gas supplies, and policy makers implemented well-designed policies to support households and firms that maintained price signals to encourage gas to go to the sectors and countries where it was most needed.

The main rationale for sanctioning Russian energy exports has always been simple, namely that these exports represent an important source of fiscal revenues for the Russian state, money that is then used to wage war in Ukraine. As Oleg Itskhoki has put it: “each marginal euro received [by Russia] from energy exports to Europe contributes exactly one euro to the war, as simple as that”.[50]

Despite this clear rationale for sanctioning Russian energy exports, Western countries opted for a cautious approach and such sanctions did not begin in earnest until the EU crude oil embargo took effect in December 2022, i.e. almost ten months after the start of the war. Sanctions on gas exports have still, to this day, been absent from any sanctions packages. This delayed and cautious implementation of energy sanctions contributed to Russia earning record export revenues in 2022 and likely to its ability to wage war in Ukraine. For example, Babina et al. (2023) argue that, even though the EU oil embargo, only came in effect in December 2022, it has already materially affected Russian export revenues and, furthermore, that an earlier introduction of the EU oil embargo and/or G7 price cap in the immediate aftermath of the invasion could have reduced Russia’s oil export earnings by up to $50 billion or about one third.

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[49] See the speech by Kukies (2022) on 4 May 2022 at minute 8:55 and 10:13. The original German is “Wir werden es nie und nimmer entscheiden können, ob das jetzt 2% oder 10% BIP-Einfluss hat.” “Wir versuchen einfach den pragmatischen Mittelweg zu gehen, weil wir nicht wissen und nicht wissen können [was der Effekt ist] bei einem so abrupten Abbruch.”

[50] Oleg Itskhoki on Twitter on 8 April 2022 https://twitter.com/itskhoki/status/1512508687641763844?s=20. A particularly good exposition of the case for energy sanctions is by Guriev and Itskhoki (2022). Opponents of the energy embargo idea have often argued that Russian war expenditures would be unaffected because the Russian government can print its own money and therefore does not need to rely on export revenues. A good rebuttal of this argument is due to Hanno Lustig: “Suppose we did a helicopter drop of dollars in Red Square in Moscow. If no one bothers to pick them up, then export curbs are irrelevant. Not a likely outcome.” (Hanno Lustig on Twitter on 4 June 2022 https://twitter.com/HannoLustig/status/1533000546659012608?s=20)

Naturally, just like Germany substituted and adapted in the face of the gas cut-off, Russia has also been substituting and adapting in the face of Western sanctions. The power of substitution cuts both ways. However, the Russian government's strong reliance on fiscal revenues from energy exports does mean that the situation is asymmetric and that export sanctions likely bite.[51] One manifestation of declining export revenues due to energy sanctions has been the ruble's depreciation throughout the spring and summer of 2023 (Itskhoki and Mukhin, 2022; Lorenzoni and Werning, 2022). This has already forced hard choices on Russian policymakers with the central bank recently implementing significant interest rate hikes (Guriev, 2023).

Keeping Russia's natural gas exports out of the sanctions regime generates substantial revenues for the Russian state – some €200 million per week (Centre for Research on Energy and Clean Air, 2023). Not sanctioning the financial institutions used for the corresponding payments, specifically Gazprombank, is similarly problematic. Apart from the unsanctioned gas exports contributing to Russia's war effort, Europe effectively allowed Russia to decide on the price and volume of these exports to individual destination countries, thereby creating divisions between countries that still receive Russian gas via pipeline (e.g., Austria and Hungary) or LNG (e.g. Spain) and those that do not. As Europe will use natural gas for at least two decades and Russia's gas export infrastructure to Europe is still very potent, Europe should consider taking advantage of the historically low flows to establish joint political control over gas flows from Russia rather than buying cheaply produced gas at high prices.

The failure by Western countries to implement sanctions sooner and more decisively represents a major missed opportunity to stand up to Putin and help avert enormous human suffering in Ukraine. There are good arguments that the west should tighten its sanctions regime against Russia, including on natural gas and oil, and avoid making the same mistakes in future similar crises.

[51] In the words of former U.S. Senator John McCain: "Russia is a gas station masquerading as a country. It's kleptocracy. It's corruption. It's a nation that's really only dependent upon oil and gas for their economy, and so economic sanctions are important."

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Online Appendix for "The Power of Substitution: The Great German Gas Debate in Retrospect"

Benjamin Moll, Moritz Schularick, Georg Zachmann

Appendix A: Second-order approximation of aggregate production function (1)

Bachmann et al. (2022a) show that a second-order approximation of the CES production function (1) around $(\bar{G}, \bar{X})$ is

$$\Delta \log Y \approx \tilde{\alpha} \times \Delta \log G + \frac{1}{2}\left(1 - \frac{1}{\sigma}\right)\tilde{\alpha}\left(1 - \tilde{\alpha}\right) \times (\Delta \log G)^2,$$

where $\tilde{\alpha} := \frac{\alpha^{\frac{1}{\sigma}}\bar{G}^{\frac{\sigma-1}{\sigma}}}{\alpha^{\frac{1}{\sigma}}\bar{G}^{\frac{\sigma-1}{\sigma}} + (1-\alpha)^{\frac{1}{\sigma}}\bar{X}^{\frac{\sigma-1}{\sigma}}}$ is a constant. Denoting the prices of gas and the other input by p_G and p_X and the price of the final good by $P = \left(\alpha p_E^{\,1-\sigma} + (1 - \alpha) p_X^{\,1-\sigma}\right)^{\frac{1}{1-\sigma}}$ so that $\left(p_G G\right)/(PY)$ is the gas expenditure share, we have

$$\Delta \log Y \approx \frac{p_G G}{PY} \times \Delta \log G + \frac{1}{2} \times \Delta\left(\frac{p_G G}{PY}\right) \times \Delta \log G,$$

where we have used that the expenditure share equals $\frac{p_G G}{PY} = \tilde{\alpha}$ and that the change in the expenditure share equals $\Delta\left(\frac{p_G G}{PY}\right) \approx \left(1 - \frac{1}{\sigma}\right)\left(1 - \tilde{\alpha}\right)\Delta \log G$. Thus the change in the gas expenditure share $\Delta\left(\frac{p_G G}{PY}\right)$ becomes a sufficient statistic for the key parameters that matter for output losses including the elasticity of substitution σ.

Appendix B: Supplement to section 3

B.1 German imports of Russian gas taking into account indirect flows

We consider monthly natural gas imports and exports to Germany by aggregating data from the ENTSO-G transparency platform API. This allows us to calculate net imports. We use the *Bruegel Dataset on Gas Attribution by EU Country* to attribute a share of this gas to Russia. This allows us to take into account that the European gas market is complex and heavily interconnected, in particular that a country like Germany both imports gas via third countries (e.g. flows of Russian gas through Ukraine Transit which pass through Austria or Czechia) and re-exports part of its direct imports, and to compute the amount of Russian gas that effectively ends up in Germany (either ending up in German storages or being consumed by German households and firms). This is the series used in figure 4 as well as various other figures.

Bruegel Dataset on Gas Attribution by EU Country

The European gas market is complex and heavily interconnected. Foreign gas enters the market through pipelines or LNG terminals. This gas then continues its journey through

European pipelines, often crossing multiple international borders, before being dispersed into city centres and industrial clusters. With gas crossing multiple borders, tracking the true origin is complicated. We consider all gas flows into and across Europe. By doing so, we can apply a version of Wassily Leontief's Nobel prize winning input-output matrix, using the average share of gas in each country to attribute proportions to origin countries.[52] In this way we split gas imports by Russia (Nord Stream, Yamal, Ukraine Transit, Turkstream, Other), Norway, Azerbaijan, North Africa, Domestic production in the United Kingdom, the Netherlands, or elsewhere, and LNG according to source country.

The main dataset used is the ENTSO-G transparency platform. We queried all points both within and entering the EU's gas market. Manual validation was necessary to remove redundant points due to duplication of direction (i.e., when both imports and exports of the same gas are reported), duplicates by operator (i.e., where the same gas is reported by multiple operators and aggregators), duplicates by point (i.e., when points are duplicated, such as through VIPs). We compared the resulting dataset to a range of sources including the IEA, Eurostat, ACER, and in the German case, BNetzA. Our data are broadly consistent across these sources – although discrepancies among the range of sources are noted.

We take LNG data from the Bloomberg terminal. Bloomberg's ship tracking shows the origin of ships which arrive in LNG ports. We combine this monthly proportionally with the LNG send-out recorded from each terminal on the ENTSO-G platform.

Net imports from Russia taking into account indirect flows

Finally, we use the *Bruegel Dataset on Gas Attribution by EU Country* to attribute a share of imported gas to Russia to arrive at our series for effective imports from Russia taking into account indirect flows.

B.2 Change in German natural gas balances compared to 2019-21 average (Figure 4)

Figure 4 compares German natural gas balances for the period July 2022 to March 2023 to the average for the respective months across the period 2019 to 2021.

Eurostat trade data are used to compute the change in net imports to Germany for the period July 2022 to March 2023 compared to the average for these months in the period 2019 to 2021. The series for gas imports from Russia and from third countries takes into account indirect flows within Europe using the Leontief methodology explained in Appendix B.1. The computation of the flows for the period July 2022 to March 2023 follows the exact methodology described there. The computation of the flows for the 2019-21 baseline period (the denominator in the percentage calculations) uses a variant of this methodology: because the *Bruegel Dataset on Gas Attribution by EU Country* only goes back to 2021 rather than covering the entire period

[52] While assuming Leontief input-output structures with elasticities of substitution equal to zero is generally inappropriate when analyzing production networks (and may have played an important role for analysts overestimating the economic costs of a gas import stop), this strategy is likely more appropriate for analyzing a fixed physical pipeline network, at least in the short run.

2019-21, we instead assess the attribution for the more recent period July 2021 to March 2022 and apply the resulting input-output matrix to the average trade flows for the 2019-21 baseline period. We do this to retain consistency in the baseline period (July to March in 2019 to 2021) considered throughout the paper.

To compute the demand reduction component, natural gas demand data is taken from the Bruegel Natural Gas Demand Tracker (McWilliams and Zachmann, 2023). Storage data is taken from AGSI. To allow comparison, storage change is calculated as the difference in filling for the period July 1st 2022 to April 1st 2023 compared to average filling for the three years from July 1st 2019 to 1st April 2022.

Appendix Figures B.1 and B.2 provide two alternative versions of Figure 4. Figure B.1 is an extended version of Figure 4 but with imports from third countries broken down by individual source country. Section 3.5 discusses the figure in more detail.

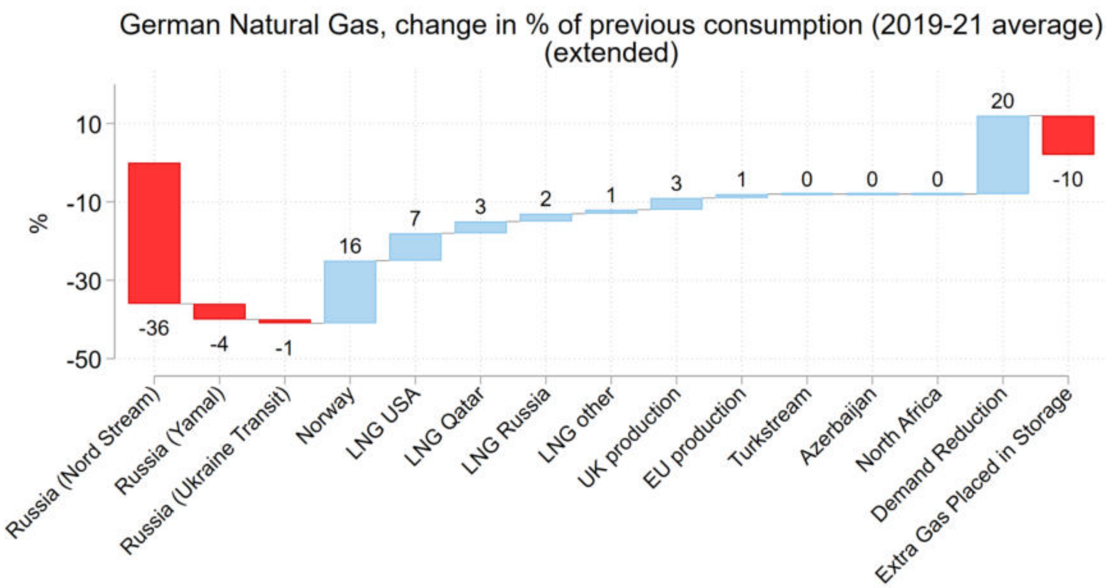


Figure B.1: Version of Figure 4 breaking down gas imports by source country

As already discussed, Figures 4 and B.1 plotted gas flows taking into account indirect imports and re-exports using the *Bruegel Dataset on Gas Attribution by EU Country*. For comparison, Figure B.2 plots the direct gas flows into Germany. One main takeaway from the figure is that the direct flows are often quantitatively larger than the indirect flows. For example, direct imports from Russia dropped by a whopping 81% (55% via the Nord Stream pipeline and 26% via Yamal pipelines). This is because prior to 2022, Germany re-exported a lot of the direct imports from Russia to third countries (say Denmark). However, as also discussed in section 4, focussing on this large drop in direct imports would considerably overstate the cost of the Russian gas cut-off because it would amount to assuming that Germany had just kept re-exporting the missing Russian gas as if nothing had happened. It is therefore more sensible to work with the attributed flows taking into account indirect imports and re-exports in Figures 4 and B.1. Finally, one use of Figure B.2 is that it shows the contribution of the new LNG terminals Germany built on its coast to getting through the 2022/23 winter. Direct imports via these new LNG terminals made a small positive contribution of around 3%. As shown in Figure B.1, LNG imports via third countries were instead considerably more important.

