An Empirical Approximation of the Effects of Trade Sanctions with an Application to Russia*

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November 2023

Abstract

We propose a data-based approximation of the effects of trade sanctions that can readily be computed on the basis of international input-output data. Approximated effects are very close to the exact responses obtained from a canonical multi-country multi-sector model, without having to make difficult calibration choices. We illustrate the approximation with trade sanctions against Russia and obtain estimates well within the existing range. Russia is much more affected by trade sanctions than the EU, even though the importance of EU markets for Russia has been falling, especially since 2014 with China picking up the slack. Within the EU the consequences are largest in ex-"satellite" countries of the Soviet Union: These countries do not typically have access to substitute markets and in fact have historically been highly dependent on Russia. This extreme and persistent dependence is at least partly explained by the existence of specific energy transporting infrastructure (pipelines) that appears to constrain tightly the production of electricity. Our proposed approximation is practical and can be implemented in a variety of contexts: We have developed a web-based dashboard, accessible at exposure.trade that can be used to approximate the costs of trade sanctions for any combinations of sanctioning and sanctioned countries or sectors.

JEL Codes: F14, F42, F51.
Keywords: European Energy Imports, Russian Sanctions, Economic Consequences of Sanctions, Global Value Chain.

*We thank two anonymous referees, our discussant Inga Heiland, the participants at the 77th Economic Policy Panel, and the editor Isabelle Méjean. The data are available from https://zenodo.org/records/10122045 and the replication codes from https://zenodo.org/records/10184324. Please consult our web-based dashboard for bespoke simulations at https://exposure.trade/. All errors are our own.

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”*We have to get rid of our dependency on Russian fossil fuels all over Europe. Last year, Russian gas accounted for 40% of our gas imports. Today it's down to 9% pipeline gas.*”

Ursula Von Der Leyen, State of the Union 2022

1 Introduction

The invasion of Ukraine in February 2022 has had immeasurable human and economic consequences. Global trade had barely recovered from the pandemic when tensions rose again, rippling through global value chains as talks of sanctions and embargoes intensify. In this paper we propose a data-based approximation of the consequences of trade sanctions that is both easy to compute and reasonably robust to alternative parametrizations, particularly as regards the substitutability between goods.[1] We apply the approach to trade sanctions between Europe and Russia. Our hope is to illustrate the relative simplicity of our data-based approach with acceptable limitations.

The approximation relies on the fraction of nominal output that is supplied from (or sold to) a sector that is subjected to an embargo. The numerator is computed allowing for the *indirect* trade linkages affected by an embargo. We show in a canonical multi-country multi-sector model that the response of sector-level value added to an embargo is in fact well approximated by this ratio. Simulations show that the approximation holds best for high substitutability between inputs, but is still palatable for low elasticities.

We consider two types of sanctions: an embargo on Russian exports to Europe, and an embargo on European exports to Russia. For each type we approximate the effects on the Russian economy and on individual European countries. We document the sometimes very large differences in approximated effects that would emerge from the use of direct trade as opposed to indirect trade measures. For example, we approximate the effects in Europe of an embargo on Russian (energy) exports by the fraction of production in European sectors that remunerates (energy) inputs from Russia, inclusive of indirect linkages. The approximation includes for instance the forgone production of steel or cars in Germany as direct imports of Russian oil are embargoed. This is potentially very different from the value of direct oil exports to Europe as a share of production in Russia (ignoring indirect linkages). This difference is important because direct trade ratios are usually central to policy discussions about the interdependence between countries. And they are often a basis for rule-of-thumb approximations of the consequences of sanctions, as in the quote by Ursula von Der Leyen in her 2022 State of the Union speech that opens this paper.

The differences between direct and indirect measures of trade linkages between Russia and

[1] See Bachmann et al. (2022) or Baqaee and Farhi (2019) for a discussion of the importance of elasticities of substitution in this context. See also the application in Lafrogne-Joussier et al. (2022).

European countries are far from proportional: indirect trade is between 2 and 40 times larger than direct trade across countries. Therefore, direct trade measures do not provide a proper estimation of the effects of trade embargoes. Between Europe and Russia, we document that this ratio takes largest values between Russia and "satellite" countries such as the Baltic States and Eastern Europe. The ratios are much lower for large western European economies. This suggests that value chains are important and integrated between Russia and these geographically close economies. But trade with Germany or France is essentially horizontal, commodity based with short supply chains.

The first embargo we consider targets Russian exports to Europe, either focused on energy producing sectors or applied to all activities. We find that an embargo on Russia's energy exports affects mostly Russia's energy producing sectors, but also some manufacturing and transport services. The overall effect on the Russian economy is small, 1.17 percent decrease in GDP. The effect on the European economy is 15 times smaller, a decrease of 0.08 percent in European GDP. We note some asymmetries, with heavy manufacturing, transport services, and extractive sectors affected the most in Europe. But the most salient asymmetry happens between countries: Bulgaria, Estonia, Latvia, Lithuania, Finland, or the Czech Republic are much more affected than, say, France of Germany, which contributes to explaining the very low aggregate effect on Europe.

A blanket embargo on Russian exports to Europe has larger consequences. The effect on the Russian economy is a substantial 3.4 percent fall in GDP; The effect on the European economy is still small, 0.23 percent fall in the European GDP, still about 15 times smaller. Again, the most affected European countries are Russia's ex-satellites while large European economies are barely affected.

The second embargo we consider targets European exports to Russia. We find a very small effect on the European economy, about 0.24 percent, because the most affected countries are once again small economies relatively close to Russia. Large economies are almost insulated from the shock. The effect on Russia is much larger: a fall of 1.31 percent of Russian GDP, about 5.5 times larger than the effect on Europe. The consequences of the embargo are once again highly asymmetric, affecting Russia much more than Europe. An embargo on Russian exports to Europe has substantially larger consequences on both regions than the opposite embargo on European exports to Russia. Russia depends much more on its exports to Europe than it does on its imports from Europe. Europe as a whole does not depend heavily on imports from Russia (although some EU member countries do) and it barely depends at all on its exports to Russia.

A key feature that determines the efficacy of trade embargoes has to do with the availability of alternative exports markets or input suppliers. While we cannot amend the approximation of the effects of trade sanctions accordingly, we can use indirect trade data to characterize alternative supply chains available to the two parties involved in an embargo. We show that Russia and Europe are very asymmetric in that respect. Alternatives to Russian exports markets in the EU are few and far between, and constitute a considerably smaller share of Russian output than European markets. For example, in 2018 Russia sells the equivalent of 34.3 percent of its energy to European-based supply chains. Its next highest export market is China, but the share of that market in Russia output is 16.7 percent, about 50 percent smaller. Interestingly, the share of the EU at its peak in 2008 was substantially larger (52.7 percent): it decreased sizably over the period, with an acceleration around the invasion of Crimea in 2014. This fall was partly compensated by an increase in the share of China.

On the other hand, France or Germany import energy inputs from other sources than Russia, and in equal proportions. For example, Russian energy inputs constitutes about 4 percent of the production of German electricity, but Norwegian supply actually represents 5 percent. Since the 2000s, large European economies have had access to alternative supply chains from which to source energy inputs - Saudi Arabia, Norway, Kazakhstan - whose importance is comparable to that of Russia. By contrast, small Eastern European countries have not had access to alternative suppliers: for instance in 2018 the largest alternatives to Russian energy inputs available to Bulgaria are South Africa or Turkey, whose shares are minuscule. The numbers have barely changed since these countries accessed the EU: The diversity of available supply chains is close to non-existent for small, ex-satellite countries in Europe. We discuss one potential explanation of this dependence: The existence of pipeline infrastructure between Russia and its small European neighbors that have historically prevented these economies from redirecting their input imports away from Russia. This finding reinforces the relevance of a discussion about the sharing of the burden of sanctions costs within groups of sanctioning countries, particularly the European Union.

Estimating the effect of trade disruptions, e.g., caused by sanctions, is a venerable literature that has experienced a revival with the invasion of Ukraine and its consequences on world trade. Crozet et al. (2021) document firm behavior in the presence of sanctions. Exploiting the COVID pandemic as a natural experiment, Lafrogne-Joussier et al. (2022) examine how firms substitute suppliers when faced with shortages. Bonadio et al. (2021) study the propagation of disruptions in the supply chain caused by lockdown shocks from COVID. Ghironi et al. (2022) explore the welfare losses created by joint trade and financial sanctions. Eichengreen et al. (2022) study the consequences of trade sanctions on exchange rates throughout recent history. Huo et al. (2021) selectively shut down trade in their multi-country multi-sector model to evaluate the role of supply chains in shock propagation. de Souza et al. (2022) analyze the design of cost-efficient sanctions targeting specific Russian sectors. Bachmann et al. (2022) simulate the canonical model in Baqaee and Farhi (2019) to evaluate the consequences on Germany of a ban on Russian energy inputs.

