THE "BAQAEE-FARHI APPROACH" AND A RUSSIAN GAS EMBARGO – SOME REMARKS ON BACHMANN ET AL.

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ABSTRACT

In a much-discussed policy paper, Bachmann et al. (2022) argued back in March 2022 that the economic effects for Germany of a complete immediate stop of energy imports from Russia would be small, limited to a 0.5% to an absolute maximum 3% GDP loss. In a follow-up report for the French Council of Economic Analysis (CAE), Baqaee et al. (2022) would even present 0.3% GDP loss (around 100€ per person, per year) in the case of an embargo as the headline estimate. This note argues that these estimates are both problematic from a scientific point of view, and also strongly biased towards finding small of a gas embargo: this is true of the (so-called) "Baqaee-Farhi approach" arriving at 0.2-0.3% of GDP, the "production function approach" arriving at 1.5% to 2.3% of GDP, as well as the "sufficient statistics approach" (also based on Baqaee-Farhi) arriving at 1% of GDP. This note argues that Olaf Scholz was correct in saying that the mathematical models which were used "don't really work" here, and tries to explain why. In any case, these models did not allow such uncaveated statements.

KEYWORDS :

Energy, sanctions, economic models.

JEL

D2, E1, Q4.

The "Baqaee-Farhi approach" and a Russian gas embargo – some remarks on Bachmann et al. (2022)
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In a much-discussed [policy paper](#), Bachmann et al. (2022) argued back in March 2022 that the economic effects for Germany of a complete *immediate* stop of energy imports from Russia (including natural gas) would be small, **limited to a 0.5% to a maximum 3% GDP loss**. In a [follow-up report](#) for the French Council of Economic Analysis (CAE), Baqaee et al. (2022) would even present **0.3% GDP loss (around 100€ per capita / year)** in the case of an embargo as the headline number for Germany; they would also compute the estimated losses for other European countries, including France and the EU as whole, where the losses would also amount to around 0.2%-0.3% of income per year, so around 100€ per year, per European adult. In a [vox column](#), Bachmann et al. (2022) confidently asserted: "Public fear-mongering about the catastrophic consequences of an energy embargo from lobby groups and affiliated think tanks does not hold up to academic standards."

This study by internationally renowned economists, strongly endorsed and advertised by leading authorities in the profession including two Nobel Laureates[2], has been very influential, both in academia and in the public debate. On May 1, the majority of CfM-CEPR experts (a panel of European macroeconomists) were [convinced](#): more than 70% thought that an embargo on Russian energy would cut less than 3% from German GDP in 2022-23. At the same time, the report as well as this "scientific consensus" at the international level was at odds with German government officials' assessment. In the most important political talk show in Germany (Anne Will's show), Olaf Scholz [targeted](#) economists: "But they get it wrong! And it's honestly impossible to calculate around with some mathematical models that then don't really work." This comment caused a backlash: for many economists especially working outside of Germany, Scholz had left the camp of reason and science. On the German government's side, many German economists including at the German Council of Economic Experts (GCEE, 2022), were also much more critical and cautious towards the strong and confident claims made in Bachmann et al. (2022).

This note agrees with this more cautious stance of the GCEE (as well as with Olaf Scholz), and argues that the approach in Bachmann et al. (2022) is both very problematic from a scientific point of view, and also strongly biased towards finding small of a gas embargo: this is true of the (so-called) "Baqaee-Farhi approach" arriving at 0.2-0.3% of GDP, the "production function approach" arriving at 1.5% to 2.3% of GDP, as well as the "sufficient statistics approach" (also based on Baqaee-Farhi) arriving at 1% of GDP. This note argues that Olaf Scholz was correct in saying that the mathematical models which were used "don't really work" here, and that these models did not allow such uncaveated statements.

1) <u>Some remarks on the so-called "Baqaee-Farhi approach"</u>

The so-called[3] "Baqaee-Farhi approach" is used in the paper to calculate the impact of a Russian gas embargo. According to this approach, the effects of an embargo would be 0.2% of GDP when the parameters of Baqaee-Farhi (2021) are used, and around 0.3% of GDP using the most conservative

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[2] Among others, [Paul Krugman](#) in the New York Times (March 15), and [Esther Duflo and Abhijit Banerjee](#) in Bild (April 15): "Germany is fortunate to have many very competent economists, and they have rightly made their voices heard. We have based our remarks on their work, but also on the general understanding of how economies work, which is shared by a large majority of economists. Their standard model says that the negative impact of an embargo will be 0.3% of GDP, and they consider worst-case scenarios that come to 3%."
[3] "So-called" because I am not sure it's really true to Emmanuel Farhi's and David Baqaee's earlier work.

assumptions. This number is then rounded up to yield the lower bound for Bachmann et al. (2022)'s bottom line (the effects of an embargo would be between 0.5% and 3% of GDP). The worst-case from the Baqaee-Farhi approach (0.3% of GDP) is also used as the central estimate for the follow-up paper by Baqaee et al. (2022), published by the French Council of Economic Analysis, which advises the French Prime Minister. The Baqaee-Farhi approach is no doubt the most sophisticated methodology (especially compared to the production function approach which I shall discuss in section 2) and it also is the basis for the "sufficient statistics approach" which I shall discuss in section 3. It is presented as having a high level of scientific authority: a "state-of-the-art multi-sector model with rich input-output linkages." But unfortunately, it is problematic for many reasons. I list some of these reasons below.