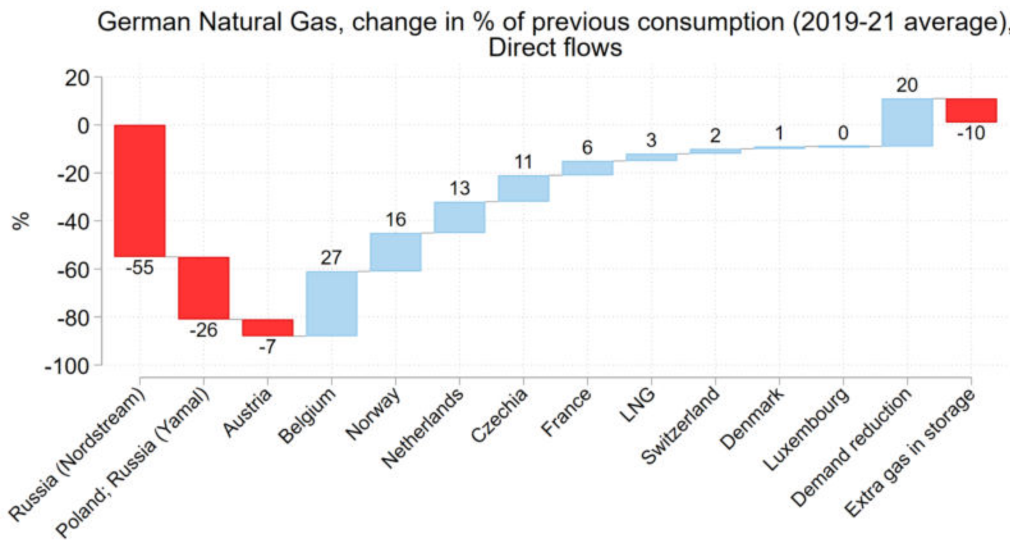


Figure B.2: Version of Figure 4 showing direct gas imports to Germany

B.3 Evolution of gas expenditure share in GNE

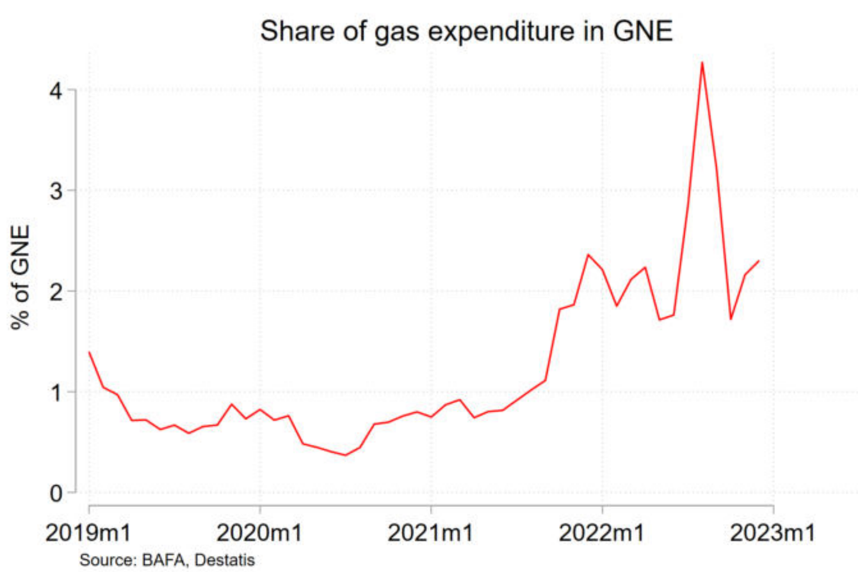


Figure B.3: Gas expenditure share

Notes: the gas expenditure share is calculated as the value of total German gas imports divided by Gross National Expenditure (GNE, the C+I+G in GDP – see section 2.1). The series for the value of gas imports is from the German

Federal Office for Economic Affairs and Export Control (BAFA) available at https://www.bafa.de/DE/Energie/Rohstoffe/Erdgasstatistik/erdgas_node.html. This series was discontinued at the end of 2022. The series for GNE is from table 81000-0020 of the German National Accounts ("Inländische Verwendung" or "Domestic uses" in the English version).

B.4 Temperature-adjusted household gas consumption

Figure B.4 plots temperature-adjusted household gas consumption using the same methodology as in Figure 11 in the main text. The key takeaway is that that demand reduction by households was significant even when controlling for temperature.

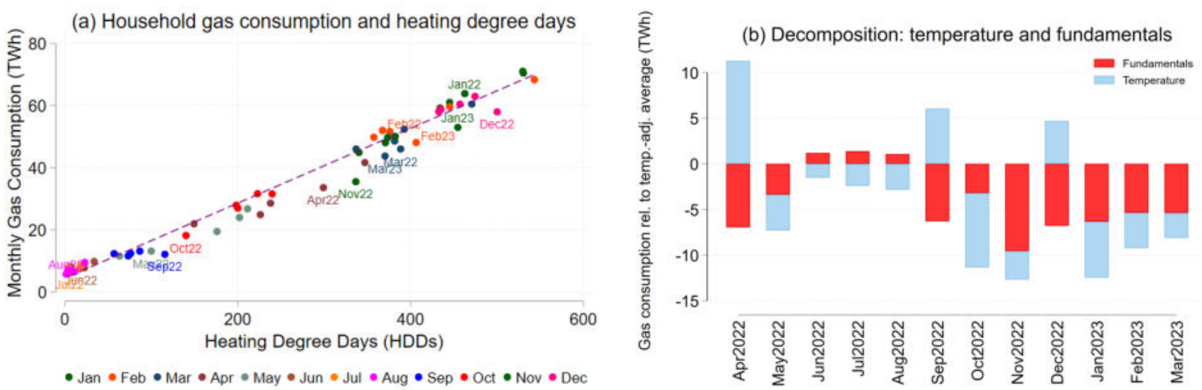


Figure B.4: Temperature-adjusted household gas consumption

Notes: Gas consumption data is from BNetzA. Data on heating degree days (HDD) is from Eurostat (database code nrg_chdd_a). As previously noted, "households" are SLP consumers and therefore include not just households but also some commerce and small businesses. 2023 heating degree days not from Eurostat but extrapolated from temperature data. In Panel a, the line is fitted using data before April 2022. In Panel b, the reduction in gas consumption compared to the pre 2022 average is decomposed into two parts. The term 'fundamental' represents the difference between actual gas consumption and its predicted value from the fitted line, while the remainder is called 'temperature'.

B.5 The 1970s oil shocks were larger than the 2022 gas shock

Panel (a) of Figure 6 plots the since the 1970s of world oil expenditures as a share of world GDP to those on natural gas. Panel (b) repeats the exercise for both Germany and the European Union.

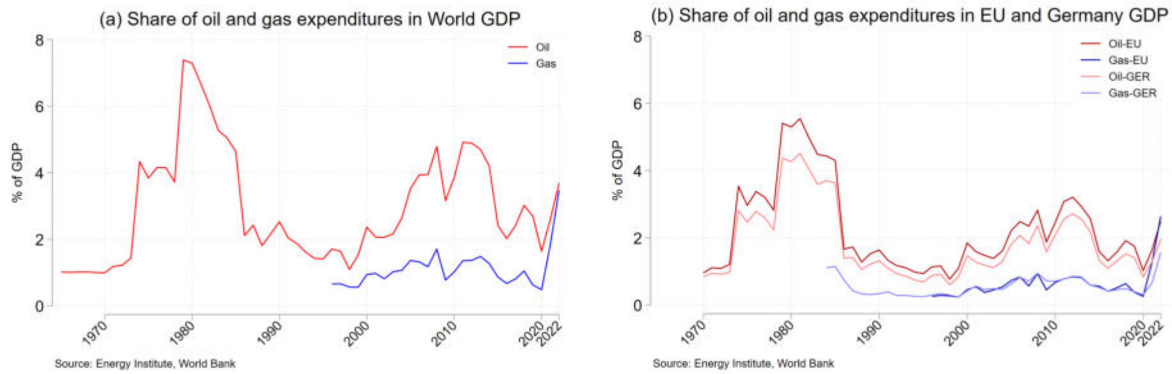


Figure B.5: The 1970s oil shocks were larger than the 2022 gas shock

Notes: Data on oil and gas consumption, as well as their prices, are sourced from the "Statistical Review of World Energy, 2023" published by the Energy Institute. GDP data is obtained from the World Bank.

Appendix C: Supplement to section 4

C.1 Details on construction of German imports of Russian gas after March 2022 and counterfactual storage evolution (Figure 10)

This appendix provides the details for constructing the counterfactual storage evolution series plotted in Figure 10. This series is, in turn, based on a series for German imports of Russian gas after March 2022. This appendix explains how the two series are constructed, starting with the gas imports.

German imports of Russian gas after March 2022

For imports of Russian gas after March 2022, we use the series taking into account indirect flows constructed using the *Bruegel Dataset on Gas Attribution by EU Country*, see Appendix B.1 for a more detailed explanation. Figure C.1 presents the results with the orange solid line plotting net imports (taking into account re-imports and -exports) in each month, and the red solid line plotting cumulative imports since April 1, i.e. the red line is a cumulative version of the orange line.

An important fact highlighted by Figure C.1 is that, while Germany continued to import Russian gas through the end of August 2022, these imports were small from June onwards. This is because Russia started weaponizing gas, substantially cutting deliveries in June in particular through the Nord Stream 1 pipeline which saw deliveries fall to 20% of capacity for much of the summer 2022. Thus, out of the cumulative 100 TWh of gas imported between April and August, 67 TWh were imported in the first two months April and May alone and only about 15 TWh were imported in the last two months before the complete cut-off, July and August.

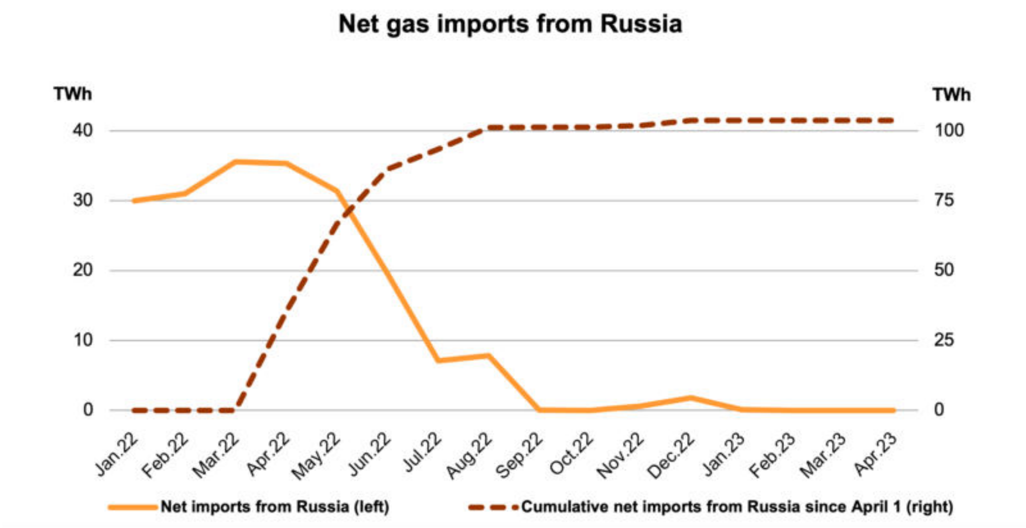


Figure C.1: Net imports of Russian gas after March 2022

Notes: the data source and construction of the figure is described in the text (Appendix C).