Two conclusions emerge from this literature. First, the costs of trade sanctions are typically small, a fraction of a percentage of GDP, except when substitution is actually impossible, i.e., with elasticities of substitution equal to zero. Second, in most cases empirical estimates of these parameters are hard to come by. As a result most simulations run extensive robustness checks along this dimension. For example Bachmann et al. (2022) simulate many versions of Baqaee and Farhi (2019) even though the key elasticity in their exercise (between energy inputs and other factors of production) is estimated in a large literature.

We make three contributions. First, our proposed approximation of the effects of trade sanctions can be readily computed from international input-output tables. Most existing models imply that trade sanctions have low costs, despite very different theoretical environments and calibrations. In these models, sanctions only have high costs in the extreme case of non substitutability. In such a context, the empirical approach can have some merit in the sense that it replicates the low costs of trade sanctions without a model. Our second contribution is precisely to exploit historical input-output data to document how much substitution did in fact happen at sector level in response to geopolitical tensions. This approach is akin to what Fontagné et al. (2023) establish at the level of French firms. Finally, we have designed a web-based interface available at exposure.trade that can be used to perform our approximation with great flexibility. The dashboard provides an environment in which approximations of the effects of trade sanctions can be obtained over time, for any sanctioning countries, and for any set of sanctioned sectors or countries. It is meant for students of geoeconomics as a quick and flexible alternative to fully calibrated models of trade.

2 The model

This Section presents a multi-country, multi-sector model with input-output linkages adapted from Imbs and Pauwels (2022) and Huo et al. (2021). The model's linearized equilibrium provides an expression for the response of production to trade shocks and disciplines its approximation using data-based ratios.

2.1 Building blocks

Production in sector r of country i is given by

$$\mathrm{Y}_i^r = \mathrm{Z}_i^r \ \left[(\mathrm{H}_i^r)^{\alpha^r} (\mathrm{K}_i^r)^{1-\alpha^r}\right]^{\eta^r} (\mathrm{M}_i^r)^{1-\eta^r},$$

where Z_i^r is a supply shock, H_i^r denotes labor input, K_i^r is capital input, and intermediate input $\mathrm{M}_i^r = \left(\sum_j \sum_s (\mu_{ji}^{sr})^{\frac{1}{\epsilon}} (\mathrm{M}_{ji}^{sr})^{\frac{\epsilon-1}{\epsilon}}\right)^{\frac{\epsilon}{\epsilon-1}}$, where μ_{ji}^{sr} is a taste shifter and ϵ is the elasticity of substitution between varieties of the intermediate goods.[2] Throughout the paper, subscripts denote countries and superscripts denote sectors. Both indexes are ordered so that the first identifies the location of production, and the second identifies the location of use. Capital is predetermined. Cost minimization implies

$$\begin{aligned} \mathrm{W}_i^r \, \mathrm{H}_i^r &= \alpha^r \eta^r \, \mathrm{P}_i^r \, \mathrm{Y}_i^r, \\ \mathrm{P}_{ji}^{sr} \, \mathrm{M}_{ji}^{sr} &= \xi_{ji}^{sr} (1-\eta^r) \, \mathrm{P}_i^r \, \mathrm{Y}_i^r, \end{aligned}$$

where P_{ji}^{sr} is the price of the intermediate input produced in sector s of country j and used in sector r of country i and P_i^r is the price of output in sector r of country i. The expenditure share ξ_{ji}^{sr} is given by

$$\xi_{ji}^{sr} = \frac{\mu_{ji}^{sr} (\tau_{ji}^{s} \, \mathrm{P}_j^s)^{1-\epsilon}}{\sum_{k,l} \mu_{ki}^{lr} (\tau_{ki}^{l} \, \mathrm{P}_k^l)^{1-\epsilon}}.$$

Cost minimization implies that $\xi_{ji}^{sr} = \frac{\mathrm{P}_{ji}^{sr} \, \mathrm{M}_{ji}^{sr}}{\mathrm{P}_i^r \, \mathrm{M}_i^r}$. Throughout, transport costs τ_{ji}^s are such that $\mathrm{P}_{ji}^{sr} = \mathrm{P}_{ji}^s = \tau_{ji}^s \, \mathrm{P}_j^s$. The purpose of the model is to evaluate the response of production to transport costs shocks and to evaluate the precision of our proposed approximation.

Households choose consumption to maximize $\mathrm{U}\left(\mathrm{C}_i - \sum_r (\mathrm{H}_i^r)^{1+\frac{1}{\psi}} \right)$ subject to $\mathrm{P}_i^c \, \mathrm{C}_i = \sum_r \mathrm{W}_i^r \, \mathrm{H}_i^r + \sum_r \mathrm{R}_i^r \, \mathrm{K}_i^r$, where

$$\begin{aligned} \mathrm{C}_i &= \left[\sum_j \sum_s (\nu_{ji}^s)^{\frac{1}{\rho}} (\mathrm{C}_{ji}^s)^{\frac{\rho-1}{\rho}} \right]^{\frac{\rho}{\rho-1}}, \\ \mathrm{P}_i^c &= \left[\sum_j \sum_s (\nu_{ji}^s) (\mathrm{P}_{ji}^s)^{1-\rho} \right]^{\frac{1}{1-\rho}}, \end{aligned}$$

P^c denotes the consumption price index, ν_{ji}^s is an exogenous taste shifter, ρ is the elasticity of substitution between final goods, R_i^r denotes the rental rate of capital, and W_i^r denotes the wage rate in sector r of country i. Labor supply is given by

$$\mathrm{H}_i^r = \frac{\psi}{1+\psi} \left(\frac{\mathrm{W}_i^r}{\mathrm{P}^c} \right)^{\psi},$$

Expenditure shares in the final good are given by

$$\pi_{ji}^s = \frac{\nu_{ji}^s (\tau_{ji}^s \, \mathrm{P}_j^s)^{1-\rho}}{\sum_{k,l} \nu_{ki}^l (\tau_{ki}^l \, \mathrm{P}_k^l)^{1-\rho}} = \frac{\mathrm{P}_{ji}^s \, \mathrm{C}_{ji}^s}{\sum_{k,l} \mathrm{P}_{ki}^l \, \mathrm{C}_{ki}^l} = \frac{\mathrm{P}_{ji}^s \, \mathrm{C}_{ji}^s}{\mathrm{P}_i \, \mathrm{C}_i}.$$

Equilibrium is defined by a set of allocations and prices such that households maximize

[2] All inputs are therefore equally substitutable, a simplifying assumption that is key for our proposed approximation.

utility, firms maximize profits, and all markets clear. For each country-sector (i, r) markets clear according to

$$\mathrm{P}_i^r\,\mathrm{Y}_i^r = \sum_j \mathrm{P}_j^c\,\mathrm{C}_j\,\pi_{ij}^r + \sum_j \sum_s (1-\eta^s)\,\mathrm{P}_j^s\,\mathrm{Y}_j^s\,\xi_{ij}^{rs}, \tag{1}$$

where we used the facts that $\mathrm{P}_{ij}^r\,\mathrm{C}_{ij}^r = \mathrm{P}_j^c\,\mathrm{C}_j\,\pi_{ij}^r$ and $\mathrm{P}_{ij}^{rs}\,\mathrm{M}_{ij}^{rs} = (1-\eta^s)\,\mathrm{P}_j^s\,\mathrm{Y}_j^s\,\xi_{ij}^{rs}$. Following Huo et al. (2021) we impose financial autarky, which implies all of value added is consumed, i.e., $\mathrm{P}_j^c\,\mathrm{C}_j = \sum_s \eta^s\,\mathrm{P}_j^s\,\mathrm{Y}_j^s$. Market clearing becomes

$$\mathrm{P}_i^r\,\mathrm{Y}_i^r = \sum_j \sum_s \eta^s\,\mathrm{P}_j^s\,\mathrm{Y}_j^s\,\pi_{ij}^r + \sum_j \sum_s (1-\eta^s)\,\mathrm{P}_j^s\,\mathrm{Y}_j^s\,\xi_{ij}^{rs}.$$

2.2 Equilibrium and Approximations

We follow Huo et al. (2021) and express the equilibrium in deviations from a steady state created by shocks to the transport costs τ_{ij}^r. Percentage deviations from the steady state are denoted with $\ln$-deviations and time subscripts. Appendix A details the steps of the derivations establishing that the vector $\ln \mathbf{Y}_t$ of real production at sector level is given by

$$\ln \mathbf{Y}_t = \mathbf{\Lambda}^{-1} \ln \mathbf{T}_t, \tag{2}$$

where $\ln \mathbf{T}_t$ denotes a vector summarizing changes in trade costs across all country-sectors. $\mathbf{\Lambda}^{-1}$ is an influence matrix that spells out how output in each country-sector depends on changes in trade costs potentially everywhere. $\mathbf{\Lambda}^{-1}$ and $\ln \mathbf{T}_t$ are both defined in Appendix A. Like in all models of this class, shocks to trade costs affect the expenditure shares ξ_{ji}^{sr} and π_{ji}^s and the composition of the composite material input M_i^r, see Baqaee and Farhi (2019) for example.