(1a) A permanent embargo. The model used in Bachmann et al. (2022) is actually based on a specific version of the "Baqaee-Farhi approach": the paper by Baqaee and Farhi (2021) which is a long-run model which was designed to investigate trade questions, such as what happens when a country opens up to trade, or when the trade barriers are suddenly and *permanently* lifted. One implication is that in Bachmann et al. (2022), the embargo will be put in place *permanently*, and the question is how lower GDP will be in the new *steady-state equilibrium*. The model is doing what economists call "comparative statics", that is comparing different economies at steady-state: one with natural gas from Russia and the other without, assuming Germany needs to forever run without such gas. This is a problem because this experiment amounts to answering a very different question: what would happen if Germany had to cope with a permanent -30% reduction in gas *supply*, in which case it would be clear that for example, labor would need to be reallocated away from the natural gas intensive sectors. Some of what makes the current situation very different to that experiment is that the reduction in gas supply will be transitory, and that the German authorities would have to deal with what to do about this temporary situation. The duration of this episode is also unknown, which does not help: it could last for one or more winters. People would have to be put onto temporary unemployment schemes but the model assumes no such thing: in the model, reallocation of labor is immediate and permanent. Overall, it's not even clear whether a permanent drop would be harder or easier to deal with, but it doesn't matter if we can agree it would in any case be very different. Moreover, by construction a comparative statics exercise does not allow to compute "adjustment costs". These are probably substantial both on the labor and on the capital markets, when one wants to move to an economy which consumes 30% less gas overall.

(1b) Very few factors of production. The other issue is that because it's a trade paper, designed to deal with the long run, the Baqaee and Farhi (2021) model assumes only four factors of production for the whole economy, with only 3 factors for labor (low-, medium-, high-skilled) and one for capital: the reason being that implicitly, high-skilled workers are supposed to be able to reallocate across sectors (and locations) costlessly, which is perhaps a reasonable assumption for the long run, but definitely not for the short/medium run.[4] This is way too strong an assumption for the short or even medium run: there are reasons to believe that an engineer in the chemical industry cannot work from one day to the next as a banker, and then go back to their old job when the embargo is lifted. This is another very important reason why this study tends to overestimate the possibilities of substitution.

(1c) Baqaee and Farhi (2019a), not Baqaee and Farhi (2021)! The importance of the number of factors one assumes was illustrated in the previous paper by Baqaee and Farhi (2019a) (in my opinion, much more relevant) where they showed how crucial the number of factors was for the conclusions one draws: the more factors, the less substitutability at the aggregate level, which is intuitive. Again, as spelled out in (1a), the timing is absolutely essential. David Baqaee and Emmanuel Farhi, in their 2019 paper, indeed write: "we view the no-reallocation case as more realistic for modeling the short-run impact of shocks, and the full-reallocation case as better suited to study the medium to long-run impact shocks." In

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[4] Note in passing that recent empirical research in trade such as Autor et al. (2013) casts doubt on this assumption, even for the long run: two decades after China's entry in the WTO, the labor market effects of import competition are still apparent.

the case of natural gas, one could even argue that one does not need to assume just a few factors for each sector (say, engineers and technicians in the chemical industry) but also that one needs to assume that factors are located in a particular region, and cannot easily move from one month to the next. To quote Olaf Scholz in his interview on the Anne Will talk show, in the case of natural gas, location is of crucial importance because it's important to know "where is the gas actually supposed to run through, where are the pipelines, what is the regasification capacity, where are the terminals, and if everyone else is doing it, is there enough capacity to achieve that." (Ben Moll's translation).

(1d) Very few sectors, very few goods. The model is very stylized in other crucial ways. For example, it only has 30 sectors (the World Input Output Table they use has 35 sectors originally, but they wanted to get rid of 0 which cannot be dealt with in trade models) and therefore, only as many goods. Importantly for the issue of calculating the consequences of a natural gas embargo, water supply is mixed with electricity and gas in the "Electricity, Gas and Water Supply" sector (this particular limitation is indicated in Bachmann et al. (2022) and Baqaee et al. (2022) but it's unclear why rounding up the numbers, or lowering the elasticities should address the problem and get to the right magnitudes quantitatively) – one should remember that within one sector and one country, goods are assumed to be perfect substitutes, so here by assumption when there is less gas, one can replace it with water. Also quite importantly, the chemical industry is mixed with rubber and plastics (sectors 9 and 10 in Table 5 from Baqaee and Farhi (2021)), and it is assumed that in Germany, this whole aggregate produces only one product. Because of the importance of the chemical industry for the issue of computing the consequences of a natural gas embargo, one would have perhaps liked to zoom a bit more onto this particular industry rather than assume that this whole sector simply produces one commodity: "plastics". Tom Krebs noted very early on that the treatment of the chemical industry was essential (Krebs (2022)). Baqaee and Farhi (2019a) which had 88 sectors. One could also have thought to use the 2016 vintage of WIOD instead, which has more sectors even though it has much less detail on factors (but in any case, it's probably better to assume that factors are industry-specific).