Another noteworthy feature of this series is that effective net imports from Russia differ substantially from direct imports via the Nord Stream pipeline. On the one hand, there are substantial onward exports from Germany, i.e., not all of the gas imported via Nord Stream served the German market but some was also re-exported. On the other hand, flows through Ukraine Transit which pass through Austria or Czechia and end in Germany add to the amount of Russian gas ending up in Germany. In practice, re-exports were larger than indirect imports resulting in effective net imports that were smaller than direct imports via the Nord Stream pipeline. For example, in April 2022 effective imports were around 35 TWh whereas direct imports were approximately 50 TWh. This is important because it means that the cumulative amount of Russian gas imported after March 2022 and actually ending up in German storages or being consumed in Germany was lower than measured direct imports.

Counterfactual storage evolution with 1 April 2022 cut-off (Figure 10)

Our scenarios begin with actual gas storage of 66 TWh on 1st April 2022 in Germany. We then plot a hypothetical evolution of German gas storage in a world where no Russian gas imports were received after 1 April 2022. Although we focus on outcomes in Germany, our counterfactual scenario considers a cut-off from Russian gas of the European Union as a whole rather than just Germany. Because the European gas market is complex and heavily interconnected, we therefore take into account indirect flows via third countries. Starting from the actual storage level on 1 April 2022, we calculate the counterfactual evolution by subtracting the effective net imports from Russia (calculated as explained above) from total net imports to Germany. Our analysis identifies from an accounting perspective the Russian gas which entered and was consumed or stored in Germany and which is therefore “missing” in the event of an earlier import stop. Our study thus evaluates the German position assuming relative gas flows and consumption remained unchanged.

Note that, in this counterfactual scenario, we do not subtract re-exports, i.e. gas which enters Germany but is then passed on to neighbouring countries (e.g., France, Austria, Czechia). Subtracting re-exported gas would effectively assume that, in the counterfactual scenario in which Russian gas is cut off on 1 April, Germany would have just kept re-exporting the same total amount of gas as if nothing had happened, thus considerably overstating the amount of missing Russian gas.

To be precise, consider the April 2022 import numbers from the previous section. As noted there, direct imports from Russia were around 50 TWh but Germany re-exported around 15 TWh of this gas so that 35 TWh of Russian gas were actually consumed or stored in Germany. In our counterfactual scenario, when the Russian gas stops flowing on 1 April 2022 and direct imports from Russia drop by 50 TWh, Germany cuts its consumption and storage inflows by 35 TWh and its re-exports by 15 TWh. If we had instead assumed that German net imports would fall by 50 TWh, we would have effectively assumed that Germany would have just kept re-exporting the same 15 TWh as if nothing had happened and would thus overstate the drop in gas available for consumption and storage. We then calculate the counterfactual storage level on 1 May 2022 as follows: starting from the initial storage level on 1 April 2022 of 66 TWh, we add total net imports from all countries minus these 35 TWh of missing Russian gas and then subtract total German domestic consumption.

We isolate the impact on Germany while not considering the impact on neighbouring countries. As discussed in the main text, our estimate is likely a lower bound, as Germany would have been able to increase imports without running out of storage capacity and demand would have likely been lower.

C.2 Additional considerations regarding our counterfactual calculations

One more observation helps put things into perspective. This observation is that the observed cumulative Russian imports after March 2022 of around 100 TWh were small relative to typical annual gas demand and supplies, totaling only around 10% of typical annual consumption. This is important because there is another quantity that is small relative to typical consumption, namely total storage capacity which has a maximum capacity of “only” about a quarter of typical annual consumption (or about the consumption of two winter months).

The observation of storage being small raises the question: how would these limited storage facilities have been sufficient to get Germany through the winter following an earlier 1 April import stop? The answer is “demand reduction”. Because demand is large relative to storage, the sizable demand reduction observed in the data resulted in Germany emerging from the winter with substantial storage levels of 65%.[53] In turn, because the imports from Russia were

---

[53] See also Moll (2022a) who showed that German gas storages are small to typical inflows and outflows and therefore gas demand reduction would be much more important than entering the winter with full gas storages.

small relative to demand, our counterfactual calculation concludes that the loss of these imports would not have led to storages running out and shortages.

While our analysis considers the isolated case of Germany, a remaining question is how the whole European market would have managed with an earlier cut-off from Russian gas. Zooming out, we have therefore also computed a counterfactual scenario analogous to the one in Figure 10 but for the European Union as a whole. This exercise shows that also the EU as a whole exited the winter with more gas remaining in its storages than it imported from Russia after March 2022 and, therefore, would have similarly made it through the winter without this additional Russian gas. While this exercise shows that an earlier cut-off would have been feasible at the aggregate level, it does not speak to the feasibility for individual member countries. Most countries to the west of Germany had lower shares of Russian gas and did have a comparatively easier time adjusting. On the other hand, certain member states such as Hungary (which is supplied via the Turkstream pipeline) and Slovakia (supplied via Ukraine Gas Transit) might have faced more significant difficulties without Russian gas.

Appendix D: The time trend in heating degree days due to climate change

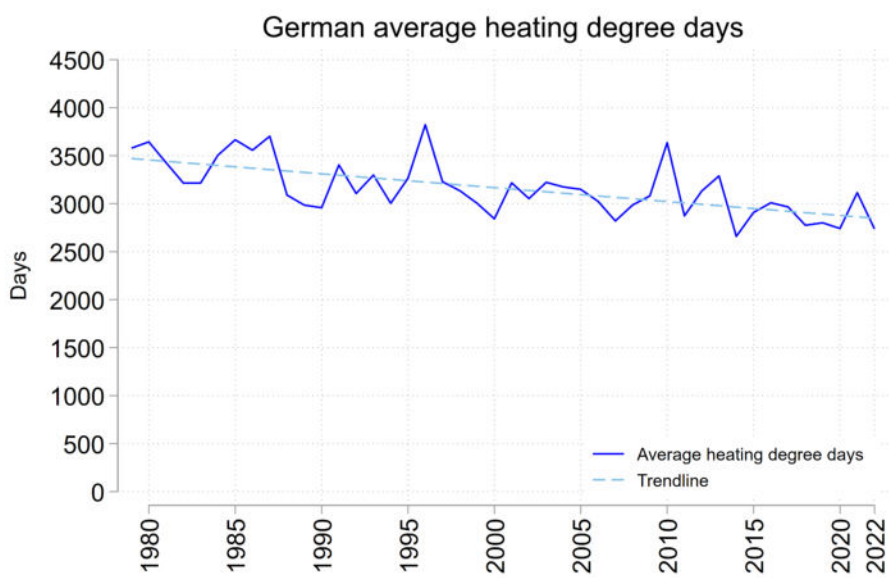


Figure D.1: German average heating degree days 1979 to 2022

Notes: Data from Eurostat (database code nrg_chdd_a).

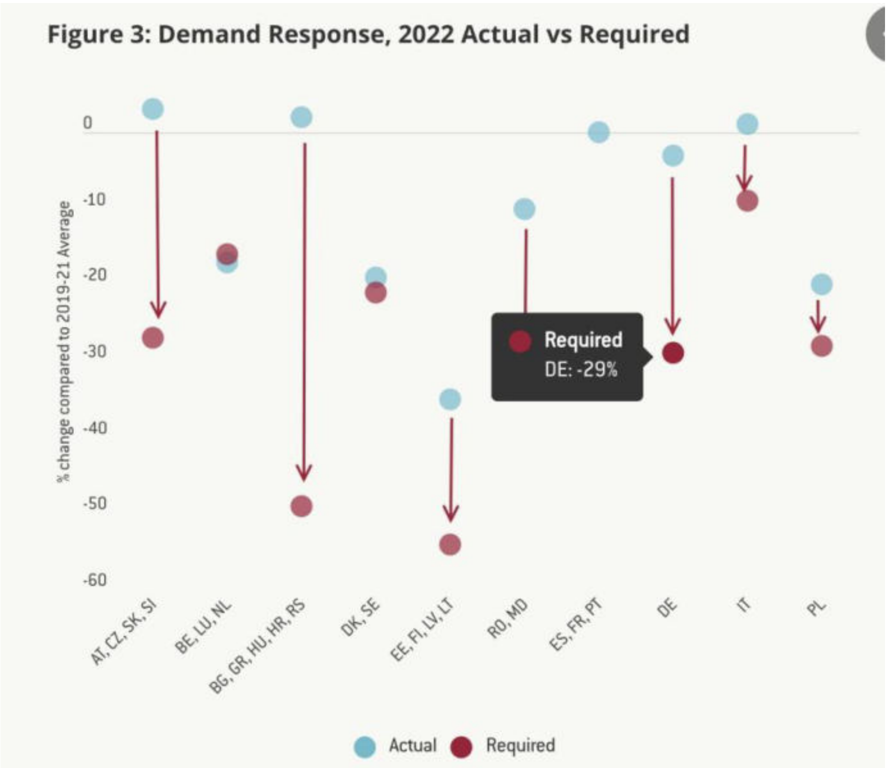
Appendix E: 36 concrete cases of substitution and demand reduction that illustrate how Germany weaned itself off Russian gas

Benjamin Moll, Moritz Schularick and Georg Zachmann

This appendix is a lightly edited version of a twitter thread by Benjamin Moll.[1] The original thread can be found here https://twitter.com/ben_moll/status/1548004135294754817?s=20. When citing these examples, please cite the paper by Moll, Schularick and Zachmann (2023).

Economic theory predicts that, as prices rise, households & firms reduce demand and substitute. We're starting to see more and more such cases I'll collect these here as we go along.

Background: EU countries must cut gas demand by substantial amounts, e.g. Germany by around 29%, to withstand a Russian gas cut-off. Other energy is getting scarcer as well. Where might such demand reduction come from? And how costly will it be?



[1] An example of this light editing: we removed a number of references to other users' twitter handles for better readability.

Guntram Wolff
@GuntramWolff

Bei vollkommen Gas stop aus Russland muss Deutschland seinen Gaskonsum um 29% ab jetzt reduzieren, um leere Speicher zu verhindern.

Translated from German by Google

If Russia completely stops gas, Germany will have to reduce its gas consumption by 29% from now on in order to prevent empty storage facilities.

In our import stop paper we emphasize that it makes a big difference how much substitution occurs. Importantly, this is not just about substitution of gas itself. Downstream substitution of gas-intensive products, e.g. via imports, also does the trick.