In deviations from the steady state the production function implies that the response of value added to shocks in trade costs is given by

$$\ln \mathbf{V}_t = \alpha \ln \mathbf{H}_t = \frac{\alpha\psi}{1+\psi}\left[\ln \mathbf{PY}_t - \ln \mathbf{P}_t^c\right], \tag{3}$$

where the second equality uses labor market equilibrium, $\ln \mathbf{PY}_t$ denotes the vector of nominal sector-level production, and $\ln \mathbf{P}_t^c$ denotes the vector of consumption price indices, both in deviations from the steady state. The response of value added to trade shocks is therefore proportional to that of nominal production, amended for the response of the consumption price index. The model takes into account all the general equilibrium effects that affect value added in any country-sector in response to a change in trade costs anywhere. At first order, expenditure shares respond immediately to change in trade costs: That changes equilibrium prices and quantities, which has second and higher order effects that the model is designed to capture.

Our purpose is to provide a data-based approximation to $\ln \mathbf{V}_t$, close to the theory implied by equation (3), but that does not necessitate the coding and the calibration of the full general equilibrium of the model described here. This is not meant as a substitute to the model, which continues to be the best approach to obtain precise predictions on the consequences of policy choices under precise parametrization. But parametrization is not easy to discipline, especially as regards the elasticities of substitution. We believe our data-based approximation provides a useful practical approach that bypasses the need for exhaustive parametrization, and facilitates the type of cross-country cross-sector comparisons we present subsequently.

The model implies that the general equilibrium response of value added is exactly proportional to $\ln \mathbf{PY}_t - \ln \mathbf{P}^c_t$. In what follows we describe well-known empirical models of sector-level nominal output $\ln \mathbf{PY}_t$ that approximate the response of value added under the assumption that the response of the CPI is negligible relative to the response of nominal output. A price increase in a subset of sectors in the CPI arithmetically implies a muted response of the price index, which covers all goods in the typical consumption basket. When compared with the response of sector-level nominal output, which typically involves the directly affected sector-level price, the response of CPI is smaller. For example, energy represents a small fraction of consumption spending in most advanced economies: The response of CPI to a spike in energy prices is likely smaller than the response of nominal output in energy producing sectors.

We consider two decompositions of nominal output that are promising. The first one exploits the market clearing condition in equation (1), amended into a recursion by introducing $a^{rs}_{ij} = \frac{\mathrm{P}^{rs}_{ij}\,\mathrm{M}^{rs}_{ij}}{\mathrm{P}^s_j\,\mathrm{Y}^s_j}$. Solving recursively gives

$$\begin{aligned}
\mathrm{P}^r_i\,\mathrm{Y}^r_i = {} & \mathrm{P}^r_{ik}\,\mathrm{C}^r_{ik} + \sum_{l\neq k} \mathrm{P}^r_{il}\,\mathrm{C}^r_{il} \\
& + \sum_{j,s} a^{rs}_{ij}\,\mathrm{P}^s_{jk}\,\mathrm{C}^s_{jk} + \sum_{l\neq k}\sum_{j,s} a^{rs}_{ij}\,\mathrm{P}^s_{jl}\,\mathrm{C}^s_{jl} \\
& + \sum_{j,s}\sum_{m,t} a^{rs}_{ij} a^{st}_{jm}\,\mathrm{P}^t_{mk}\,\mathrm{C}^t_{mk} + \sum_{l\neq k}\sum_{j,s}\sum_{m,t} a^{rs}_{ij} a^{st}_{jm}\,\mathrm{P}^t_{ml}\,\mathrm{C}^t_{ml} + \ldots,
\end{aligned}$$

which means the value of production in country-sector (i, r) must equal the total value of its final uses. Here final uses are split according to destinations: country k vs. all other countries. Country k will be the one with which trade sanctions are implemented: An embargo on trade from (i, r) to country k implies that direct final demand $\mathrm{P}^r_{ik}\,\mathrm{C}^r_{ik}$ and direct intermediate demand $a^{rs}_{ik}\,\mathrm{P}^s_{kk}\,\mathrm{C}^s_{kk}$ (for all s) are both set to zero. We proceed following the "hypothetical extraction" technique discussed in Los et al. (2016) to compute the empirical change in nominal output that corresponds to such an embargo.[3] In particular, our data-based approximation to the change in nominal output induced by the embargo is given by the following Hadamard division

$$\ln \widetilde{\mathbf{PY}}_d = \left[(\mathbf{I} - \mathbf{A})^{-1} \, \mathbf{PC} - (\mathbf{I} - \tilde{\mathbf{A}})^{-1} \, \widetilde{\mathbf{PC}} \right] \oslash \left[(\mathbf{I} - \mathbf{A})^{-1} \, \mathbf{PC} \right],$$

where $\mathbf{PC}$ denotes the vector of all final demand, $\widetilde{\mathbf{PC}}$ is a version of $\mathbf{PC}$ where final demand arising from country k is set to zero, $\mathbf{A}$ is an $\mathrm{NR} \times \mathrm{NR}$ matrix with typical element a_{ij}^{rs}, and $\tilde{\mathbf{A}}$ is a version of $\mathbf{A}$ with the values of a_{ik}^{rs} set to zero for all s. By definition, $\ln \widetilde{\mathbf{PY}}_d$ denotes the vector of percentage changes in nominal output that prevail if direct trade between country-sector (i, r) and its downstream market k were shut down by an embargo. In the model's notation this corresponds to the elements of $\ln \mathbf{PY}_t$ for very large increase in the trade costs τ_{ik}^{r}. Assuming negligible responses of consumption price indices, $\ln \widetilde{\mathbf{PY}}_d$ constitutes a potentially promising empirical approximation to the consequences of a large positive shock to τ_{ik}^{r} on value added V_i^r.

A typical element of $\ln \widetilde{\mathbf{PY}}_d$ is the share of total nominal output in country-sector (i, r) represented by the value of final and intermediate exports to market k and the corresponding downstream value chains. We call this ratio HOT, for High Order Trade. In what follows we consider $\mathrm{HOT}_{\mathrm{EUR,RUS}}^{r}$, the fraction of European production in sector r that corresponds to direct exports to Russia and the associated value chains. We also consider $\mathrm{HOT}_{\mathrm{RUS,EUR}}^{r}$, the fraction of Russian production in sector r sold directly to Europe, and the associated value chains.

The second measure of high-order trade we propose as an approximation to $\ln \mathbf{V}_t$ derives from an identity that defines sector-level value added:

$$\mathrm{P}_j^s \, \mathrm{Y}_j^s = \sum_{i,r} \mathrm{P}_{ij}^{rs} \, \mathrm{M}_{ij}^{rs} + \mathrm{P}_j^s \, \mathrm{VA}_j^s,$$

where $\mathrm{P}_j^s \, \mathrm{VA}_j^s$ is nominal value added in country-sector (j, s). Defining the allocation coefficient $b_{ij}^{rs} = \frac{\mathrm{P}_{ij}^{rs} \, \mathrm{M}_{ij}^{rs}}{\mathrm{P}_i^r \, \mathrm{Y}_i^r}$ and recognizing the recursion gives

$$\begin{aligned} \mathrm{P}_j^s \, \mathrm{Y}_j^s = \mathrm{P}_j^s \, \mathrm{VA}_j^s + \; & b_{kj}^{ts} \, \mathrm{P}_k^t \, \mathrm{VA}_k^t + \sum_{i,r} b_{ki}^{tr} b_{ij}^{rs} \, \mathrm{P}_k^t \, \mathrm{VA}_k^t + \ldots \\ & + \sum_{i \neq k, r \neq t} b_{ij}^{rs} \, \mathrm{P}_i^r \, \mathrm{VA}_i^r + \sum_{l \neq k, u \neq t} \sum_{i,r} b_{li}^{ur} b_{ij}^{rs} \, \mathrm{P}_l^u \, \mathrm{VA}_l^u + \ldots, \end{aligned}$$

which decomposes nominal output in country-sector (j, s) into the value of primary factors, sourced from three origins: (j, s) itself, country k, and everywhere else. An embargo on direct

[3]The idea of hypothetical extraction is to compare output as implied by the complete observed set of input-output linkages with a hypothetical version where some input-output linkages are set to zero, i.e., are "extracted". The difference between the two objects measures the value of output associated with the omitted linkages.

inputs coming from sector t in country k means that b_{kj}^{ts} is equal to zero, potentially for all sectors s, depending on the magnitude of the embargo (i.e., whether it applies to country j as a whole or only to selected sectors). If the embargo pertains to more than one sector in country k, then b_{kj}^{ts} would be set to zero for all concerned sectors t in country k. Applying the hypothetical extraction approach, the corresponding percentage change in nominal output in country-sector (j, s) is given by the Hadamard division

$$\ln \widetilde{\mathbf{PY}}_u = \left[(\mathbf{I} - \mathbf{B}^\top)^{-1} \, \mathbf{PVA} - (\mathbf{I} - \tilde{\mathbf{B}}^\top)^{-1} \, \mathbf{PVA} \right] \oslash \left[(\mathbf{I} - \mathbf{B}^\top)^{-1} \, \mathbf{PVA} \right],$$

where $\mathbf{PVA}$ denotes the vector of sector-level nominal value added, $\mathbf{B}$ is an $\mathrm{NR} \times \mathrm{NR}$ matrix with typical element b_{ij}^{rs}, and $\tilde{\mathbf{B}}$ is a version of $\mathbf{B}$ where b_{kj}^{ts} is set to zero. By definition, $\ln \widetilde{\mathbf{PY}}_u$ denotes the vector of percentage changes in nominal output that prevail if trade between country-sector (j, s) and its upstream primary inputs from sector t in country k were shut down by an embargo. In the model's notation this corresponds to the elements of $\ln \mathbf{PY}_t$ for large increases in τ_{kj}^t. Assuming negligible responses of consumption price indices, $\ln \widetilde{\mathbf{PY}}_u$ constitutes a potentially promising empirical approximation to the consequences of a large positive shock to τ_{kj}^t on value added V_j^s.