(1e) What are the implied price changes? One would really like to know what the *implied price changes* of natural gas are in the Baqaee and Farhi (2021) model in order to achieve such a large reduction in natural gas consumption. I asked this question when the authors presented the paper at Markus' academy (hosted by Professor Markus Brunnermeier from Princeton) on April 7 but at the time at least, the authors had not looked at what prices would lead to such a drop in natural gas consumption in the context of the Baqaee-Farhi model. This is potentially problematic because in the "production function approach" the price of natural gas needs to increase by +1293% to +3440% depending on the scenario (see remark (2b) below). So, this really looks like a first-order issue, also from a policy perspective, just because too large price changes might be intolerable, both for the industry but also for households.

(1f) "Efficient" burden sharing? Related to the price issue, Bachmann et al. (2022) implicitly assume that energy reductions would be broken down "efficiently" between the industrial and the household sector, because in the model, the price mechanism allocates energy reductions efficiently (the price of energy is the same for households and for businesses). This implies that if households can substitute more, then they will be bearing more of the adjustment. Among households, poorer households would be forced to turn down heating, because they cannot afford the extra cost. If the price increases are indeed 13-fold, or even 34-fold, it would clearly be politically infeasible. And in fact, in Germany, in the case of an energy crisis which would trigger an emergency program, gas rationing would occur primarily in industry and businesses, with private households and hospitals being protected, which violates that the constraint would be broken down between households and businesses according to the price mechanism. In such a situation, the GDP decline would clearly be much greater because the industry would have to bear more of the adjustment, while it also has a lower elasticity of substitution. It would be interesting to know how this affects the results.

(1g) What about long-term and hedging contracts? Moreover, in reality neither households nor the industry tend to pay the spot price of natural gas. There are long-term contracts which may renew every few years for households and the industry, and there are hedging possibilities for industry. Primarily, what shall determine who will need to reduce consumption is much more when these contracts renew (and that depends also on luck!), how much hedging firms were able to buy, than who needs natural gas the most. This is another reason why the losses will be much greater than what is implied in Bachmann et al. (2022): the price mechanism will apply only to a subset of households and firms. Again, these are first-order issues which determine in the end how a reduction in natural gas can reasonably be achieved.

(1i) Some other questionable assumptions. There are plenty other questionable assumptions in the model. Of course, "all models are wrong" as the old adage goes, but one would still like to know how sensitive the results are to these assumptions. For example, only one elasticity of substitution governs the substitution between all consumption goods entering symmetrically. This is a very debatable assumption in the context of a natural gas embargo as heating for example, may be less substitutable to other consumption – which implies that consumer surplus is large for heating, so that the utility losses are much larger than the monetary losses. To put it bluntly, 100€ per year in heating expenses is worth much more than 100€ per year in restaurants, when one is already freezing because of a natural gas embargo (And again, both numbers seem really small).

Related to remark (1d), there is only one good in each sector and each country, and goods from the same sector and different countries are also assumed to be imperfect substitutes. The elasticities of substitution are taken from the median estimates of a paper (Caliendo and Parro (2015)) using elasticities in the U.S. in 1993 before NAFTA, and extrapolates "other manufacturing industries" to services. All of this to show that despite all its complexities, the model still is quite stylized and simplified, and the quantitative estimation is probably no more than a first pass.

2) <u>Some remarks on the production function approach</u>

Bachmann et al. (2022) then turn a very simple "production function approach" for the main bottom line in their paper, which allows them to argue that the losses could be 1.6% or 2.3% of GDP at the maximum. This approach is much simpler, but is also quite problematic, although the problems are different in nature.

(2a) Production function approach. The production function approach consists in assuming that GDP is a function of Energy and Non-Energy with an elasticity of substitution σ and a share of energy α, implying this formula for GDP:

$$Y(\sigma, \alpha, \text{Energy}, \text{Non-Energy}) = \left(\alpha^{\frac{1}{\sigma}} \text{Energy}^{\frac{\sigma-1}{\sigma}} + (1-\alpha)^{\frac{1}{\sigma}} \text{Non-Energy}^{\frac{\sigma-1}{\sigma}} \right)^{\frac{\sigma}{\sigma-1}}$$

Then, the paper's estimates are obtained by assuming $\sigma = 0.04$, $\alpha = 0.04$ and looking at what the change in GDP ΔY is for a 10% energy reduction (hence the multiplication by 0.9), and plugging these numbers for σ and α together with Energy = 0.04 and Non-Energy = 0.96 in the above formula:

$$\Delta Y = Y(0.04, 0.04, 0.04 * 0.9, 0.96) - Y(0.04, 0.04, 0.04 * 1, 0.96) \approx -1.57\%.$$

Clearly, this approach is very crude and does not do justice to the complexities of the problem at hand: it only relies on one line of algebra, and one parameter, the aggregate elasticity of substitution between energy and non-energy which honestly, we know very little about! A paradox is that Baqaee-Farhi's research agenda with input-output networks was precisely to move away from these extremely stylized production functions. [5] In Baqaee and Farhi (2019b), they argued against such an approach, especially for quantitative

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[5] There is another paradox: why use such a simple approach for the bottom-line of Bachmann et al. (2022), after all these modeling efforts on the so-called "Baqaee-Farhi approach"?

analysis: "As micro data becomes more plentiful, parsimonious reduced-form aggregate production functions look more antiquated." Even intuitively, and even for someone who is not well versed into economics, it's a priori very hard to see how such a crude approach could allow us to compute the effects of something as complex and multifaceted as an embargo…