Moritz Kuhn
@kuhnmo

"What are the macroeconomic & distributional consequences for Germany of a stop of Russian energy imports?" Our @ECONtribute policy brief provides an answer
@BachmannRudi @DBaqaee @christianbaye13 @kuhnmo @andreasloeschel @ben_moll @APeichl #KarenPittel @MSchularick

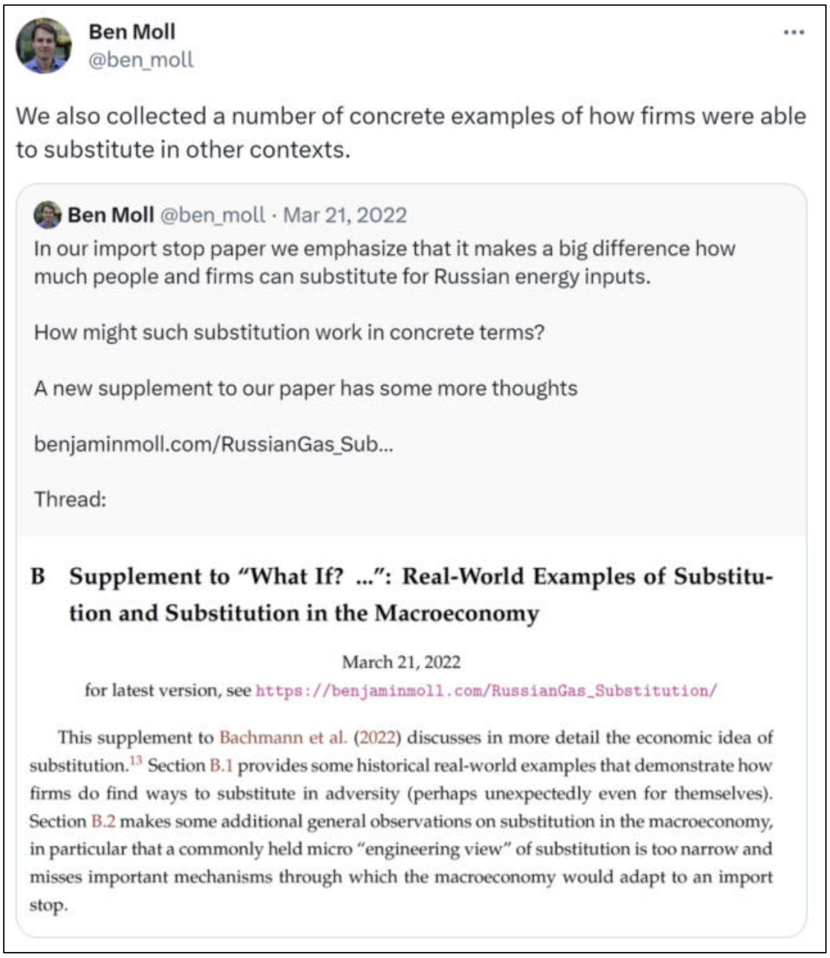
ECONtribute
Policy Brief No. 028

What if? The Economic Effects for Germany of a Stop of Energy Imports from Russia

Rüdiger Bachmann, David Baqaee, Andreas Löschel, Benjamin Moll, Moritz Schularick, Christian Bayer, Andreas Peichl, Moritz Kuhn, Karen Pittel

March 2022 www.econtribute.de

We also collected a number of concrete examples of how firms were able to substitute in other contexts.



Ben Moll
@ben_moll

We also collected a number of concrete examples of how firms were able to substitute in other contexts.

Ben Moll @ben_moll · Mar 21, 2022

In our import stop paper we emphasize that it makes a big difference how much people and firms can substitute for Russian energy inputs.

How might such substitution work in concrete terms?

A new supplement to our paper has some more thoughts

benjaminmoll.com/RussianGas_Sub...

Thread:

B Supplement to "What If? ...": Real-World Examples of Substitution and Substitution in the Macroeconomy

March 21, 2022

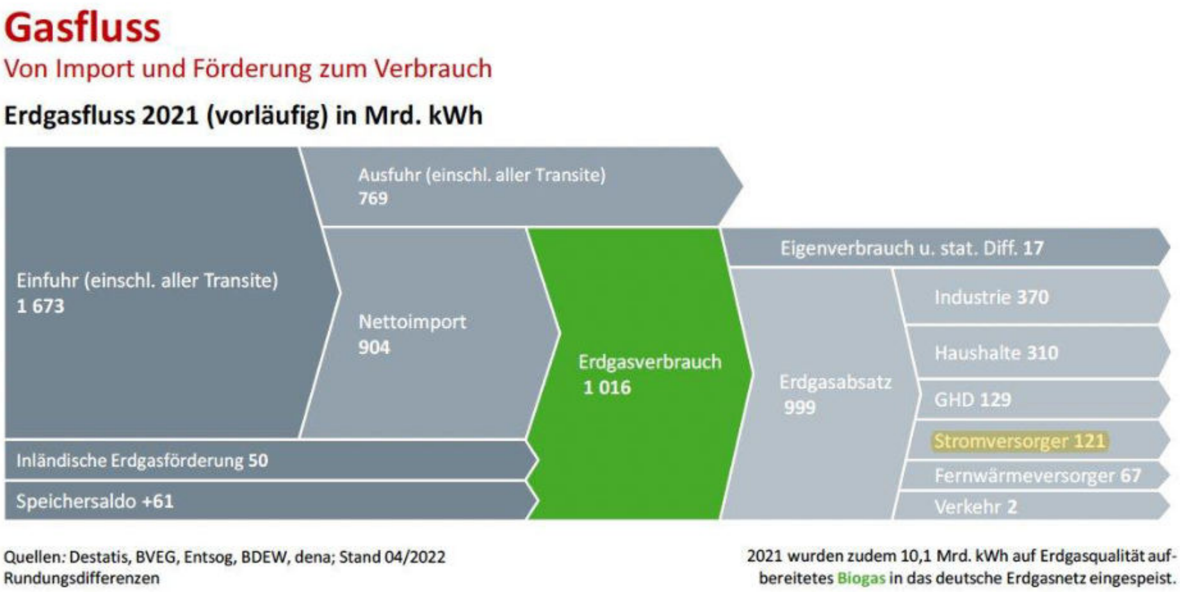
for latest version, see https://benjaminmoll.com/RussianGas_Substitution/

This supplement to Bachmann et al. (2022) discusses in more detail the economic idea of substitution.[13] Section B.1 provides some historical real-world examples that demonstrate how firms do find ways to substitute in adversity (perhaps unexpectedly even for themselves). Section B.2 makes some additional general observations on substitution in the macroeconomy, in particular that a commonly held micro "engineering view" of substitution is too narrow and misses important mechanisms through which the macroeconomy would adapt to an import stop.

Many people, especially industry lobbyists, claimed "substitution is impossible." Remarkably, prices usually weren't mentioned. So it's really "no substitution even when prices skyrocket." Of course, this then conveniently implies that subsidies to industry aren't all that bad 😉. But how much do firms and households actually respond as prices are rising?

Let's get started. How long will the list grow? I'm unsure and curious. If you know of a case of substitution that's not part of this thread, please send it my way.

0. (= actually one where everyone agrees) Substitution of gas in electricity generation: switching on coal-fired power plants. This is big, e.g. in Germany electricity accounts for ~12% of gas consumption. EU countries are now preparing this. But this should have happened long ago!



1. Screw manufacturer Würth is converting some of the ovens it uses to make screws from gas to electricity. (Frankfurter Allgemeine Zeitung,2022a[2]). This could take up to a year. Philip Jung is furious: if Würth had started doing this in March, the ovens may have been just about ready by late winter. Now they will likely be ready too late. There should have been less lobbying and more substituting.

Philip Jung
@makro_philip

Also Umrüstung von Gas auf Strom bei Schrauben geht jetzt doch in 12 Monaten... Deswegen wollten wir im März anfangen...und nicht jetzt, aber Industrie musste erstmal 5 Monate Lobbying betreiben. Umrüsten auf Strom heisst übrigens, dass wir dann mehr Strom verbrauchen Herr Habeck!

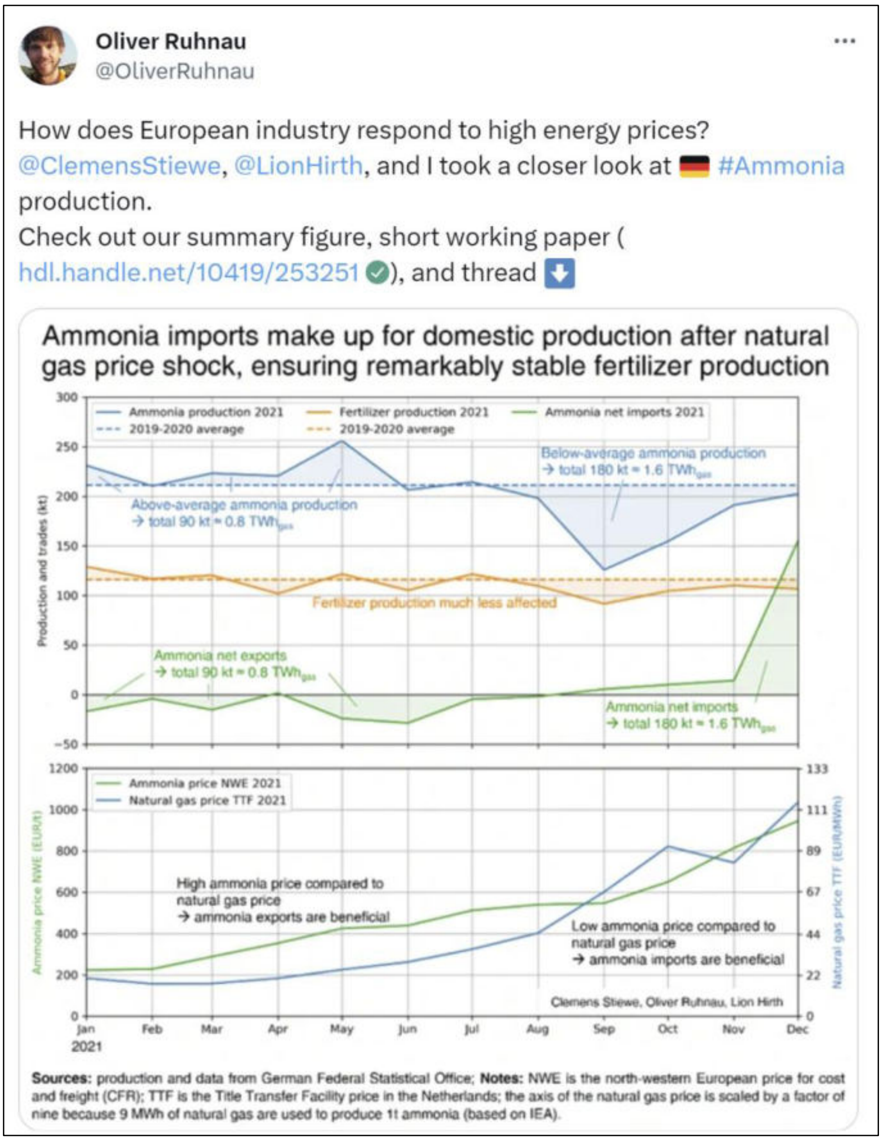
Translated from German by Google

So converting from gas to electricity for screws can now be done in 12 months... That's why we wanted to start in March... and not now, but the industry had to lobby for 5 months first. Incidentally, converting to electricity means that we then use more electricity, Mr. Habeck!

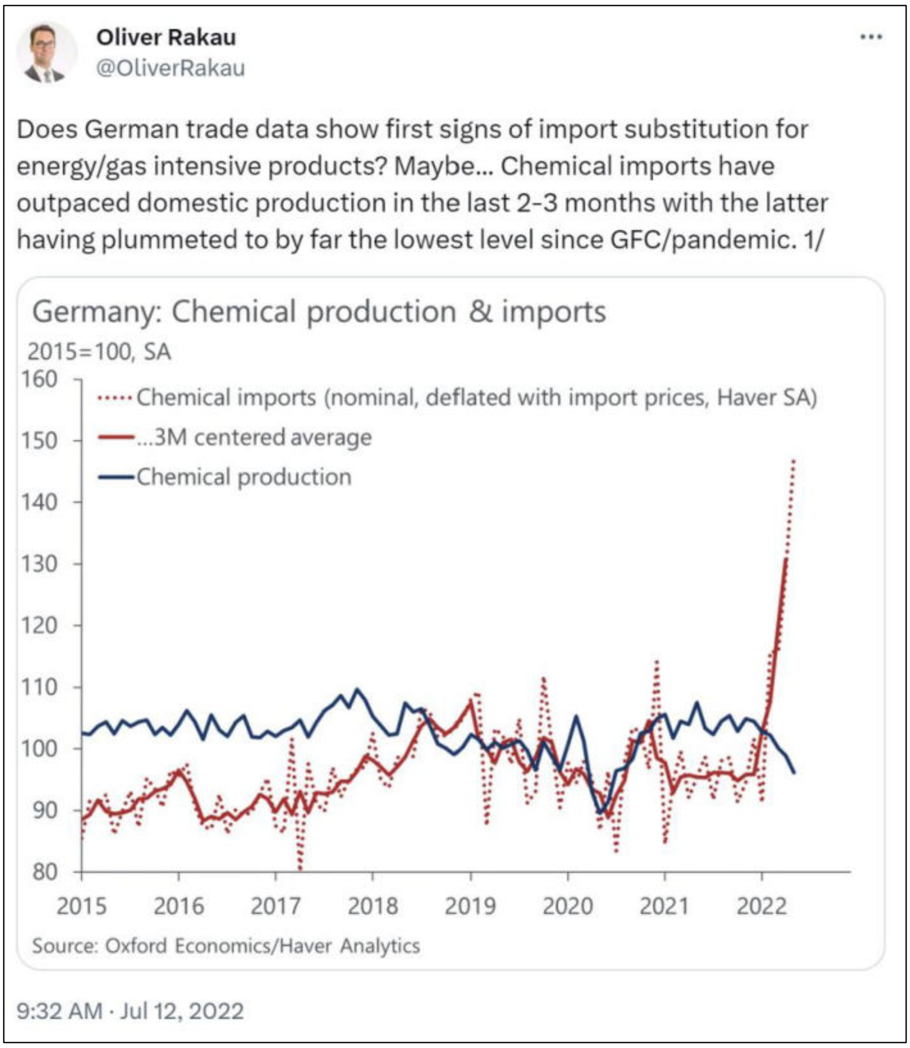
2. BASF can apparently substitute by producing ammonia (which is used in fertilizer production) in the U.S. rather than in Germany. So the substitution via imports can even happen **within** the same firm: "BASF's Antwerp, US ammonia output could offset potential shutdown in Germany – bank" (Icis, 2022)[3]