A typical element of $\ln \widetilde{\mathbf{PY}}_u$ is the fraction of total nominal output in country-sector (j, s) that corresponds to the value of direct input trade with country-sector (k, t) and the upstream value chains associated with it. We call this ratio SHOT, for Source High Order Trade. In what follows we consider $\mathrm{SHOT}_{\mathrm{RUS,EUR}}^{rs}$, the fraction of European production in sector s that corresponds to the value of direct inputs from Russia's sector r and the associated value chains. We also consider $\mathrm{SHOT}_{\mathrm{EUR,RUS}}^{rs}$, the fraction of Russian production in sector s that corresponds to direct inputs from Europe's sector r and the associated value chains.

The approximation decomposes nominal output into components associated with final sales to a specific destination, or input usages purchased from a specific origin. In each decomposition the transactions that involve the sanctioned economy are set to zero. The resulting fall in value added is taken to approximate the economic cost of the sanctions. The approximation therefore assumes away any form of substitution of the final sales or input purchases that fall under the sanction. In that sense it is close to the Leontief case. But on the other hand, the forgone output is limited to the value of those final sales or input purchases that are sanctioned, contrary to what would be implied by a Leontief production function. The approximation represents therefore a hybrid case, with some elements corresponding to very low elasticities of substitution (sanctioned markets or inputs cannot be replaced), and others corresponding to high elasticities of substitution (the consequences on value added are limited to the value of those goods that are sanctioned). This feature is in fact instrumental because it quantifies the impact of shutting down any bilateral flow: Standard models would have difficulties simulating this because even with very high trade costs, some trade survives, particularly between the regions where it is particularly desirable.

2.3 Evaluating the Approximation

We consider two types of embargoes: First a large increase in $\tau^r_{\text{RUS,EUR}}$, the cost of exporting Russian sector r to Europe. The effect on value added in the Russian sector r is given by $\frac{\ln \mathrm{V}^r_{\text{RUS},t}}{\ln \tau^r_{\text{RUS,EUR}}}$ in the model and we propose to approximate it using $\text{HOT}^r_{\text{RUS,EUR}}$. The effect on value added in the European sector s is given by $\frac{\ln \mathrm{V}^s_{\text{EUR},t}}{\ln \tau^r_{\text{RUS,EUR}}}$ in the model and we propose to approximate it using $\text{SHOT}^{rs}_{\text{RUS,EUR}}$.

Second we consider a large increase in $\tau^r_{\text{EUR,RUS}}$, the cost of exporting European sector r to Russia. The effect on value added in the European sector r is given by $\frac{\ln \mathrm{V}^r_{\text{EUR},t}}{\ln \tau^r_{\text{EUR,RUS}}}$ and we propose to approximate it using $\text{HOT}^r_{\text{EUR,RUS}}$. And the effect on value added in the Russian sector s is given by $\frac{\ln \mathrm{V}^s_{\text{RUS},t}}{\ln \tau^r_{\text{EUR,RUS}}}$ and we propose to approximate it using $\text{SHOT}^{rs}_{\text{EUR,RUS}}$.[4]

We now explore the validity of our approximations. We proceed in three steps: First we calibrate and simulate the full model for a broad range of elasticities of substitution ρ and ϵ. This gives us the values of $\ln \mathbf{V}_t$ and its proposed approximation $\frac{\alpha\psi}{1+\psi} \ln \mathbf{PY}_t$ across all available country-sectors (and for many values of ρ and ϵ) in response to a specific trade shock. Second for each pair (ρ, ϵ) we perform a regression of $\ln \mathbf{V}_t$ on $\frac{\alpha\psi}{1+\psi} \ln \mathbf{PY}_t$ across country-sectors, and explore to what extent they are aligned along a 45 degree line. Third for each pair (ρ, ϵ) we compare the simulated $\ln V^r_{i,t}$ with the corresponding approximations based on HOT or SHOT.[5]

In the main text we simulate the effects of a shock to $\ln \tau^{\text{OIL}}_{\text{RUS,EUR}}$ and compute the model-implied responses across all available country-sectors. Figure 1 presents a few illustrative scatterplots of $\ln \mathbf{V}_t$ against $\frac{\alpha\psi}{1+\psi} \ln \mathbf{PY}_t$ for some calibrations of ρ and ϵ that correspond to recent contributions on the topic. We follow Bachmann et al. (2022) and set ϵ to 1.5, 0.1, and 0.05, the lowest value considered by these authors; We also set ρ to 2.5, 0.1, and 0.05, which covers the range of calibration values explored in this literature, see Huo et al. (2021) or Bachmann et al. (2022). The scatterplots confirm that $\ln \mathbf{V}_t$ and $\frac{\alpha\psi}{1+\psi} \ln \mathbf{PY}_t$ align along the 45 degree line for the proposed combinations of elasticities. As is well-known and intuitive, the effects of sanctions can become very large in some sectors for very low values of the elasticities - see for example scatterplots (d) - (f): What is interesting however is that the approximation implies

[4]In both cases we consider 100 percent increases in trade costs to simulate sanctions. This does not prevent trade altogether as an embargo would, which is a common problem in the literature.

[5]The model is calibrated on data from the World Input-Output Database because some of the necessary data are not available from other sources, mostly because of the Socio-Economic Account data associated to WIOD. All steady state values are obtained as averages over the full available period.

similarly very large responses.[6]

Figure B.1 in Appendix B plots the coefficient estimate $\hat{\beta}$ and the R^2 associated with the same regression as in Figure 1 but for a grid of elasticity calibrations of ρ in $[0.05, 2.5]$ and ϵ in $[0.05, 1.5]$ with increments of 0.1.[7] We see that both $\hat{\beta}$ and the associated R^2 are close to 1 when both elasticities are greater than 1. This is not surprising since this is when the response of prices is likely to be muted, so that consumption price indices respond the least. Estimates $\hat{\beta}$ and the associated R^2 fall precipitously around the Cobb-Douglas case, i.e., $\rho, \epsilon \simeq 1$. This is not surprising either since the approximation is based on the response of nominal output, which is zero under unitary elasticities of substitution in production or in preferences. What is more interesting is that the approximation is again palatable for low values of ϵ, including very low values, combined with any values of ρ, except perhaps extremely low values of ρ around 0.05.

Figure B.2 (a) presents the simulated values of $\frac{\ln \mathrm{V}^{\mathrm{OIL}}_{\mathrm{RUS},t}}{\ln \tau^{\mathrm{OIL}}_{\mathrm{RUS,EUR}}}$ against its proposed approximation $\mathrm{HOT}^{\mathrm{OIL}}_{\mathrm{RUS,EUR}}$. The approximation implies value added in the Russian oil sector falls by 1.33 percent. The average response in the simulations is equal to 1.37 percent, which is apparent in the Figure where simulated responses remain close to 1.33 percent for most values of the elasticities, except when ρ and ϵ are both extremely low. Figure B.2 (b) presents the simulated values of $\frac{\ln \mathrm{V}^{s}_{\mathrm{EUR},t}}{\ln \tau^{\mathrm{OIL}}_{\mathrm{RUS,EUR}}}$ where s is Chemicals.[8] We look at the approximate effect of the embargo on Germany given by $\mathrm{SHOT}^{\mathrm{OIL,CHEM}}_{\mathrm{RUS,DEU}}$, which is equal to 0.08 percent. For most elasticity values, the simulated responses are very close to our approximation. The only exceptions on the Figure correspond to simultaneously extremely low values of ρ and ϵ, where simulated responses become unrealistically large, see Bachmann et al. (2022). For the rest of the parameter space, both our approximation and the model imply low effects: Indeed the average simulated response is 0.2 percent.[9]

[6] The elasticity of substitution between factors of production is set to 1 in the model, following the estimates in Huo et al. (2021). Bachmann et al. (2022) consider specifically energy inputs and show the elasticity of substitution between energy and the other factors of production has large consequences on the magnitude of the simulated effects of sanctions: This happens because a low elasticity makes it hard to substitute away from expensive factors of production. Here we do not separate between energy and other factors of production, which justifies the Cobb-Douglas assumption (see Huo et al., 2021). We note however that the scatterplots in Figure 1 confirm the possibility of very large effects of sanctions under some extreme parametrizations: Our key point is that the approximation continues to show some validity even in these extreme cases. We conjecture such would also be the case under low substitutability between factors of production.