Alternatively, the authors assume that GDP is a function of Gas and Non-Gas, with an elasticity of substitution σ and a share of gas α:[6]

$$Y(\sigma, \alpha, \text{Gas}, \text{Non-Gas}) = \left(\alpha^{\frac{1}{\sigma}}\text{Gas}^{\frac{\sigma-1}{\sigma}} + (1-\alpha)^{\frac{1}{\sigma}}\text{Non-Gas}^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}}$$

Assuming an elasticity of substitution for natural gas $\sigma = 0.1$ and a share of gas $\alpha = 0.01$ and a reduction in natural gas supply equal to 30% allows to compute:

$$\Delta Y = Y(0.1, 0.01, 0.01 * 0.7, 0.99) - Y(0.1, 0.01, 0.01 * 1, 0.99) \approx -2.34\%.$$

This -2.34% number is then rounded up to -3% to give the paper's upper bound for the reduction in GDP…

(2b) The implied change in energy prices is gigantic. The authors emphasize the output effects of the production function approach, but they do not comment much on the *gigantic* energy price changes that their analysis implies. In Bachmann et al. (2022)'s Appendix page 12 (page 29 of this pdf) they note that in the scenario where the drop of energy is 10%, "the marginal product of energy and hence its price rises by a factor of almost 10". To them, this is "borderline reasonable" which explains why to them an elasticity of $\sigma = 0.04$ for energy is the absolute maximum that they are willing to consider. (Note that this however leads to a drop in GDP equal to -1.57%.) The *relative* price change, which is what matters for substitution, is in fact even greater than the absolute price change. (Their model predicts deflation for the price of non-energy goods…) With a constant elasticity of substitution, it is easy to prove that the change in the relative price of energy p_E is related to the change in the quantity of energy E through the formula:

$$\Delta \log(p_E) = -\frac{\Delta \log(E)}{\sigma}$$

For an energy reduction of 10%, and an elasticity of $\sigma = 0.04$, the price is multiplied by a factor:

$$(1-0.1)^{-\frac{1}{0.04}} \approx 13.93.$$

As a consequence, prices have to increase by 1293% (!). Using this formula for a reduction in natural gas equal to -30%, and an elasticity of $\sigma = 0.1$ shows that prices need to increase by 3440%:

$$(1-0.3)^{-\frac{1}{0.1}} \approx 35.40.$$

This calculation is not reported in Bachmann et al. (2022), but this is what the production function approach implies. These price changes need to be taken seriously, since the authors advocate to let the price mechanism work in order to help achieve substitution, rather than to use rationing schemes for example.[7]

(2c) What are the implications of these gigantic price changes? These gigantic price changes have important implications which contradict the main message in the paper: that a Russian gas embargo would have only small effects on the overall economy. As has been noted before, these gigantic price effects would certainly have big aggregate demand consequences that are not captured in the production function approach: there would be a large transfer of wealth towards energy producing countries, and households'

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[6] Of course, these two formulas are mutually inconsistent models for GDP. Remark (2d) discusses this more.

[7] As a point of comparison, Dutch TTF gas futures trade on August 26, 2022 at around 300€/MWh, compared to around 20€/MWh about a year ago, a 15-fold increase. This is unprecedented, and this is not even the price that all consumers and industries pay for natural gas: in the Bachmann et al. logic, all consumers and industries need to be faced with the spot price for substitution to occur.

purses would be severely hit which would reduce spending on other goods.[8] Lump-sum transfers targeted to low-income households would not be enough to avoid these consequences, as some households might have particularly large budget shares on energy because they live in rural areas and don't have access to other heating technologies. Not the mention the social and political consequences of such large increases in prices, which explain why some economists have instead advocated price caps on energy: see for example Dullien, Weber (2022). Many manufacturing companies would stop producing rather than substitute and use less gas in production. At such high prices, even trading on energy might stop.

(2d) Energy, gas, gas in Karlsruhe or in Hamburg? Comparing the formula where GDP depends on Gas and Non-Gas and the formula where GDP depends on Energy and Non-Energy should lead us to ask the following question: which formula should we favor, and if we believe that breaking-up energy into natural gas and other types of energy is necessary because they are imperfect substitutes, then why stop here? For example, considering natural gas as a whole, why not assume that there is imperfect substitution between gas available in one location in Germany with gas available in other locations, and the rest of the economy? Indeed, natural gas cannot be easily transported through Germany, and oftentimes needs to be present in some given location: so it matters whether natural gas in Karlsruhe or in Hamburg. In such a case, there could actually be a drop of -100% in that particular location, which according to the production function approach would then lead to a -100% drop in GDP as well… The point is not to take any of this seriously, but rather that it is very hard to conclude: the GDP numbers one gets from the production function approach seem largely arbitrary, depending on the level of sectoral / geographical decomposition.

(2e) High sensitivity to "the elasticity". The results, it turns out, are quite sensitive to the choice of "the elasticity", assuming that there exists such a thing as "the elasticity" (see remark (2f)). It is mathematically incorrect, as Baqaee et al. (2022) claim that "a world where substitution is impossible, and a world where even a small amount of substitution is possible, behave drastically different at the macro level." For example, the authors are willing to assume an elasticity of $\sigma = 0.04$ for energy, but do not get below $\sigma = 0.1$ for natural gas to get their headline numbers of -1.57% or -2.34%. If one instead uses an elasticity of $\sigma = 0.04$ for natural gas as well, then one gets a -15.26% drop in GDP, which is much lower than the headline estimate of -2.34%:

$$Y(0.04, 0.01, 0.01 * 0.7, 0.99) - Y(0.04, 0.01, 0.01 * 1, 0.99) \approx \mathbf{-15.26\%} \ll -2.34\%.$$

Therefore, a world where a small amount of substitution is possible can behave very much like a world where substitution is impossible. In fact, the results depend a lot on the elasticity.