[2] https://www.faz.net/aktuell/wirtschaft/unternehmen/wuerth-chef-warnt-teilemangel-erschwert-gassparen-18172847.html
[3] https://www.icis.com/explore/resources/news/2022/06/28/10779322/basf-s-antwerp-us-ammonia-output-could-offset-potential-shutdown-in-germany-bank/

3. This study looks at German fertilizer production and shows "that increased ammonia imports have allowed domestic fertilizer production to remain remarkably stable."



4. Consistent with these stories, what looks like substitution via imports is starting to show up in aggregate trade data:

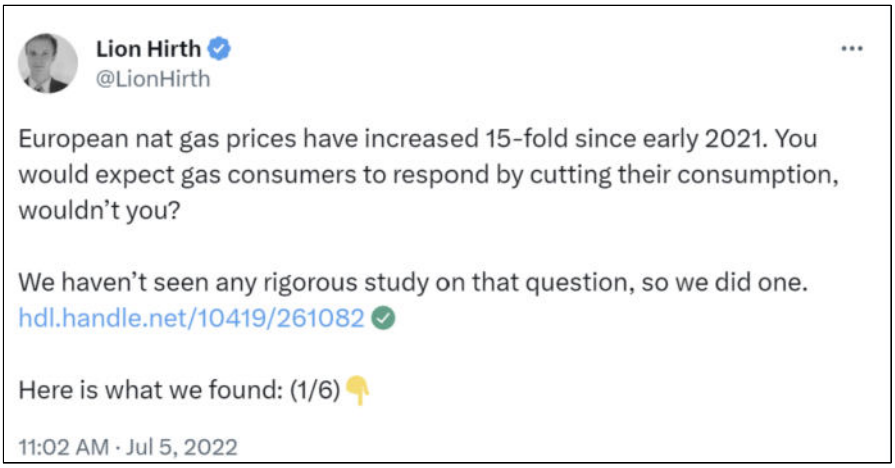


5. This article cites an Arcelor-Mittal manager essentially saying: we could, of course, import inputs for steel production from abroad. But we'd rather not because it's expensive. Also, saving additional gas would result in lower production. (Frankfurter Allgemeine Zeitung,2022b[4]). Shocking I know.

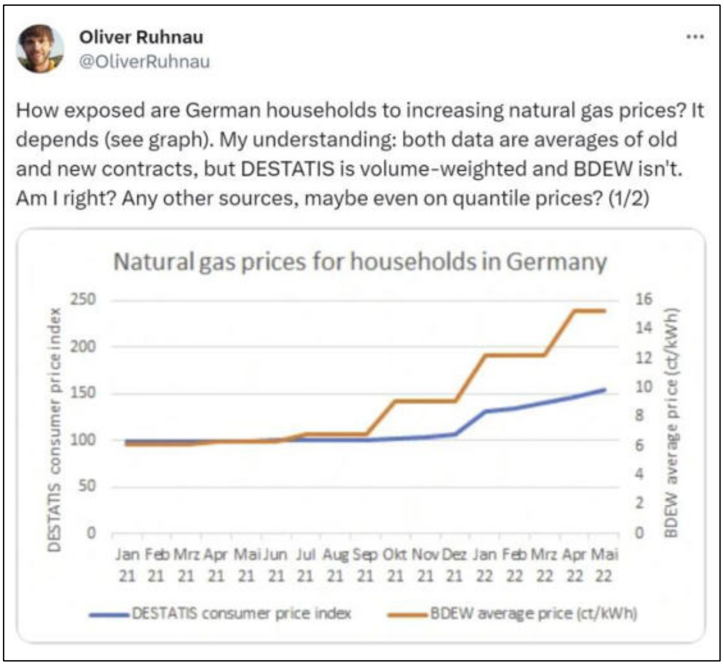
> Every additional step to achieve further efficiencies in our own production. "We do not see any further potential for reduction. Any further reduction of natural gas would lead to production stoppages and have negative effects on employment," says Arcelor-Mittal.
>
> The only way out they see there is to externally purchase steel pre-products and thereby reduce gas consumption in production. Switching to oil, coal, or electricity requires significant modifications and technical adjustments. "In our production processes, it is either not possible or only to a negligible extent."

[4] https://www.faz.net/aktuell/wirtschaft/unternehmen/wie-in-der-industrie-am-besten-gas-gespart-werden-kann-18126831.html

6. Households and firms have already reduced their gas demand: according to this study for Germany, household demand is down 6% and industrial demand down 11% relative to early 2021. (Ruhnau et al. 2022a[5], Twitter thread[6])



One thing to note about households: prices are passed through to a much smaller extent due to long-term contracts, "only" between a 50% and 140% increase.



One can use these price increases and the 6% demand reduction to compute back-of-envelope elasticities. These are between 0.07 to 0.15. As expected, small but very much not equal to zero. In our paper we used 0.1. (Math: log(0.94)/log(2.4) = -0.07 and log(0.94)/log(1.5) = -0.15)

[5] Ruhnau, O., Stiewe, C., Muessel, J. and Hirth, L., 2022. Gas demand in times of crisis. The response of German households and industry to the 2021/22 energy crisis.

[6] https://twitter.com/LionHirth/status/1544260511465889792

7. Some German dairy producers will switch from gas to oil in case gas deliveries get cut. (tagesschau,2022a[7])

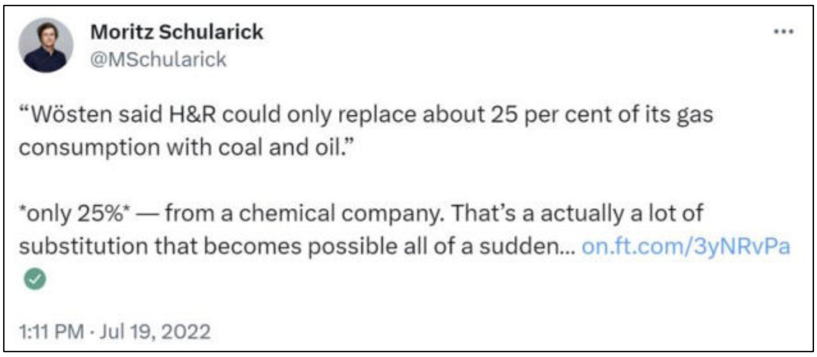
> **Oil instead of gas: Some dairies are now converting**
>
> If Russia's President Vladimir Putin actually turned off the gas tap, Germany would have to work with what is in the German gas storage facilities and what comes to Germany from other countries. But because that will not be enough for all areas, Germany would have to prioritize gas. Prioritizing means here: It is likely that some sectors will fall behind and not get any gas. That's why some dairies in Germany are now converting - as long as they can afford it.
>
> The Berchtesgadener Land dairy has been building an emergency operation with heating oil for months. The dairy has already bought oil tanks and a heating oil truck. The company sent two drivers of milk trucks to a training course so that they can also transport the dangerous goods heating oil. The dairy also relies on emergency generators. That cost several million euros, says Bernhard Pointer, the managing director of Berchtesgadener Land.

8. Munich's energy supplier Stadtwerke Muenchen
    - is postponing the conversion of a heating plant from coal to gas
    - will convert two heating plants from gas back to oil (Frankfurter Allgemeine Zeitung,2022c[8])

> **How do you prepare in the short term for an impending natural gas shortage in winter?**
>
> We have postponed the conversion of a large thermal power plant from coal to gas and will convert two heating plants from natural gas back to heating oil. In addition, we have increased the number of staff in the energy saving advisory service because the number of inquiries has quintupled. And we have set up a hardship fund with 20 million euros. Because we expect that many Munich households will be completely overwhelmed by the high energy prices in winter. We spoke to the social authorities. They tell us that you can get very far with this sum.

9. CEO of German chemicals producer H&R tells the Financial Times they "could only replace about 25% of its gas consumption with coal and oil." Moritz Schularick: 25% is a hell of a difference from the "no substitution possible" typically claimed by the chemicals lobby.

[7] https://www.tagesschau.de/wirtschaft/unternehmen/gasknappheit-molkereien-101.html
[8] https://zeitung.faz.net/fas/wirtschaft/2022-07-17/9db2c3db5df167136d04035d5f00c832/?GEPC=s3


Moritz Schularick
@MSchularick

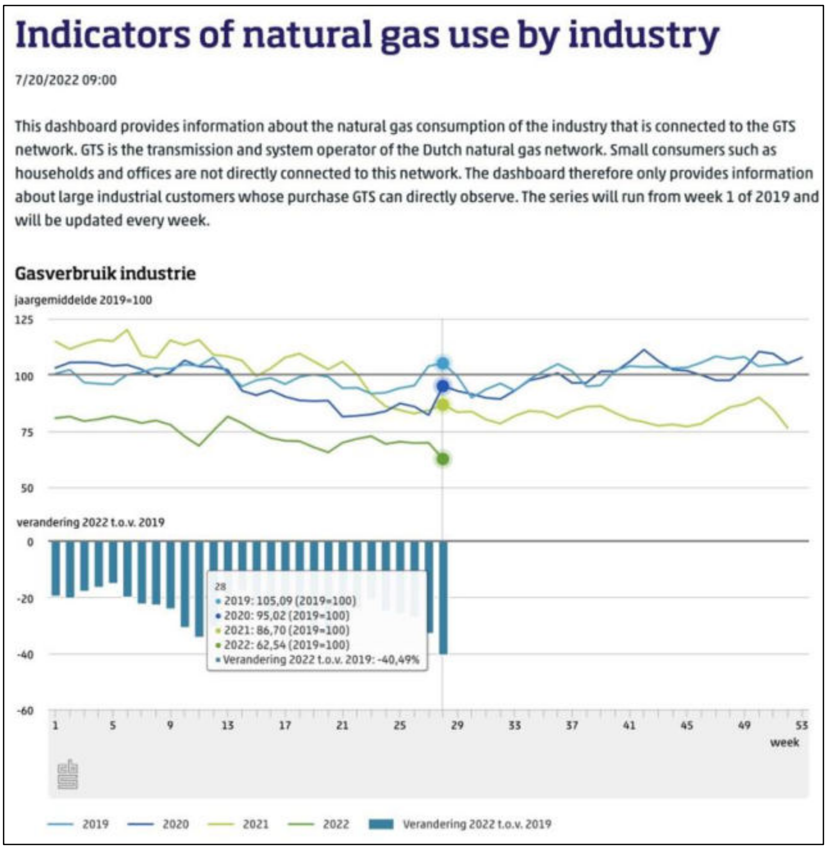
"Wösten said H&R could only replace about 25 per cent of its gas consumption with coal and oil."

only 25% — from a chemical company. That's a actually a lot of substitution that becomes possible all of a sudden... on.ft.com/3yNRvPa