[7] We exclude the purely Leontief case, reasoning that zero substitutability is unlikely at this level of aggregation.

[8] This choice is arbitrary but largely innocuous for the results presented on the Figure: We obtain very similar shapes for most other European sectors.

[9] We also consider a shock to $\tau^{r}_{\mathrm{EUR,RUS}}$, an embargo on European exports of sector r in the same Appendix B (see Figures B.4 and B.3).

3 The Approximate Effects of Trade Sanctions

3.1 Computing the approximation

The 2021 OECD release of Inter-Country Input-Output database (ICIO) provides data for 66 countries from 1995 to 2018. The input-output data is available for 45 sectors for each country and each year.[10] The ICIO follows the fourth revision of the Industry Standard International Classification (ISIC Rev. 4). The data are in millions of USD at current prices. HOT and SHOT are constructed using the latest year available, 2018. We use ICIO for the purpose of computing our approximations because of coverage, both across countries and sectors. ICIO has data on more countries and better sector coverage than WIOD as regards energy. In addition concordance tables are available between ICIO and WIOD, which we need because values of α^r are necessary to compute the approximations and they are available from the Social-Economic Accounts of WIOD.

The matrix $\mathbf{W}$ constructed by ICIO has typical element PM_{ij}^{rs}. $\mathbf{W}$ contains intermediate trade within and between countries and also includes vectors of final demand PC_{ij}^{r} and a vector of value added PVA_{i}^{r}. Final demand breaks down into a domestic and an international component by country j, but not by sector s, whereas inputs suppliers have both a country and a sector dimension. In addition, $\mathbf{W}$ also keeps track of the net inventories, which we correct using a proportion rule following Antràs and Chor (2013, 2018). The direct requirement matrix $\mathbf{A}$ and the allocation matrix $\mathbf{B}$ are computed on the basis of the rescaled $\mathbf{W}$. The typical element of $\mathbf{A}$, a_{ij}^{rs}, is normalized column-wise by destination sector-level gross output. $\mathbf{B}$ with typical element b_{ij}^{rs}, is normalized row-wise by source sector-level gross output.[11]

3.2 Comparing Direct and Indirect Measures

We explore the differences between the measures we introduce, HOT and SHOT, and their counterparts focused on direct trade only. The comparison illustrates how much conventional measures of direct trade potentially under-value the consequences of trade sanctions, which are approximately proportional to HOT and SHOT. We consider an embargo on Russian exports of Coke and Refined Petroleum Products into Europe, which corresponds to a large increase in $\tau_{\mathrm{RUS},j}^{\mathrm{OIL}}$ where j indexes European countries. The effect on value added in the Russian sector is approximately proportional to $\mathrm{HOT}_{\mathrm{RUS},j}^{\mathrm{OIL}}$, which we compare with the value of direct oil exports from Russia to country j as a fraction of total oil production in Russia. The effect of the embargo on value added in sector s of country j is approximately proportional to $\mathrm{SHOT}_{\mathrm{RUS},j}^{\mathrm{OIL},s}$, which we compare with the value of direct oil imports from Russia into country-sector (j, s) as a fraction of total production there. In both comparisons, HOT and SHOT embed direct trade

[10]The data is publicly available at https://www.oecd.org/sti/ind/inter-country-input-output-tables.htm

[11]Appendix C lists the sectors available in ICIO and WIOD.

and will therefore take larger values than their counterparts based on direct trade. The question is how much.

Table 1 presents the values of $\mathrm{HOT}^{\mathrm{OIL}}_{\mathrm{RUS},j}$ and of direct exports for all 28 countries j in Europe ranked on the basis of the ratio of indirect to direct trade. Unsurprisingly HOT is systematically larger than direct oil exports from Russia to Europe. What is interesting here is that the magnitude of direct exports is essentially uninformative on the effect of trade sanctions: There is no proportionality between HOT and direct exports as the ratios between the two vary between 2 and more than 40 across countries. Direct trade is not close to approximating the costs of trade sanctions.

Table 1 suggests that the ratio between indirect and direct trade is largest for ex “satellite” countries of the Soviet Union, including Latvia and Lithuania, Eastern Europe (Bulgaria, Czech Republic, Poland, Slovakia, Hungary), Finland, and Malta. This reflects the intensity of value chains downstream of Russian energy in these countries, presumably for historical and geographic reasons. Large European countries, like Germany, France, or the UK present substantially lower values for this ratio, presumably because the Russian energy they import is much closer to final demand.

Table 2 presents the values of $\mathrm{SHOT}^{\mathrm{OIL},s}_{\mathrm{RUS},j}$ and the corresponding direct imports. There are 28 countries $\times$ 45 sectors = 1,260 country-sectors (j, s) with distinct values of $\mathrm{SHOT}^{\mathrm{OIL},s}_{\mathrm{RUS},j}$. Table 2 presents the top twenty country ranked according to the ratio of indirect to direct trade.[12] The Table confirms that indirect and direct trade are far from proportional: The ratio between the two varies across country-sectors, from 1 to 2. There, too, it would be a gross mistake to approximate the effects of trade sanctions with a measure of direct imports of energy inputs from Russia. We note however that the ratios are much smaller in Table 2 than in Table 1, which suggests short supply chains using Russian energy as an input.

3.3 The (Approximate) Effects of Trade Sanctions

We present approximations of the effects of three different categories of sanctions: (i) an embargo on the exports of Russian energy sectors to Europe, (ii) a blanket embargo on Russian exports to Europe, and (iii) an embargo on European exports to Russia. In each case we use our approximation method to quantify the effects on the two parties involved. Even though the embargoes we consider are implemented by (or targeted to) Europe as a whole, we consider effects at the individual country level to inform the discussion about unequal consequences within Europe.

For each considered shock, we evaluate the effect on the importing region with SHOT and on the exporting region with HOT. We summarize our results at sector level, at country level

[12] Country-sectors (j, s) are aggregated across sectors s using value-added weights.

when possible, and aggregate it further to obtain overall effects. Consider first the effect on the importing region: The approximation of the (percentage) effect of a shock to τ_{ij}^r on value added in country-sector (j, s) is proportional to SHOT_{ij}^{rs}. We compute the average response in country j as the value-added weighted average response across sectors:

$$\ln \mathrm{V}_{j,t} \,/\, \ln \tau_{ij}^r \simeq \sum_s \left(\frac{\mathrm{VA}_{j,t}^s}{\sum_s \mathrm{VA}_{j,t}^s} \right) \frac{\alpha^r \psi}{1+\psi} \, \mathrm{SHOT}_{ij}^{rs},$$

and the average response in sector s as the value-added weighted average response across countries:

$$\ln \mathrm{V}_t^s \,/\, \ln \tau_{ij}^r \simeq \sum_j \left(\frac{\mathrm{VA}_{j,t}^s}{\sum_j \mathrm{VA}_{j,t}^s} \right) \frac{\alpha^r \psi}{1+\psi} \, \mathrm{SHOT}_{ij}^{rs}\,.$$

Finally we evaluate the total effect of the embargo on the importing region (where all countries j are located) as

$$\ln \mathrm{V}_t \,/\, \ln \tau_{ij}^r \simeq \sum_s \left(\frac{\sum_j \mathrm{VA}_{j,t}^s}{\sum_s \sum_j \mathrm{VA}_{j,t}^s} \right) \left[\sum_j \left(\frac{\mathrm{VA}_{j,t}^s}{\sum_j \mathrm{VA}_{j,t}^s} \right) \frac{\alpha^r \psi}{1+\psi} \, \mathrm{SHOT}_{ij}^{rs} \right].$$

The approximation of the effect of a shock to τ_{ij}^r on value added in the exporting country-sector (i, r) is proportional to HOT_{ij}^r. We compute this response across exporting sectors r, and obtain the total effect on country i as the value-added weighted average response across sectors:

$$\ln \mathrm{V}_{i,t} \,/\, \ln \tau_{ij}^r \simeq \sum_r \left(\frac{\mathrm{VA}_{i,t}^r}{\sum_r \mathrm{VA}_{i,t}^r} \right) \frac{\alpha^r \psi}{1+\psi} \, \mathrm{HOT}_{ij}^r,$$

and the total effect on the exporting region (where all countries i are located) is

$$\ln \mathrm{V}_t \,/\, \ln \tau_{ij}^r \simeq \sum_i \left(\frac{\sum_r \mathrm{VA}_{i,t}^r}{\sum_i \sum_r \mathrm{VA}_{i,t}^r} \right) \left[\sum_r \left(\frac{\mathrm{VA}_{i,t}^r}{\sum_r \mathrm{VA}_{i,t}^r} \right) \frac{\alpha^r \psi}{1+\psi} \, \mathrm{HOT}_{ij}^r \right].$$

3.3.1 An Embargo on Russian Energy

We first consider selected embargoes on Russia's extractive sectors as defined in ICIO: Coke and refined petroleum, and Mining and quarrying in energy producing products, which includes crude oil and natural gas. See Appendix C for a list of sectors in the ICIO dataset.