(2f) What is "the elasticity"? As can be seen, the results are very sensitive to the value of "the elasticity". So, how is "the elasticity" chosen? For calibration, the authors point to various studies such as Labandeira et al. (2017), or another by Auffhammer and Rubin (2018). The problem is that few studies in the meta-study by Labandeira et al. (2017) are on natural gas, all studies were published before 2008, the estimates have a large standard deviation which is as large as the average, and the median is much closer to 0 than the average estimate.[9] One also worries about publication bias, as the sign of the elasticity is known, which leads to **overestimation** in absolute value through a meta-study. Even more importantly, there is no reason to believe in external validity with respect to these estimates as the magnitude of the embargo that Germany would have to face has never been observed before: it is likely that "the elasticity" could drop as natural gas comes in shorter supply (see remark (2h)). Auffhammer and Rubin (2018) report elasticities for residential natural gas usage in California, which arguably has a different climate than Germany. Not to mention that realistically, more of the adjustment would bear on the industrial sector, which has a lower elasticity of substitution in the limit (see remark (1e) for a discussion). In these

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[8] An alternative could be that the government finances this through twin fiscal/trade deficits, but this situation cannot last for long.
[9] Moreover, the meta-study does not estimate the elasticity to the *material* usage of natural gas (Krebs (2022)).

conditions, why would values of elasticities for natural gas below 0.1 be "nonsensical"? As shown in remark (2e), using an elasticity equal to 0.04 instead of 0.1 one gets an estimate of -15.26% instead of -2.34%.

(2g) Opening up the "black box" of substitution. In fact, there is probably not such thing as "the elasticity", even regardless of the magnitude of the shock. "The elasticity" of substitution is actually a very crude and reduced form way of trying to capture what would happen if the price of natural gas was to increase substantially, or if natural gas was rationed through some other (non-price) mechanism. Finding new technologies which economize more on gas requires time, but also resources and some R&D by engineers: there is no reason to think that these costs would be captured in a reduced form elasticity of substitution. They would also depend on the overall availability of such skills, etc. In this context, subsuming the process of replacing natural gas through a single parameter seems like a hopeless endeavor.

(2h) Evidence against Leontief production functions? Strictly speaking, a Leontief production function implies no possibility of substitution between energy (or natural gas) and other goods anywhere. "Elasticity optimists" keep pointing at examples of possible substitution of energy in practice to argue that Leontief is "nonsensical" but the fact that substitution becomes impossible when too much natural gas is lacking need not imply that there's no substitution at first. Proofs of some substitution at the microeconomic level do not tell us much about how easy natural gas is to substitute when quantities fall in large amounts. Examples of substitution do not help reject that production functions display complementarity in the limit, unless one lives in the world of Constant Elasticity of Substitution functions. Only in this world, if there is no substitution at some point, then this means that there must not have been any substitution ever. But that's a very restrictive set of functions, and in reality, production functions do not belong in that family. There are in fact reasons to believe that elasticities of substitution start declining as the quantity of an input such as gas goes to 0, as in Geerolf (2019) where "superelliptic" production functions are proposed as an alternative to constant elasticity production functions that have this property. In the chemical industry for example, natural gas used for heating purposes can be replaced, but natural gas used as a material input in production cannot. Thus, examples of *some* substitution (such as substitution of gas for heating) at some point are not a proof that perfect complementarity is nonsensical later (once you start wanting to replace natural gas as material).

Moreover, it is important to note that elasticities of substitution do not average out. Assuming an elasticity of substitution equal to infinity for half of the natural gas that is consumed, and 0 for the remaining half of the natural gas, one would still get a 15% drop in GDP for a 30% reduction in gas supply.

(2i) Economic theory or mathematics do not allow to conclude that "Leontief is nonsensical", especially in the limit. As we have seen in remark (2h), some substitution at first is compatible with perfect complementarity in the limit, since production functions are not a priori characterized by constant elasticities of substitution. But even a fully Leontief production function at the aggregate level would not, on the basis of economic theory alone, be "nonsensical", as argued by the authors. The argument of the authors goes like this: if production functions are Leontief, then a reduction in the quantity of energy would lead other factors to become completely useless at the margin, so that their price would drop to 0, and the share of energy in GDP would become equal to 100%. There are many reasons why if high-skilled chemical engineers become unemployed in the chemical industry because there is no more natural gas to produce output, all wages of high-skilled workers will not suddenly fall to 0: wages are not set every period as the neoclassical view of the labor market has it, there would be insurance schemes which would put a floor on workers outside options, high-skilled chemical engineers cannot immediately compete for high-skilled jobs in finance, etc.