1:11 PM · Jul 19, 2022

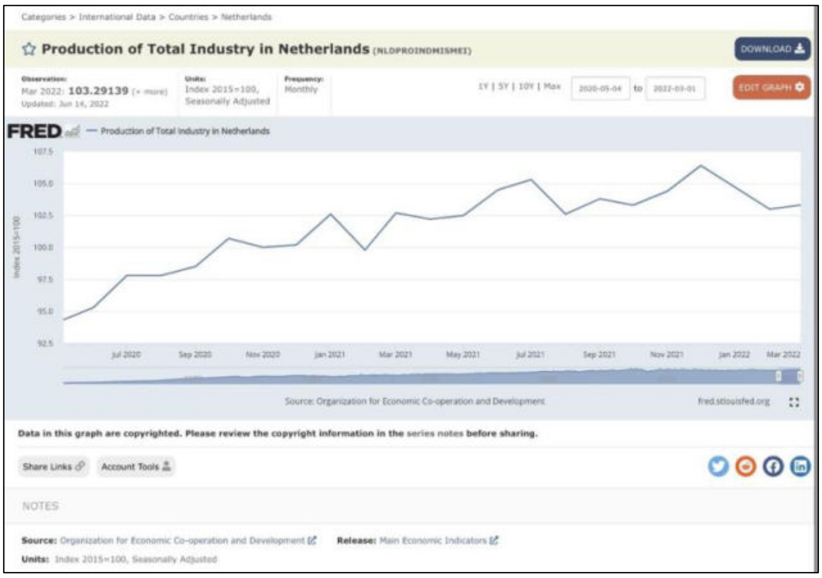
10. Related to point 6 above, industrial gas consumption in the Netherlands is
    - down 25% (!) since Jan 2022
    - down 40.5% (!!) since Jan 2019

Data: [Statistics Netherlands (CBS) & gas network operator (GTS)][9]



As a reminder: zero substitution implies production falls 1-for-1 with gas. So if you think substitutability of gas along entire supply chain =0 (Leontief "cascade effects") you must also think Dutch production should be down 25% since Jan 2022. Clearly not:

[9] https://www.cbs.nl/nl-nl/visualisaties/indicatoren-aardgasgebruik-van-de-industrie



11. Car manufacturer Audi says it can substitute 20% of its gas consumption in the near term, e.g. by turning down the heating in offices. Only 10% of gas is irreplaceable (paint shop, ovens) and "the minimum amount of gas needed". (N-TV,2022[10])

12. Car manufacturer Mercedes says it can reduce its Germany-wide gas consumption by a whopping 50% "if regional pooling is made possible." For example, the paint shop in its Sindelfingen factory can be operated without any gas whatsoever. (mbpassion, 2022[11])

13. Remember the lobbyists' favorite example of "substitution is impossible": the glass industry. Surprise surprise: Glass manufacturer Wiegand Glass "will be able to heat its melting tanks [...] with light fuel oil instead of natural gas" (Zeit Online, 2022a[12])

[10] https://www.n-tv.de/wirtschaft/Audi-kaeme-mit-20-Prozent-weniger-Gas-aus-article23484747.html
[11] https://mbpassion.de/2022/07/mercedes-benz-steigert-q2-ergebnis/
[12] https://www.zeit.de/news/2022-07/25/schnelle-genehmigung-wiegand-glas-kann-erdgas-ersetzen

> ## Quick approval: Wiegand-Glas can replace natural gas
>
> Jul 25, 2022 at 5:02 p.m / Source: dpa Thuringia /
>
> ZEIT ONLINE did not edit this report. It was automatically taken over by the German Press Agency (dpa).
>
> Wiegand-Glas was one of the first Thuringian companies to benefit from shorter approval procedures when changing energy sources. In the future, the glass industry manufacturer will be able to heat its melting tanks in its southern Thuringian plant in Groß Breitenbach with light fuel oil instead of just natural gas as before . The necessary immission control approval was granted on Monday, as announced by the Ministry of Energy.

14. Veltins brewery says that brewing can continue in the brewhouse without interruption even if gas supply stops: "We can switch from gas to fuel oil firing in the boiler house within a few hours." Plus they've cut gas by 1/3 to date. (Frankfurter Allgemeine Zeitung,2022d[13])

> Despite the current upswing, Veltins is preparing for more difficult times in the coming months - the traditional brewery has already taken far-reaching precautions in the event of a gas supply stop from Russia in the course of the Ukraine war "We are fighting to ensure that the breweries also get enough gas", says Huber, but that remains uncertain. Veltins therefore adheres to the recommendations of the Federal Network Agency: "We can switch from gas to fuel oil firing in the boiler house within a few hours," says Huber. This means that brewing can continue in the brewhouse without interruption even if the gas supply stops.
>
> **"We bought additional tanks"**
>
> The brewery has already switched from gas to oil as a test, and this currently saves about a third of the conventional gas consumption. "We have now stored almost 500,000 liters of heating oil," says Huber. In the past, the brewery always had a few reserves due to its peripheral location in the Sauerland region, away from the main traffic routes, but not to this extent: "We have now bought additional tanks," says Huber, the supply of heating oil has been increased by around 200,000 liters.

15. BASF (same amount of gas as Switzerland)
    - can substitute 15% of gas used for heat & steam (=50% of total) with oil
    - can easily substitute ammonia by importing
    - can operate as long as gas >50%
    - just revised profit expectations for 2022 **upwards**

[13] https://www.faz.net/aktuell/wirtschaft/unternehmen/brauerei-veltins-bunkert-heizoel-und-sorgt-fuer-gas-lieferstopp-vor-18175875.html

“Natural gas is extremely expensive, but business is (still) flourishing: the gas crisis using the example of BASF” (Neue Zürcher Zeitung, 2022)[14]

> BASF has reduced gas consumption since March 2022 through short-term measures such as technical optimization and switching to alternative fuels. In Ludwigshafen, heating oil can replace around 15 percent of the natural gas required to generate electricity and steam.
>
> In addition, due to the high gas prices, the group reduced the production of ammonia and supplemented it with acquisitions. In the case of ammonia, the production of which requires a lot of gas and which is mainly used for the production of fertilizer but also, for example, for polyamides for the automotive industry, this replacement is relatively easy on the world market, in contrast to other production methods. Therefore, ammonia plays an important role in risk prevention plans.

For comparison here's BASF CEO Brudermüller back in March: a cut-off from Russian gas would mean the "destruction of the entire German economy" and the "worst crisis since the end of the Second World War" (Spiegel,2022[15]). Lobbyism at its best.

It’s also always good to remember how BASF got to be so reliant on Russian gas. For German speakers, this ZDF video summarizes it nicely. See in particular the timeline around minute 1:00. (ZDF, 2022[16])

16. Paper manufacturer Schoellershammer will substitute 50% of gas until early January by converting its gas-fired boiler to oil. Even without this measure, it can save 15% of gas while operating its machines at somewhat reduced capacity. (Aachener Zeitung, 2022[17])

[14] https://www.nzz.ch/wirtschaft/chemiekonzern-basf-das-gas-wird-teuer-doch-die-geschaefte-bluehen-noch-ld.1695326
[15] https://www.spiegel.de/wirtschaft/unternehmen/basf-chef-warnt-in-embargo-debatte-vor-zerstoerung-der-gesamten-volkswirtschaft-a-87009924-b320-4ba5-87b6-68d34fef864b
[16] https://amp.zdf.de/nachrichten/wirtschaft/basf-gas-ukraine-krieg-russland-100.html
[17] https://www.aachener-zeitung.de/consent/?ref=https%3A%2F%2Fwww.aachener-zeitung.de%2F#

nicht weiter. Und eine Rückkehr zur Braunkohle war auch keine Option, da Gebäude teilweise bereits abgerissen wurden, um Platz für die neue RVA zu machen. Deshalb hat die Firmenleitung beschlossen, einen Gaskessel auf Öl umzurüsten. „Wir hoffen, dass er Anfang Januar in Betrieb gehen kann“, erklärt Vetter. „Ich gehe davon aus, dass wir damit vielleicht die Hälfte unseres Erdgasbedarfs ersetzen können.“ Eine frühere Umrüstung sei mit Blick auf die Lieferzeiten der neuen Anlage nicht möglich. Vetter hofft, dass die Reserven in den deutschen Gasspeichern zumindest bis dahin reichen, ohne dass es zu Einschränkungen kommt.

> **„Ich gehe davon aus, dass wir mit der Umstellung auf Öl die Hälfte unseres Erdgasbedarfs ersetzen können.“**
> **Armin Vetter, Geschäftsführer**

Einsparszenarien durchgespielt

Und wenn nicht? Auch darauf hat sich Schoellershammer bereits vorbereitet. Mit ihrem Versorger, der Stadtwerke-Tochter Leitungspartner, hat der Papierhersteller schon vor Wochen mögliche Einsparszenarien durchgespielt, die mit Blick auf die aktuellen EU-Pläne jetzt Realität werden könnten. Ergebnis: „Wenn wir 15 Prozent Gas einsparen müssen, können beide Papiermaschinen weiterlaufen, wenn auch mit geringerer Kapazität.“ Wären Unternehmen wie Schoellershammer gezwungen, vorübergehend auf deutlich mehr Gas zu verzichten, müsste eine Maschine vorübergehend stillgelegt werden, „mit allen Konsequenzen“, betont Armin Vetter. Das heißt: Mitarbeiter würden in Urlaub geschickt, müssten Überstunden abbauen, im schlimmsten Fall sogar in Kurzarbeit.

Daran aber wollen Armin Vetter und seine beiden Kollegen in der Geschäftsführung aktuell noch keinen Gedanken verschwenden. „Wir hoffen natürlich, dass wir nicht zur Kurzarbeit gezwungen werden, die hatten wir während der ganzen Corona-Zeit nicht.“ Noch laufen beide Papiermaschinen auf Hochtouren.

17. Sugar manufacturer Pfeifer & Langen expects to cut Germany-wide gas consumption by 50%. Important part of plan: reshuffle gas across factories. Eg the factories in Appeldorn & Euskirchen can switch to oil which frees up gas for Jülich (Aachener Nachrichten,2022[18])

[18] https://www.aachener-nachrichten.de/lokales/juelich/so-wird-in-juelich-die-ruebenkampagne-gesichert_aid-73263997

Das führt natürlich zu einem Problem, wenn der Notfallplan Gas der Bundesregierung vorsieht, dass die Industrie bis zu 50 Prozent der Energie einsparen soll. „Wir haben uns darauf eingestellt, dieses Ziel deutschlandweit mit unseren Werken zu erfüllen“, erläutert Wegner. Damit sind es dann deutlich mehr als die eingangs erwähnten drei Werke, die sich zusammentun, aber speziell Appeldorn und Euskirchen spielen für den Jülicher Standort eine besondere Rolle. Die können nämlich auch mit

Heizöl betrieben werden.

Das bedeutet: Die für Appeldorn und Euskirchen vorgesehenen Gasmengen können zur Versorgung von Jülich genutzt werden. Das sichert die Kampagne in Jülich ab. Trotz des Einsatzes von Heizöl wird sich deutschlandweit der CO_2-Abdruck des Unternehmens nicht verschlechtern, weil man an einzelnen Standorten, etwa in Könnern in Sachsen-Anhalt, die Energieversorgung in Teilen auf Pellets und Bio-Methan umstellt.

Interesting aspect of cases 16 and 17: due to Germany's announced 2030 phase-out of lignite, both the paper manufacturer in 16 and sugar manufacturer in 17 switched everything from lignite to gas only a year ago. After all, gas was green, cheap, and secure. How times have changed!