Table 3 presents the effects of the first embargo, on coke and refined petroleum. The left panel reports the effects on Russian sectors (by decreasing size) as approximated by HOT, the right panel considers the effects on European country-sectors as approximated by SHOT. The left panel indicates that an embargo on coke and refined petroleum affects energy producing sectors the most, but also some manufactures, and some transport services (land and pipeline transport, warehouse and transport services, water transport). These sectors are clearly part of the downstream supply chain of refined petroleum products. What is interesting is that the magnitude of the effects falls very quickly, from 5 percent in the embargoed sector to less than 1 percent in non-energy producing sectors. The overall effect on the Russian economy is 0.60 percent.

The right panel of Table 3 reports the approximate effects of the same embargo on European sectors, European countries, and the overall effect on the European Union's economy. The top ten affected countries are "satellite" countries of the ex-Soviet Union (Bulgaria, Hungary, Poland, Estonia, Lithuania, Latvia, Slovakia, or the Czech Republic).[13] The effects, however, are very small: a quarter of a percent lost value added in Bulgaria (the most affected country), 0.13 percent in Hungary, or 0.11 percent in Lithuania. The top ten affected sectors in Europe are extractive (refined petroleum), heavy manufacturing (basic metals, chemical products, non-metallic products, non-energy producing products), and transport services (water transport, land and pipeline transport, postal and courier activities). These are clearly dependent on oil imports, which are essential to their activity. Once again however the effects are very small: 0.44 percent for air transport, the most seriously affected sector, and 0.18 percent on average. The total effect on the European economy is a minuscule 0.04 percent, about 15 times smaller than the effect on the Russian economy.

Next we consider an embargo on a slightly broader classification of energy extraction activity in Russia, the Mining and Quarrying of Energy Producing Products, which typically includes both crude oil and natural gas. Table 4 follows the same presentation as Table 3. The left panel presents the effects of the embargo on Russian sectors, ranked by decreasing size. The identity of the affected sectors remains similar to Table 3: extractive sectors (and their support) are the most affected, followed by transport and some heavy manufactures. Once again the sector-level effects fall very rapidly: The mining and quarrying of energy products is the only sector with large effects above 2 percent. The key difference with refined petroleum however is the size of the total effect, which is twice larger, 1.17 percent. This is more important a sector for the Russian economy than refined petroleum, presumably because it contains both crude oil and gas. Interestingly, Evenett and Muendler (2022) consider the long run effects of a similar ban on Russian oil and gas by the EU and the G7. The long run response of GDP they simulate is a fall by 0.58 percent. This is about half of our effect, but ours is a short run estimate, abstracting from substitution and reallocations, and so it should be larger.[14] Both their and our estimates point to small effects on Russia's GDP.

The right panel of Table 4 presents the effects of this embargo in Europe. The overall effect on the European economy is twice larger than it was for petroleum products (0.08 percent),

[13] This extreme asymmetry is also documented by Baqaee et al. (2022) and is a recurrent feature of the European response to an embargo on Russian exports, as we document in this and the next sections.

[14] It is also not clear what values Evenett and Muendler (2022) use for the elasticities of substitution between inputs: They are estimated on the basis of the responsiveness of trade flows to changes in prices and thus presumably display some heterogeneity.

although this is still close to negligible and about 15 times smaller than the effect on the Russian economy. The top ten affected sectors are very similar to Table 3. The top ten affected European countries are once again small economies, typically geographically close to Russia (Bulgaria, Lithuania, Slovakia, Hungary, Latvia, Czech Republic, Poland, Romania, Finland, Slovenia). The large European economies are lower in the list with truly minuscule effects. Germany for example sees its GDP fall by 0.08 percent.

3.3.2 Embargo on Russian Trade

A natural next step is to evaluate whether a total embargo on Russian exports into Europe would have a much larger impact on both parties. Table 5 follows the same structure as the previous two. The left panel reports the approximated effect of such an embargo on Russian sectors. The magnitudes become substantially larger than for narrower embargoes, ranging from a 10 percent fall in value added in the mining and quarrying of energy producing products to (still) 5.7 percent in land and pipeline transport. In contrast with previous estimates, the approximated costs remain high (above 5 percent) for all the top ten sectors, which include by and large the same categories as before: extractive sectors, transport, and heavy manufactures. The total end effect on the Russian economy is a decrease of 3.4 percent of GDP. This is a large number, but perhaps surprisingly "only" three times larger than what is implied by an embargo on the extractive sector, which presumably reflects the extreme specialization of the Russian economy. Evenett and Muendler (2022) simulate the long run effect of a similar sanction that consists of a ban on Russian gas and oil and a 35 percent increase in the tariffs applied to all other Russian exports: They find GDP falls by 1.06 percent: This is smaller than our approximation, but it is a long run estimate whereas we approximate short run effects.

The right panel of Table 5 presents the approximated effect on the European economy of a total embargo on Russian exports. The total effect is a decrease of 0.23 percent in the European Union's GDP. This is about three times larger than the effect of an embargo focused on Russian energy producing sectors and still 15 times smaller than the embargo's effect on Russia. The main reason why the effect on Europe is so much smaller than it is for Russia is that the European countries most affected by the sanction are the smallest in the Union: In Table 5, the top ten countries include Bulgaria, Lithuania, Latvia, Estonia, Cyprus, Slovakia, Hungary, Poland, Finland, and the Czech Republic. The value chains downstream of Russian exports are in fact quite localized geographically, in the vicinity of the ex-Soviet Union. This means disruptions in these value chains tend to affect small European economies, with small end effects. As before, the top ten of European sectors affected by such a blanket embargo include extractive sectors, transport services, and heavy manufactures.

The effect of this embargo on German GDP is of special interest because full simulations about it exist in the literature: Bachmann et al. (2022) consider an embargo on Russian coal, oil and gas, which lies somewhere between the shock considered here and in section 3.3.1. For low values of the elasticity of substitution between energy and other inputs, they find the embargo lowers German GDP by 0.2 to 0.3 percent. Our approximation implies a decrease in German GDP of 0.23 percent, and of 0.08 percent when considering an embargo on crude oil and gas (i.e., the mining of energy producing products) in Section 3.3.1: It is fair to say our approximation is in the same ballpark as their simulation. This is reassuring given the assumptions that go into our approach (a homogeneous elasticity of substitution between all inputs, financial autarky, unitary elasticities between capital and labor), which are fundamentally different in Bachmann et al. (2022).

Baqaee et al. (2022) conduct a similar analysis with a focus on France. They estimate the effect on French GDP of a ban on Russian energy imports at below 0.2 percent. Our approximation of the effect of a ban on mining of energy producing products is lower, 0.04 percent. But if we extend the ban to other Russian exports into Europe, our approximation of the effect of the ban on France jumps to 0.13 percent, close to their estimate.

3.3.3 Embargo on European Trade

The evidence so far suggests that a ban on Russian exports to Europe is 15 times more costly to Russia than it is to the European Union. We now turn to the reverse experiment, a ban on European exports to Russia. Given trade policy falls under the remit of the European Commission, we consider a blanket embargo in which all member countries stop exporting to Russia. We approximate the effect on Russia with SHOT and the effect on Europe (and individual European countries) with HOT.

Table 6 reports the estimated effects on Europe in the left panel, and on Russia in the right panel. The total effect on the European Union's GDP is small, about 0.24 percent. This is because the European countries most affected by an embargo on exports to Russia are once again the ex-satellite countries geographically close to Russia and very small: Lithuania, Estonia, Latvia, Bulgaria, Cyprus, Finland, Slovenia, Slovakia, or the Czech Republic. These are the countries that trade most intensely with Russia, and so they stand to lose most from a ban on those exports. Cyprus, which is the most heavily affected, would see its GDP fall by 2.1 percent.

The right panel of Table 6 reports the most affected Russian sectors. Their identity reflects the types of inputs the small European countries just listed tend to supply to Russia: all are manufacturing sectors, with the exception of air transport. The estimated responses of value added in these Russian sectors are substantial: ranging from 6.3 percent in the manufacturing of motor vehicles to 2.9 percent in the pharmaceutical sector. These are large responses. But manufacturing has a small share in the Russian economy, and the associated value chains are relatively short. As a result, the end effect on the Russian economy of such an embargo is small, 1.31 percent of Russian GDP, which is still about 5 times larger than the effect such an embargo would have on the European Union's GDP.

Our analysis suggests that an embargo on Russian exports to Europe would have a substantially larger impact on the Russian economy than limiting European exports to Russia - a fall of 3.4 percent vs. only 1.31 percent. The cost to the European Union, however, would be broadly similar under either scenario: EU GDP falls by 0.23 percent in the case of an embargo on Russian exports, vs. 0.24 percent in the case of an embargo on European exports to Russia. One of the key conclusions that emerge from our approximation -and also more generally from the simulated models in the literature- is that trade sanctions have overall small, if asymmetric, effects. In the next section we explore the existence of alternative suppliers and alternative markets for both parties, which could mitigate the costs of full embargoes.