Whether the economy is rather characterized by high or low elasticities is a long-standing debate in economics: neoclassical economists are often willing to assume high substitutability[10], while Keynesian

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[10] Not just for energy but also for labor, for capital/labor substitution, etc. Whether elasticities are large or small is at the heart of many economic policy questions: taxation, the environment (carbon tax), secular stagnation, etc.

economists (especially post-Keynesian economists) often assume lower elasticities. At the aggregate level, Paul Samuelson, one of the fathers of neoclassical economics, was contemplating in 1948 in his economics textbook that the production function might actually be Leontief between capital and labor, that is that capital and labor may be perfect complements.[11] So economic theory or mathematics do not imply that Leontief is "nonsensical" as argued by the authors, or that the shares of different factors necessarily go to 0 or 100%. It just implies that production functions are not smooth and differentiable, so that marginal products are indeed not well defined, and marginalists' definition of "value" does not apply.[12]

3) Some remarks on the so-called "sufficient statistics" approach (also based on Baqaee-Farhi)

As we can see, neither the so-called "Baqaee-Farhi approach", nor the "production function approach" can reassure us that the effects of an embargo of natural gas would not be larger than 3% of GDP. What about the so-called "sufficient statistics" approach? This approach, also based on work by Baqaee-Farhi, holds that for a large class of models, regardless of the structure of the production system, a second-order approximation of the effect of losing natural gas only depends on the initial share of natural gas, and the change in that share should the embargo takes place. According to the authors, applying this sufficient statistics approach to the problem at hand guarantees that the economic losses from an embargo would remain "small"[13], and allows to compute a point estimate of 1% of GDP. But unfortunately, this approach is not really operative here either, for many reasons, and in any case it does not at all guarantee that the losses from an embargo would be small.

(3a) The "sufficient statistics" approach is not operative: the "energy share of natural gas" conditional on an embargo is unknown. In order to apply the "sufficient statistics approach", one needs to know how much the share of energy imports would rise conditional on an embargo. Unfortunately, there is no way to know what that number would be, since it depends on what would occur, should an embargo take place. In other words, the so-called "sufficient statistic" here is not readily observable and in any case cannot be identified through exogenous microeconomic variation, which is acknowledged very transparently in Baqaee and Farhi (2019a).[14] One approach measure this would be to refer to a historical precedent. But here too, the problem is the same: Germany, or for that matter another country, has never had to cope with a natural gas embargo of that magnitude. In particular, the two oil shocks in the 1970s are not a good point of comparison. There is no reason to think that a Russian gas embargo would lead to a change in the energy share similar to what the world has experienced during the two oil shocks in the 1970s (a tripling of that share), and yet this is what the authors assume. This past situation is not even remotely comparable: oil is very different from natural gas in terms of its use, 2022 is very different from 1973-1979, the shock was then at the world level while it would this time be at the level of Germany, or at the level of Europe, etc. In such a situation, there is no reason why the energy share of gas would only triple.

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[11] From _Economics_ by Paul Samuelson. Paul Samuelson first gives the definition of a Leontief production function, in a case where the two factors are not energy and non-energy as here, but labor and capital: "One catch to this theory was the fact that often product seems to depend upon a joint combination of labor and capital in such a way that increasing one without increasing the other results in no extra product; whereas decreasing the one without changing the other often results in a loss of product equal to the whole productivity of the combined "dose"." He then contemplates the implications of such Leontief production functions on factor shares for labor and capital: "The marginal product theory then would set limits on the separate shares of labor and capital which varied between 0 and 100 per cent. Of course, such limits would be quite useless and would make a mockery of the proposed theory of distribution."

[12] In that respect, this is an example of what Paul Romer (another Nobel laureate) calls "mathiness". See Romer, P. M. (2015). Mathiness in the Theory of Economic Growth. _American Economic Review_, _105_(5), 89-93.

[13] The full quote is: "The model simulations in the next section imply that, while this share rises considerably, it does not rise by an unreasonably large amount. This will imply that the GNE losses of an embargo on Russian energy are _small_."

[14] As such, it is not as useful and powerful as the "sufficient statistics" approach in public finance, where it allows to avoid fully specifying a structural model, and estimate sufficient statistics through quasi-experimental evidence. It just says that the change in the (and the initial) energy share is all that matters, and that two models will lead to the same predictions (at the second order) if both are the same. For more on the sufficient statistics approach in public finances, see Chetty, R. (2009). Sufficient Statistics for Welfare Analysis: A Bridge Between Structural and Reduced-Form Methods. _Annual Review of Economics_, _1_(1), 451-488.

Moreover, even though the authors forcefully argue against it from a policy perspective, the adjustment would need to take place through rationing and not just through the price mechanism (again, see remark (2b)), simply because markets would shut down given the large price changes which are needed, so that the energy share of natural gas could rise by less through these non-price mechanisms, and the formula would not apply anymore. In the 1970s, many countries were similarly resorting to non-price rationing mechanisms in order to reduce the energy bill: without them, the share of energy imports in GDP would probably have increased by even more.

(3b) Hulten's theorem: a faulty logic. Even if this sufficient statistics approach was applicable, the second-order approximation ("sufficient statistics approach") is only an improvement on a first-order approximation ("Hulten's theorem") which is very problematic. According to that first-order approximation, the impact of an embargo on natural gas would be given by the share of natural gas in output. Since the share of natural gas in GDP is rather small, say equal to 1.7% of GDP, then to the first-order a cut of 30% in gas supply would then lead to only a reduction in 0.3*1.7%=0.51% of GDP.