Jahrzehntelang setzte Schoellershammer Braunkohle zur Wärmeerzeugung ein. Mit dem von der Bundesregierung beschlossenen Kohleausstieg im Jahr 2030 aber entschied Tagebaubetreiber RWE Power die Briketterzeugung schon Ende 2022 einzustellen. Schoellershammer musste reagieren, ent-

Mit der im Dezember 2016 in Betrieb genommenen PM6 (Papiermaschine 6) hat

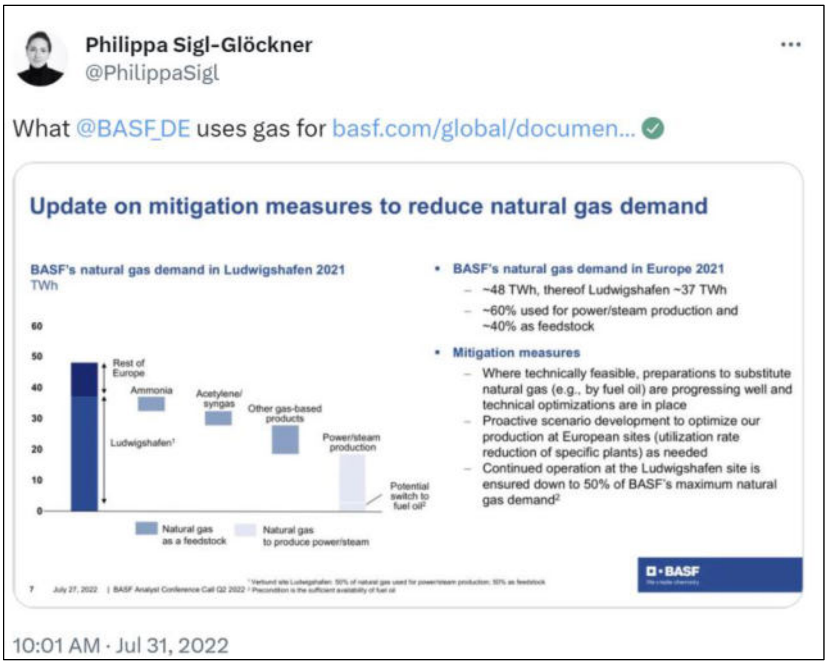
schloss sich wie so viele andere, von Kohle auf Gas umzustellen.

Von Braunkohle zu Gas

„Wir haben unser Braunkohle-Kraftwerk im September des vergangenen Jahres abgestellt und einen Gaskessel mit Turbine in Betrieb genommen“, erklärt Vetter den ersten, kurzfristigen Schritt eines zweiteiligen Energiekonzepts. Gaskrise war zu diesem Zeitpunkt noch ein Fremdwort. Aktuell werden 88 Prozent des Wärmebedarfs des Papierherstellers mit Gas erzeugt, der Rest über eine Contracting-Anlage, die noch mit Braunkohlestaub betrieben wird.

Schon damals aber blickte die Geschäftsführung über den Tellerrand hinaus und entschloss sich zum Bau einer eigenen Reststoffverwertungsanlage (RVA), die sich derzeit im Bau befindet. In ihr sollen ausschließlich die Rückstände aus der firmeneigenen Altpapieraufbereitung, die bislang in Müllverbrennungsanlagen in

18. (follow up on 15.) BASF now even advertise their substitution prowess in their analyst conference calls:
    - “preparations to substitute natural gas are progressing well”
    - “Continued operation at Ludwigshafen site is ensured down to 50% of BASF’s maximum natural gas demand”



19. (Follow-up on 5.) Remember that poor Arcelor Mittal manager who essentially said "we could of course substitute by importing metal inputs, but it really wouldn't be good for our bottom line"? Guess what they ended up doing: (The New York Times, 2022[19])

> For instance, a steel mill owned by ArcelorMittal on Hamburg's busy harbor in Germany has for years used natural gas to extract the iron that then goes into its electric furnace. But recently, it shifted to buying metal inputs for its mill from a sister plant in Canada with access to cheaper energy. Natural gas prices in North America, while elevated by historical standards, are about a seventh of European prices.

Importantly, just like BASF in case 2, ArcelorMittal is yet another case of substitution via imports even happening **within** the same firm. An important clarification because people often ask: doesn't substitution via imports destroy some production in importing country (Germany)? Answer: of course it does. But it kills the notorious "cascading effects" = one of main arguments of industry lobby.

[19] https://www.nytimes.com/2022/07/30/business/europe-natural-gas.html

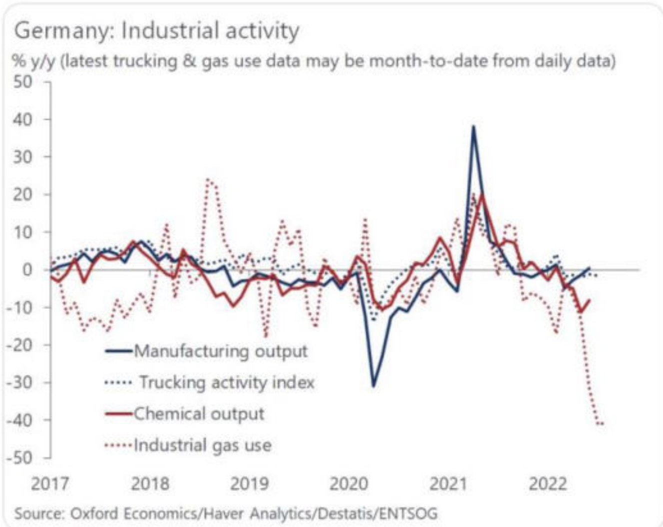
> **Fabian Lange** 🇺🇦
> @fabolange
>
> The result is to essentially import Gas embodied in inputs. Thus inputs are available for production in value-chains - so the result is some loss of production in the import substituted sector while maintaining production in the value chain. So, no cascades.
>
> 8:07 PM · Jul 15, 2022

More generally people sometimes ask: if a firm is cutting production doesn't that show it can't substitute? The answer is: no, of course substitution is costly. The question is not **whether** production falls but by **how much** it falls?

No substitutability means production falls one-for-one with gas. Some substitutability means production does fall but it falls by potentially much less than gas. That's what we're seeing now.

Here's a chart by [Oliver Rakau](#) that shows this beautifully: German industrial gas use falls of a cliff (~40%) but manufacturing output & even chemical output fall by much less (~1% &10%).[20] The world is not Leontief!

> **Oliver Rakau**
> @OliverRakau
>
> Das Ganze mal mit hoch frequenten Daten dargestellt. (ENTSOG Daten überzeichnen die Entwicklung mglw.)
>
> Translated from German by Google
>
> The whole thing is shown with high-frequency data. (ENTSOG data may overstate the development.)



> 10:23 AM · Aug 6, 2022

The next four cases are due to excellent reporting in Frankfurter Allgemeine Zeitung (2022e)[21] and Zeit Online (2022b) [22]

[20] As Oliver Rakau says the ENTSOG data may overstate the gas drop.

Johannes Pennekamp
@JoPennekamp

Geht doch - wie die Industrie plötzlich sehr viel Gas einsparen kann. Auch da, wo es angeblich unmöglich war.
zeitung.faz.net/faz/unternehme... @ben_moll @IlkaKopplin @bfreytag @MaxosTaxos @GustavTheile @faznet

Translated from German by Google

It's possible - how the industry can suddenly save a lot of gas. Even where it was supposedly impossible. zeitung.faz.net/faz/unternehme... @ben_moll @IlkaKopplin @bfreytag @MaxosTaxos @GustavTheile @faznet

20. Automotive supplier ZF says it should be able to reduce gas consumption by 20% by:
    - turning down heating
    - switching some production processes to electricity
    - switching others to oil
    - importing some parts from regions with lower energy prices

> Meanwhile, the boss of the auto supplier ZF, Wolf-Henning Scheider, spoke on Wednesday of a "probable stop in gas deliveries", for which the company is preparing. For example, the heating should be turned down, some production processes could be switched to electricity, and gas and oil delivered by tanker were also used. Some needed parts would be ordered from regions that don't have energy problems. He spoke of a reduction in demand in Germany of around 20 percent. In other areas, the switch is hardly possible, he said. He counted hardships among them.

21. Semiconductor manufacturer Infineon aims to save two thirds (!) of its gas consumption by the end of 2022. One main measure is switching the energy source for the air conditioning systems cooling the rooms where their microchips are manufactured from gas to oil.

> Shortly after the start of the war in Ukraine, the semiconductor manufacturer Infineon also took measures to save gas. "The goal is to save two-thirds of our gas consumption by the end of the calendar year," said Constanze Hufenbecher, the board member responsible for digital transformation, in a conference call on the quarterly figures. At the locations in Germany and Austria, the specific aim is to convert the air conditioning in the clean rooms for chip production from gas to oil. For this, the systems would be converted and oil had been bought, she said. In exhaust air purification, for example, this is not feasible in the short term. However, Hufenbecher was confident about its own natural gas supply. Attempts are currently being made to get an overview of the situation of the most important suppliers.

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[21] https://zeitung.faz.net/faz/unternehmen/2022-08-04/02ee64ac056be5560ef6370fb67c4406/?GEPC=s3
[22] https://www.zeit.de/wirtschaft/2022-08/gaskrise-gasverbrauch-deutschland-ausstieg-speicherziel/komplettansicht

22. Yet another glass industry example, just like case 13: Special glass manufacturer Schott can switch its melting furnaces from natural gas to propane gas if necessary. To this end, it has already stocked up on large quantities of propane gas.

> Companies sometimes take unusual paths: the Mainz-based special glass manufacturer Schott, for example, stocked up on propane gas to prevent the expensive melting furnace from being irreparably damaged in the event of a gas failure. Propane gas is not extracted from the earth, but is produced, among other things, at the oil refinery in Germany. In order to secure the necessary quantities from the limited supply and not to frighten the competition, Schott has, so to speak, secretly bought a corresponding supply over the past few weeks, stored it and successfully tested it. According to Schott, it has invested an additional double-digit million amount for this purpose. CEO Frank Heinricht sees the sum as insurance to protect against even greater damage.

23. German pharma and chemicals manufacturer Merck says it can switch its production processes from gas to oil and that it is "very well prepared" for any potential gas shortage. See Zeit Online[23] (2022c) and Frankfurter Allgemeine Zeitung (2022f) [24]

24. Oil giant Exxon Mobil say they have reduced natural gas consumption in their European refineries "by 65%, that's the equivalent gas used for powering about 2 million homes in Europe." From their Q2 earnings call on July 29.

> And so I think there's an opportunity where certainly ExxonMobil could play a key role. We also have a fairly large refining footprint in Europe. We've been working hard to upgrade those facilities, make sure that we're driving their emissions footprints to zero and developing plans to do that. And within this current crisis, we have really stepped up the efforts to reduce our consumption of natural gas. In fact, if you look at our refining circuit, we reduced the use of natural gas by 65%, that's the equivalent gas used for powering about 2 million homes in Europe. And so there are some substantial steps that we can take with respect to optimizing our current operation. Longer term, we're opening up, looking at projects to expand our LNG import facilities. And of course, we are bringing LNG projects online.

25. You may also remember ENI, the Italian energy giant that was extremely keen to pay for its gas in rubles back in May. Just like Exxon Mobil, they have also reduced gas consumption in their refineries by 70%. (Seeking Alpha,2022[25])

[23] https://www.zeit.de/wirtschaft/2022-08/gaskrise-gasverbrauch-deutschland-ausstieg-speicherziel/komplettansicht

[24] https://www.faz.net/aktuell/wirtschaft/unternehmen/merck-chefin-belen-garijo-m-interview-zur-gaskrise-und-inflation-18182102.html

[25] https://seekingalpha.com/article/4528120-eni-s-p-e-ceo-claudio-descalzi-on-q2-2022-results-earnings-call-transcript

> **Giuseppe Ricci**
>
> About the gas reduction in the refineries, our reduction reached more or less 70% versus the previous one. This was a pathway started last year when in the second half of last year, we started to – the spike of price, 70%. And so, when the Ukraine-Russian war started, we were already very strong to push again the reduction of gas consumption in the refinery.
>
> On a yearly basis, it means approximately 0.6 billion, 0.7 billion cubic meter of consumption. If you consider that, in the same time, we crossed from a minimum utilization of the refineries because low margin, COVID, low consumption, so to a big jump to the maximum utilization because the lack of Russian. And so, the combination of the two fact allow us to reach this result. And take into account that, for instance, our Sannazzaro refinery today has gas imports closed, completely closed

Here's an article from May on the ruble saga starring ENI (Financial Times,2022a[26]). Note: the ruble payments were probably economically irrelevant to a certain extent, see e.g PIIE (2022)[27], but it's still worth pointing out this is the same company.

26. Also BP have reduced natural gas by almost 50% in their German, Spanish, and Dutch refineries. Strikingly, they say this "has not impacted output in any way"! (British Petroleum,2022[28]). In economics lingo: not only is production not Leontief -- instead (close to) perfect substitutes!