3.4 Substitute Markets

We now introduce an approach meant to capture the flexibility available to the two parties involved in an embargo to substitute away from markets or from inputs that have become the objects of trade sanctions. We exploit historical data on existing supply chains that can be used to obtain access to alternative destination markets or alternative sources of inputs to the ones that are embargoed. We track the persistence of these substitutes over time.

The analysis builds on the following steps. First, we consider the sectors in Russia and in European countries that are most affected by a European embargo on Russian energy exports as per the most recent data. Second for these sectors we run a search on alternative destination markets (for Russia) and alternative input origination (for European countries). The search is based on the share of Russian production that historically served these alternative markets and on the share of European production that historically used these alternative inputs. Both shares are computed allowing for indirect trade, i.e., reflect the value chains associated with these destination or source markets. Third, we compare the shares of output lost because of the embargo with the "substitute" shares of output just described, which are still available under the embargo. If the substitute shares are not much lower, this means alternative value chains of comparable importance are available to redirect trade in response to sanctions.

Of particular interest is the evolution over time of the "embargoed" and the "substitute" shares. The former illustrates how the co-dependence between the EU and Russia evolves over time; The latter illustrates the emergence (or fading) of substitute markets for both parties. The time period includes the invasion of Crimea in 2014, which informs from history which markets have responded to past geopolitical tensions, and how.

The approach can be understood as a data-based counterpart to the exercise performed in Hausmann et al. (2023), who use theory to evaluate how much coordination across countries can enhance the effects of trade sanctions. Interestingly their theoretical criterion is based on direct trade only. Chowdhry et al. (2022) simulate a model for the same purpose, focusing on the sanctions imposed on Iran in 2012 and on Russia in 2014.

3.4.1 Substitute Export Markets

We start with the magnitude of Russia's export markets to Europe vs. other destinations. We report the value of $\mathrm{HOT}^r_{\mathrm{RUS,EUR}}$ for the two most affected sectors r in Russia, in response to embargoes on Russian energy exports to Europe. From Section 3.3.1 we know which ones they are. Table 7 compares the values of $\mathrm{HOT}^r_{\mathrm{RUS,EUR}}$ in these most affected sectors with the alternative $\mathrm{HOT}^r_{\mathrm{RUS,K}}$ for any country K located outside of Europe, i.e., with alternative export markets K as implied by both direct and indirect trade there. In practice we compute $\mathrm{HOT}^r_{\mathrm{RUS,K}}$ for all countries K and report the highest values for K outside of the European Union. The idea is to identify the "runner-up" export destinations for each heavily affected Russian sector, as measured by the historical importance of alternative value chains.

Table 7 considers the two Russian sectors r most affected by a European embargo on Russia's Mining and Quarrying of Energy Producing Products in 2018, which are: (i) the Mining and quarrying of energy producing products sector itself, for which more than 34 percent of output is sold into the EU directly and indirectly, and (ii) Mining support service activities, which exports 7.95 percent of its output into European value chains. For each of these sectors, we search for the alternative export market K that maximizes $\mathrm{HOT}^r_{\mathrm{RUS,K}}$. In both cases, the runner-up country (outside of the EU) is China; But in both cases the value of downstream linkages with China are about half what they are with Europe: In 2018, China is Russia's second buyer of energy products, but it is a far second behind the European Union. The subsequent substitute markets, Israel, Korea, the US, or Turkey are all far behind China, with a cumulated share of output about 7.6 percent in Mining and quarrying of energy producing products and 1.75 percent in Mining support service activities. The fact that the substitute value chains outside of the EU should be far smaller than those with the EU suggests an inherent difficulty for Russia to sell its output outside of the EU in response to an embargo.[15]

Figures 2a and 2c consider the time change in shares presented in Table 7 for the two most exposed sectors of Russia, energy producing products and mining support services. Several results are interesting. Firstly, the share of EU markets downstream of Russian energy has dramatically fallen since its peak in 2008, from 53 to 34 percent. The rate of this decrease has accelerated since the 2010s, especially in mining support services. Secondly, China's emergence as an alternative market coincides with the invasion of Crimea in 2014: China was a minuscule downstream market for Russian energy prior to the 2010s. This is consistent with

[15]Interestingly the runners-up immediately after China for these sectors are Germany, Italy, Poland, and the Netherlands.

the Russian announced intention that China should replace the EU as a downstream market for Russian energy, even though the magnitude of downstream value chains to China continues to be dwarfed by those into the EU. Thirdly, there are no significant alternative downstream markets for Russian energy. We show this in Figures 2b and 2d, where the EU is omitted from the sample of regions and the scale is modified accordingly. As of 2018, the combined weight of the EU and China in Russian energy output is around 50 percent, as compared with the combined weight of the five biggest runner-up export markets (Israel, Korea, the US, Turkey, and Japan) altogether below 10 percent. In fact, among these five runner-up markets, the shares of Japan and the US have fallen precipitously since the early 2010s, possibly as a result of the invasion of Crimea. This illustrates the extreme concentration of Russia's energy export markets.

3.4.2 Substitute Input Sourcing

We now consider the importance of the inputs used in the European Union and sourced from Russia vs. other countries. We first re-run our approximations to establish which sectors s in country j are most affected by an energy embargo, since Section 3.3.1 only report average country and average sector effects. For each country-sector (j, s) we report the values of $\mathrm{SHOT}^{rs}_{\mathrm{RUS},j}$ where r denotes the sector concerned by the embargo, Mining and Quarrying of Energy Producing Products. We compare this value with $\mathrm{SHOT}^{rs}_{\mathrm{K},j}$, computed for the most affected sectors s in European country j to the same embargo on Russian energy, for all K located outside of the EU.[16] Here the idea is to identify the "runner-up" countries that can supply to heavily affected sectors in Europe similar inputs as the ones under embargo in Russia.

In order to focus the analysis on the key heterogeneity in input trade between Russia and the EU, we limit the approach to five countries j: three countries that are heavily affected by the embargo on Russian inputs, Latvia, Lithuania, and Bulgaria, and two countries that are not, France and Germany. Table 8 presents the values of $\mathrm{SHOT}^{rs}_{\mathrm{RUS},j}$ in 2018, where r is Russia's Mining and Quarrying in Energy Producing Products, for the five countries j and the two most affected sectors s in each one of them. Coke and Refined Petroleum is the sector most affected in all five countries, which is not surprising given this sector's main input is probably crude oil, one of the activities constituting Mining and Quarrying in Energy Producing Products. The second most affected sector is typically Electricity, Gas, Steam and Air-conditioning, presumably because it is very energy intensive, except in Germany, where it is the embargoed sector itself, Mining and Quarrying in Energy Producing Products.

The first salient result in Table 8 is the difference in magnitudes between small and large

[16] We could consider alternative source countries within the EU, within which there is of course extensive input trade. There is a possibility, however, that inputs coming from other European countries are in fact sourced from Russia, and therefore would not be available under an embargo. We prefer to rule out that possibility and only consider upstream value chains originating from outside of the EU, since we are sure those would not be affected by an embargo.

countries: $\mathrm{SHOT}^{rs}_{\mathrm{RUS},j}$ takes much smaller values in France and Germany (a maximum of 6.8 percent) than in Latvia, Lithuania, and Bulgaria (about 4 to 7 times larger). This illustrates the relative independence of large European countries from Russia's inputs.

We then report the identities of countries K outside of the EU that display maximum values of $\mathrm{SHOT}^{rs}_{\mathrm{K},j}$ in 2018. We immediately see that historically both France and Germany have readily available alternatives to raw energy materials extracted in Russia that can serve as inputs into their most affected sectors. For example, 1.84 percent of the production of electricity, gas, steam and air-conditioning in France is associated with Russian energy exports, but Saudi Arabia's constitutes more (2.26 percent), Kazakhstan's constitutes almost as much (1.24 percent), and Norway's is about half as important (0.8 percent).[17] Similarly, 3.8 percent of Germany's output in mining of energy producing products is used to purchase Russian coke and refined petroleum, but 5.37 percent is used to purchase the same from Norway, 1.31 percent is used to purchase it from Kazakhstan, and 1.14 percent is used to purchase it from Britain. In other words, the large countries of the EU do have historical alternatives to Russian raw energy material.

The contrast could not be starker in the three Russian "satellite" countries we consider: Latvia, Lithuania, and Bulgaria are heavily dependent on inputs from Russia. For example, 43.3 percent of Bulgaria's inputs in Coke and Refined Petroleum actually come (directly or indirectly) from Russia's energy producing sector. Strikingly, there is no clear alternative to these inputs. The "runner-up" countries provide much smaller proportions of Bulgaria's inputs in this sector: Mining of energy products from South Africa represents 0.03 percent of Bulgarian output, 0.02 percent from Turkey, and less than 0.01 percent from the US. These are the *largest* alternative suppliers of raw energy supplies outside of the EU. Latvia's case is very similar in that the sizes of alternative countries supplying these inputs are minuscule, even though they come from plausible exporters of energy (Britain, Norway, the US). Lithuania is more diversified in its energy sourcing, with Kazakhstan and Saudi Arabia representing sizable proportions of output, almost two-thirds of the proportion coming from Russia.