The problem is that in the case of energy, "Hulten's theorem" really isn't a good starting point. Larry Summers at the 2013 IMF Annual Research Conference (where he made is famous "secular stagnation" speech) likened the financial crisis in 2007-09 to a power failure. He mocked a naïve vision some neoclassical economists could have (he talked about "people in Minnesota and Chicago") who would then use "Hulten's theorem" in order to calculate the effects of such power failure, as everyone could see that if there wasn't much electricity there would not be much economy.[15] Arguably, this is not what Bachmann et al. (2022) have done, but improving on such a faulty logic unfortunately does not always lead to something good. Baqaee and Farhi (2019a) warned us: "In (these) limiting cases, the first-order approximation is completely uninformative, even for arbitrarily small shocks." In 2007, many economists were also arguing that subprime losses were tiny as a percentage of GDP, so could not lead to a major crisis.

Intuitively, we can see that Hulten's theorem isn't a good starting point also because the share of energy in GDP varies a lot over time, mostly with the price of oil (since again, substitution is very limited). Thus, depending on when the forecaster applies Hulten's theorem, he might conclude that the effects of an embargo will be very high when energy prices are high, and conversely when energy prices are low… This shows very intuitively that there is an intrinsic problem with that logic.

(3c) "Second-order" effects should not be first-order. Unfortunately, the second-order effects calculated through the so-called "sufficient statistics" approach are first-order according to the authors' own calculations, which contradicts the hypothesis that would justify this calculation. For example, page 13 of the appendix, the first-order effect is equal to the second-order effect, equal to -0.36% of GDP:

$$\Delta \log W \approx 1.2\% \times -30\% + \frac{1}{2} \times 2.4\% \times -30\% = -0.36\% - 0.36\% = 0.72\%$$

This invalidates the first-order approximation. It implies that the second-order approximation is really not enough, and that third-order or fourth-order terms, etc. would lead to much larger estimates.

(3d) Some other problems. First, the whole sufficient statistics approach relies on a local approximation, and therefore relies on the assumption that the shocks considered are rather small, which is clearly not the case with an embargo and a reduction of 30% in natural gas supply.[16]

Even for small shocks, the sufficient statistics approach relies on non-Leontief production functions, which as was argued in remark (2g) is not necessarily the case, at least in the limit where the drop in natural gas

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[15] Listen to the speech here: "There'd be a set of economists who would sit around explaining that electricity was only 4% of the economy and so if you lost 80% of electricity you couldn't possibly have lost more than 3% of the economy. And there would be, you know, there'd be people in Minnesota and Chicago and stuff would be writing that paper... but it would be stupid! It would be stupid! And we'd understand that, somehow, even if we didn't exactly understand in the model, that when there wasn't any electricity there wasn't really going to be much economy."

[16] There is a similar problem when one log linearizes a macroeconomic model, which is then used to study large movements in economic activity, such as the Great Depression.

supply becomes large. In such a case, Hulten's theorem does not even provide a good first-order approximation, even for small shocks (Baqaee and Farhi (2019a)).

Another assumption which needs to be valid for the sufficient statistics approach to be practicable is that there is what economists call "efficiency" which is far from certain, especially in the manufacturing sector where much of this is taking place which is characterized by increasing returns to scale and thus scope for inefficiency in the neoclassical sense.

4) <u>Some more general remarks</u>

Let me end with some more general remarks. In my mind, this policy paper is indeed revealing about many economists' perception of engineers, but also about the shortcomings of the neoclassical school's approach towards energy, and the manufacturing sector more generally.

(4a) Engineers vs. economists. In the paper and in the public debate, Bachmann et al. (2022) tend to be very dismissive of the "engineering view" which is the view that substitution of natural gas is really very hard, if not sometimes infeasible. They contrast it with what they call the "economic view" which to them is more general, because it for example takes into account substitution through imports but also creative destruction. But the fact that these key inputs will be sourced through trade rather than internally isn't an adjustment mechanism which only increases substitution, it's also a force which might hurt Germany in the long run, just as creative destruction: imports will strengthen German manufacturing firms' competitors, and creative destruction implies that German industry will be hurt. In my view, engineers might be right after all when they are more pessimistic and do not see those as a true adjustment mechanism. Moreover, only engineers can tell us how easy substitution on that scale would be, given that this has never been done before in history. In the context of substituting Russian natural gas, only engineers can help us find technologies that economize more on energy: for neoclassical economists, there is somewhat of a contradiction in assuming that everything will be fine because engineers will always find a way, but at the same time that they tend to look down upon engineers.[17]

(4b) Energy is special, and manufacturing is special as well. One thing which engineers know well, perhaps better than economists, is that energy is really special for the workings of the economy, and particularly in the manufacturing sector. In particular, energy is much more important for the macroeconomy than its share in GDP would suggest, which again explains why Hulten's theorem is such a failure – see remark (3b).[18]

Manufacturing is also key to economic prosperity, again much more than its share in GDP would seem to suggest – again a failure of Hulten's theorem and growth accounting. In the economics literature, this phenomenon is often referred to as Baumol's disease: the fact that productivity gains in the manufacturing sector are much higher than in the service sector on average. This is actually another one of Baqaee and Farhi (2019a)'s examples in their Econometrica paper, which presents the limit of Hulten's theorem: the

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[17] Abhijit Banerjee and Esther Duflo have a more modest view of the role of economists in *Good Economics for Hard Times*. To them, economists are "several rungs below engineers", because unlike engineers, economists cannot rely on fundamental laws which are given to them by scientists: "Anyone who has watched the comic TV series *The Big Bang Theory* knows that physicists look down on engineers. Physicists think deep thoughts, while engineers muck around with materials and try to give shape to those thoughts; or at least that's how the series presents it. If there were ever a TV series that made fun of economists, we suspect we would be several rungs below engineers, or at least the kind of engineers who build rockets. Unlike engineers (or at least those on *The Big Bang Theory*), we cannot rely on some physicist to tell us exactly what it would take for a rocket to escape the earth's gravitational pull. Economists are more like plumbers; we solve problems with a combination of intuition grounded in science, some guesswork aided by experience, and a bunch of pure trial and error."