> Thanks.
>
> Bernard Looney: Thanks, Jason. I will take refining. I will let Murray take the second one. On refining in Europe, we have managed to reduce our natural gas usage by almost 50% which I must say surprised me when I saw the number. I think the teams have been working very hard on trying to find different ways to power the facilities and use natural gas. And they have been doing that and optimising the refining system as they try to help their own countries. We have refineries in Germany and Spain and in Holland.
>
> Thus far, it has not impacted output in any way. In fact, our refineries' utilisation, and if you look at that compared to some others, is exceptionally high, running at over 90% utilisation, Jason, which is one of the highest for quite some time. So, we are managing to maintain strong utilisation, some of the strongest around, I think, reducing natural gas usage but no impact at this stage on the output of the refining system.
>
> Murray, inflation on renewable power.

27. Here we go with yet another example from the Chemicals industry: specialty chemicals group Evonik say they can reduce their natural gas consumption by up to

[26] https://www.ft.com/content/7b416e89-1bc2-4890-b643-429ec8adfbec
[27] https://www.piie.com/blogs/realtime-economic-issues-watch/russias-ruble-actions-are-monetary-theater-absurd
[28] https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/investors/bp-second-quarter-2022-results-qa-transcript.pdf

40%. How? They can substitute it with liquefied petroleum gas (LPG). (Tagesschau,2022b[29])

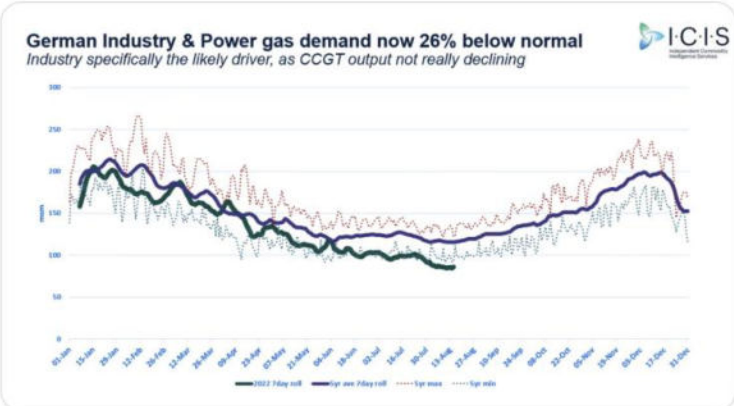
28. A case from the heavily gas-dependent aluminum industry (Spiegel,2022b[30]). German engineers are smart and inventive. Unfortunately the lobbyists pretended that they are not.

> **Janis Kluge**
> @jakluge
>
> Another interesting case: Aluminum smelter Röder substitutes gas with labor. Instead of letting the oven cool down every night, they let it run for 3 weeks straight, working in shifts, and then pause for several days. They also accelerate plans to use H2.

Here's an English version of the video (Reuters, 2022a[31]).

29. According to ICIS data, German industrial gas demand is now 26%(!) below normal (= average in previous 5 years). The chart also shows the decline really picking up in recent months.

> **Tom Marzec-Manser**
> @tmarzecmanser
>
> Clear signs emerging that German industry is cutting #natgas demand. #TTF #ONGT



Also consistent with this: overall gas consumption (i.e. not just industry) is down 15% in the first half of 2022 according to the power industry lobbyists BDEW (Reuters, 2022b[32]).

[29] https://www.tagesschau.de/wirtschaft/unternehmen/evonik-gas-alternativen-101.html
[30] https://www.spiegel.de/wirtschaft/energiekrise-wie-ein-aluminiumproduzent-gas-sparen-will-a-016a9914-6235-43de-ac50-f7972d78d0f8#rDRTh
[31] https://twitter.com/Reuters/status/1557025157381758977
[32] https://www.reuters.com/markets/commodities/german-gas-consumption-down-15-h1-says-power-industry-body-2022-08-16/

30. Sugar industry again, like case 17: sugar giant Nordzucker says that over 80% (!!!) of its German sugar production capacity has been converted back to oil. (Euronews, 2022[33]). Thanks Janis Kluge who is essentially a co-author by now!

31. Zurich airport says it can switch its heating from gas to oil. "This is technically possible, but comes with a negative impact on our CO2 emissions."

32. German PPE and sportswear manufacturer Uvex is planning on substituting 80% (!!!) of its gas consumption with propane gas (LPG). Video[34] in German.

33. Yet another lobbyist favorite where "substitution is impossible": the steel industry. (Chemicals and glass were even more popular but we've already covered those). Guess what happened? Doesn't exactly look like steel production is Leontief, does it?

[33] https://www.euronews.com/next/2022/08/25/us-sugar-germany-nordzucker
[34] https://web.archive.org/web/20220814144543/https://www.youtube.com/watch?v=o1kyDUh1wmo

34. I like this example because it's so unique: Berlin has the world's largest surviving gaslight network and will replace most of these with LED lights ([Reuters](https://www.reuters.com/markets/europe/energy-squeeze-could-see-berlins-gaslights-flicker-out-2022-08-18/),2022c[35]). The article also illustrates nicely that substitution has costs:
    - "Even the newest LEDs cannot fully imitate the colour of a tiny flame heating a rare-earth gas mantle causing it to shine brilliantly"
    - "LEDs attract more insects than gas, killing hundreds of them a night"

35. EU industrial production continues to look very much non-Leontief (data till July 22). I do expect **some** production cuts to show up in later data, just nowhere near one-for-one with gas usage...

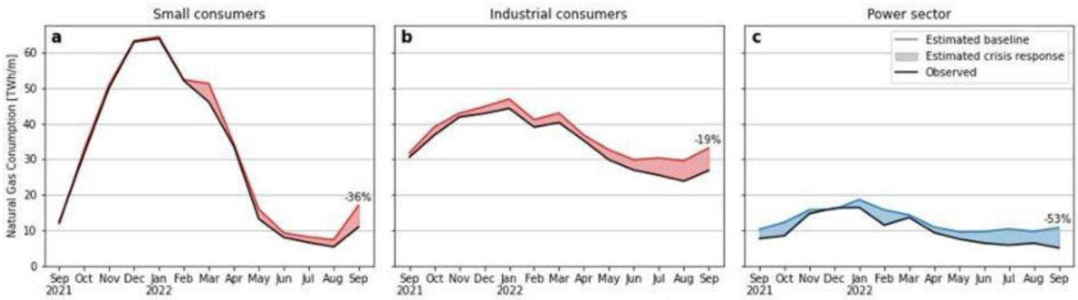
36. This new paper (Ruhnau et al. 2022b[36]) about Germany deserves an addition: controlling for temperature etc etc
    - overall consumption ⬇️30%

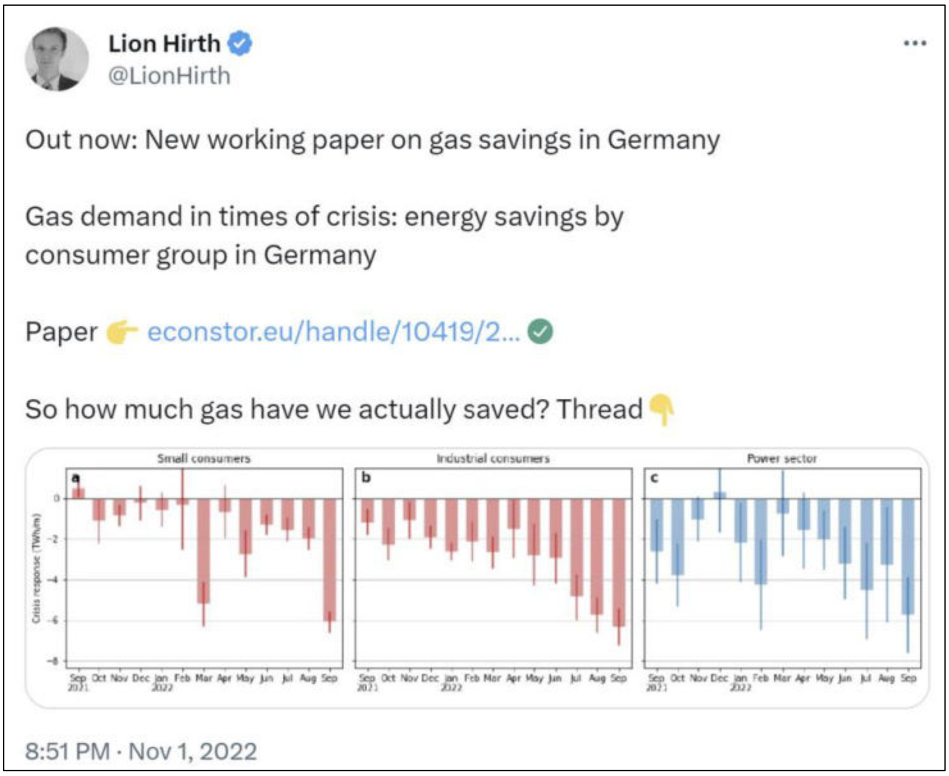
[35] https://www.reuters.com/markets/europe/energy-squeeze-could-see-berlins-gaslights-flicker-out-2022-08-18/

[36] Ruhnau, O., Stiewe, C., Muessel, J. and Hirth, L., 2022. Gas demand in times of crisis: energy savings by consumer group in Germany.

- industry ⬇️ 19%
- small consumers ⬇️ 36%
- power generation ⬇️ 53%

and... no Armageddon

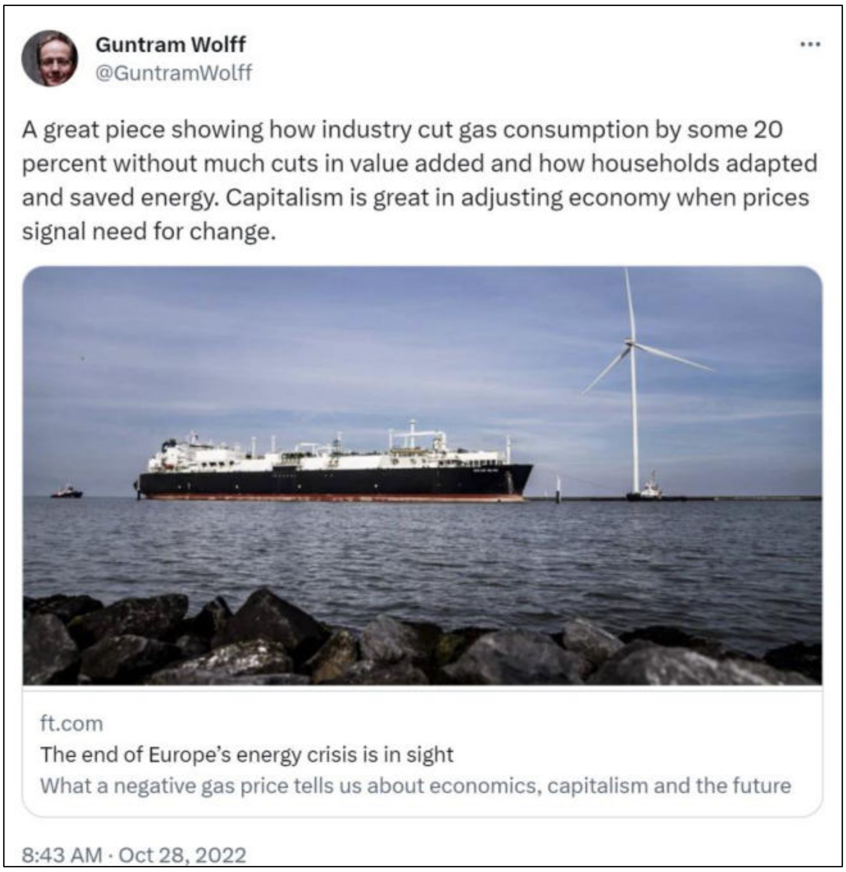




I think perhaps I'm done making this thread's point. So let me conclude with three things:

First, some current slides[37] summarizing much of this work.

Second, a pointer to this excellent recent FT piece by Chris Giles (Financial Times, 2022b[38])



Third, a parting thought: There's good economics in which households & firms reduce demand and substitute as prices rise, demand curves are downward sloping, and modern capitalist economies adapt. If someone tells you otherwise, it's bad economics. Simple as that.

[37] https://benjaminmoll.com/wp-content/uploads/2022/10/RussianGas_slides.pdf
[38] https://www.ft.com/content/8c4f9b6f-7770-490e-83e8-3fdd12f7a99f?shareType=nongift