[18] This problem is very pervasive in the neoclassical school. I think it also explains why neoclassical models of trade tend to understate so much the "gains from trade" (not more than a few percentage points of GDP): energy, which many advanced economies are net importers of, is much more useful than in models with Constant Elasticity of Substitution production functions, and also much more useful than its price suggests. As stated in remark (3b), the share of energy imports anyways fluctuates a lot over time with its price, for reasons that have nothing to do with how useful energy is for the importing country.

first application of this paper is energy, and the second one is on Baumol's disease… As a consequence, the comparisons in terms of GDP losses between Covid-19 and what would happen should Russian gas be cut are not valid, and the number of employees working in both sectors does not represent the relative economic importance of manufacturing versus restaurants for an economy like Germany, either.

Manufacturing is also special in many other important ways which the authors do not take into account. Perhaps most importantly, there are strong hysteresis effects in manufacturing, which matters a lot in this case. Indeed, many industries (e.g. German glass manufacturing companies) fear that if they have to shut down for a year in the case where Russian gas is shut off, the industries will not come back. Many of high value-added industries are indeed "winner-takes-all" industries, because of increasing returns, learning by doing, and the dynamic effects would need to be seriously taken into account. In that respect the "economic view" takes into account channels of substitution (imports, creative destruction) that engineers would tend to see more as threats.

The policy report by Bachmann et al. (2022) is also revealing in that neoclassical economists are often skeptical, even critical towards the industrial sector. They complain about industrial policy, that the industry too often has the ear of governments, and this study is just another example of this. Why that is would deserve some independent developments: perhaps because increasing returns open the scope for government intervention (industrial policy, strategic trade policy[19], etc.), make the assumptions of "welfare theorems" invalid and tend to lead to "anything goes" results? Or perhaps for sociological reasons: economists do not have as much expertise on this sector as engineers? (vs., for example, the financial sector)

5) Conclusion - "Whereof one cannot speak, thereof one must be silent"[20]?

I do not wish to argue that I (or the authors) could have done much better, if getting a quantitative estimate through a macroeconomic general equilibrium model was the name of the game: in fact, the speed at which the authors carried out this analysis is impressive especially given the time limit (a few weeks) and they had other choice than to use existing models, which were not specifically designed to answer this particular question. I am also aware that criticism is easy, and according to the old adage "all models are wrong".

But to me, the costs of an embargo are nearly incalculable and I think at this stage it is best for economists to admit that "economic science" is unable to provide us with a reliable quantitative estimate. A quantitative analysis should have taken into account "where is the gas actually supposed to run through, where are the pipelines, what is the regasification capacity, where are the terminals", as Olaf Scholz has said, because these are first-order issues. Unfortunately, I have no special expertise on all of this. Based on case studies, previous historical episodes, the general sensitivity of GDP to a rise in energy prices, press articles about how different industries might be able to cope, etc. I would not be surprised if the cost of an immediate embargo in March would have been as high as 6% of GDP, so way higher than the authors' central estimate, and even than the authors' upper bound of 3% of GDP. But this is unfortunately not much more than my prior. The point that I wished to illustrate in this note is that economists should have been way more prudent in communicating their results, and the large uncertainty / limitations should have been conveyed to decision makers rather than pretend that economists have great models to answer these issues. Since then, the baseline or adverse scenarios in the case of a cutoff of natural gas impact by major German institutes (such as the Joint Economic Forecast), the Bundesbank, or the IMF have also been much higher than Bachmann et al. (2022)'s and an order of magnitude higher than in the CAE report by Baqaee et al. (2022) (see for example, Table 1 of Lan et al. (2022); see also a new evaluation by Tom Krebs (2022)).

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[19] This is a long-standing issue. See, for example, the debates in *Foreign Affairs* in 1994 with Paul Krugman, Lester Thurow, etc. Thurow, L. C. (1994). Microchips, Not Potato Chips. *Foreign Affairs*, *73*(4), 189-192. Prestowitz, C. V. (1994). Playing to Win. *Foreign Affairs*, *73*(4), 186-189. Krugman, P. (1994). Competitiveness: A Dangerous Obsession. *Foreign Affairs*, *73*(2), 28-44.

[20] Ludwig von Wittgenstein's Tractatus 7, cited in Abhijit Banerjee and Esther Duflo's *Good Economics for Hard Times*.

In Germany the question was whether the effect of a Russian gas embargo would be major or not. One can only hope that a sudden stop of energy imports would have small economic consequences, since Russia may soon decide to cut natural gas supplies to Europe on its own. But in my view, it is clearly not the case, and the consequences would have been (will be) much more adverse. And as this note has hopefully helped show, economic reasoning and evidence more generally, are unfortunately guaranteeing no such thing.

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