Given these patterns an important question is whether the shares have changed over time, with entry into the EU or with the invasion of Crimea. If they have, it suggests some substitutability is possible in response to the current embargo, since it was possible when Russia invaded Crimea. Figure 3a and 3b report the values of SHOT over time for the two most

[17] The presence of China in this list is surprising, and seems to be related with unofficial changes in the ICIO data provided by the OECD. The data we use was officially released on 9 November 2021. We initially downloaded it from the OECD website on 6 December 2021. According to these data the results in Table 8 did not include China at all, for France, or for Latvia, Lithuania, or Bulgaria. We downloaded the data again in July 2023, and noticed (sometimes very) large changes in Chinese energy exports. Since this was not announced as an official revision of the ICIO data, we cannot know the reason for these changes. Thankfully they do not change our main conclusions.

affected sectors in France. Both graphs confirm that France has had access to many alternative energy suppliers since 2001, whose relative importance varied over time. But there is no sense that Russia was ever a dominant supplier, even to the two most dependent French sectors. There is no clear break in trends in terms of Russia's energy supply around 2014: If anything the share of Russian energy has increased since then. Figures 3c and 3d replicate the exercise for Germany, with conclusions that are by and large similar. The two most dependent sectors in Germany have had access to a variety of alternative suppliers since 2001: Norway, historically the most important, but also the UK, Kazakhstan, Saudi Arabia, and the US. The only different with France is that Russia has persistently been the second most important supplier to these sectors over the past 20 years, even the first in 2011. There has not been any noticeable downward trend in Russia's energy supply since 2014: Like for France, the trend has been upward if anything.

Figures 4a and 4b illustrate the dependence of Bulgaria's two most impacted sectors to Russia's energy and the availability of substitute suppliers. The evidence is unambiguous: Russia has been the dominant supplier since EU accession in 2007. What is more there is no apparent downward trend in the predominance of Russia, not since accession, and not since the invasion of Crimea either. The substitute suppliers are highly fragmented, as none of them constitute more than a few percent of production in Bulgaria (Kazakhstan used to represent about 5 percent in 2008-2009, but that has disappeared since). A likely explanation to the almost exclusive importance of Russia's energy inputs into Bulgaria's sectors is Bulgaria's reliance on the Trans-Balkan Pipeline system that links it directly with Russia.[18]

Figures 4c and 4d show the same pattern prevails in Latvia: Russia's energy sectors have been the dominant suppliers since EU accession, with no discernable downward trend. Alternative suppliers to Latvia are truly minuscule.

Figures 4e and 4f replicate once again the exercise, this time for Lithuania. Lithuania is an interesting case, since it has taken significant steps to reduce its dependence on Russia's energy supply. In 2006, the acquisition of an oil refinery in Lithuania by a Polish company (PKN Orlen) has allowed the country to receive oil supplies not only from Russia but also from Norway and Kazakhstan. In 2014, Lithuania started operating a liquefied natural gas terminal in Klaipeda, which allows Lithuania to import from Norway or Qatar, instead of using the Yamal-Europe pipeline, which transports Russian gas. These changes are apparent on the figures, where substitute suppliers to Russia's energy have emerged since the early 2010s, especially Kazakhstan, Saudi Arabia, and Norway. As a result, alternative suppliers to Russia have risen in prominence in Lithuania, with the share of Russian energy inputs in Coke and Refined Petroleum falling from 41 percent to 32 percent between 2007 and 2018. These trends

[18]Bulgaria is spearheading efforts to diversify its energy sources from Russia, for example from Azerbaijan through the Azerbaijan-Georgia-Romania Interconnector pipeline project, or from Kazakhstan. But these appear to still be in the project stage at time of writing.

are suggestive of the importance of transport infrastructure for the determination and existence of substitute markets.[19]

Interestingly, Latvia has also taken steps to reduce its dependence on Russian oil and gas. It has diversified its oil sources by establishing connections to the Baltic Pipeline System, which allows oil imports from various countries, including Belarus and Lithuania. This is not apparent in Figures 4c and 4d, since we have no data coverage on Belarus and we have omitted Lithuania from the set of possible substitute suppliers by construction. Nothing guarantees that the supply of energy inputs from Lithuania or Belarus into Latvia is not actually indirectly coming from Russia, so that Figures 4c and 4d may in fact reflect the high dependence of Latvia on Russian inputs once indirect linkages are taken into account.

A conclusion that emerges from this analysis is that those countries that are most affected by an embargo on Russian exports are also those that cannot easily substitute away from Russian inputs, at least on the basis of historical input-output linkages. The results about substitute markets coincide with anecdotal evidence about the development of alternative transport infrastructures to Russian pipelines: They suggest both that substitution is feasible with the adequate infrastructure, and that it is virtually impossible absent the necessary investment. Indeed for countries like Latvia and Bulgaria, Russia is close to an exclusive supplier of energy products. While it is true that the effects of sanctions remain relatively small even in those most affected countries, the evidence raises the question of equity within the Union in the face of these embargoes.

The results about Latvia, Bulgaria, and Lithuania illustrate the potency of our approach: The data-based approach makes it possible to pinpoint alternative markets to those under embargo, at least from a historical perspective. What is interesting in this illustration is the close mapping between the emergence of such alternative markets and the existence of energy transport infrastructure: It seems that substitution away from Russian energy inputs requires heavy infrastructure spending, as in Lithuania.

[19] This is consistent with the theory developed by Albrizio et al. (2022), who estimate the impact of a full shutdown of Russian pipeline gas exports to Europe allowing for alternative sourcing via an integrated global liquefied natural gas market. They show the availability of LNG substitutes reduces dramatically the consequences of a pipeline shutdown for EU countries.

4 Conclusion

We propose a data-based approach to approximating the consequences of trade sanctions. We validate the approximation by comparing it with exact responses simulated from a multi-country multi-sector model with constant and homogeneous elasticities of substitution between inputs and consumption, unitary elasticity between capital and labor, and financial autarky. The approximation is palatable for a broad range of elasticities of substitution, albeit not when they are zero. The approximation is based on a decomposition of high order trade according to destination markets or inputs origin; As such, it can be readily computed on the basis of international input-output data. We believe this provides a practical shortcut to evaluating the consequences of trade sanctions - one that is not meant to replace the precise quantification afforded by a general equilibrium model - but one that makes it possible to conduct a broad range of simple yet relevant experiments without having to take a stance on the full set of calibrated parameters in a simulated model.

We implement our approximation to evaluate the costs of trade sanctions between Europe and Russia. We find those costs to be small, in accordance with the conclusions obtained in most existing simulations of general equilibrium models, despite very different theoretical environments and calibrations. In the models, sanctions can only have high costs in the extreme case of no substitutability, which in the data is probably the exception rather than the rule. In such a context our empirical approach can have some merit in the sense that it replicates low costs of trade sanctions without a model and the associated difficult calibration choices.

Our approximation confirms that European trade sanctions on Russia have small effects on both regions, albeit asymmetric since they are about fifteen times larger on Russia than on Europe. The effects on Europe are enormously asymmetric, with much larger consequences on small, Eastern European economies that used to be “satellites” of the ex-Soviet Union than on large West European economies. We perform our approximation over time to identify emerging or disappearing supply chains that could constitute substitutes to embargoed markets, upstream or downstream. This reveals the large asymmetries within the European Union are compounded by the fact that most of the affected (small) East European countries have had no substitute energy suppliers to Russia, which has been increasing in influence despite accession to the EU or the invasion of Crimea. In contrast large Western European countries have had access to many alternative suppliers. An interesting exception is Lithuania, whose dependence on Russian energy inputs has observably diminished since the 2010s according to our approximation: Interestingly this concords with Lithuania’s large investment efforts in energy transport infrastructure.

The application of our approximation to the case of sanctions on Russia illustrates its versatility and portability. In a time of intensifying disruptions to global trade, readily available estimates of the consequences of trade sanctions, effective or putative, constitute relevant information. We have developed a web-based dashboard, accessible at exposure.trade that proposes a user friendly interface designed to facilitate the extraction of approximate costs of trade sanctions for any combinations of sanctioning and sanctioned countries or sectors. We believe this could constitute an important input in future policy discussions.

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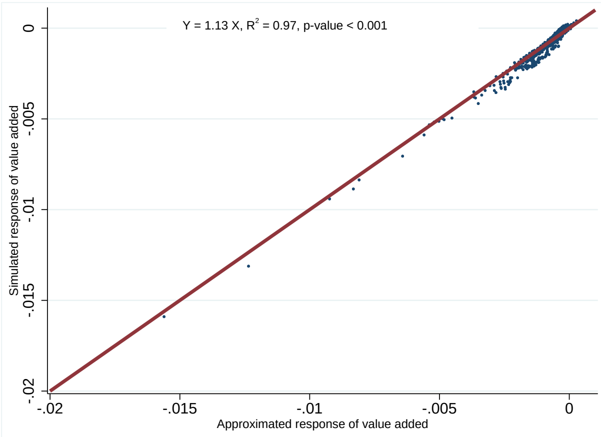

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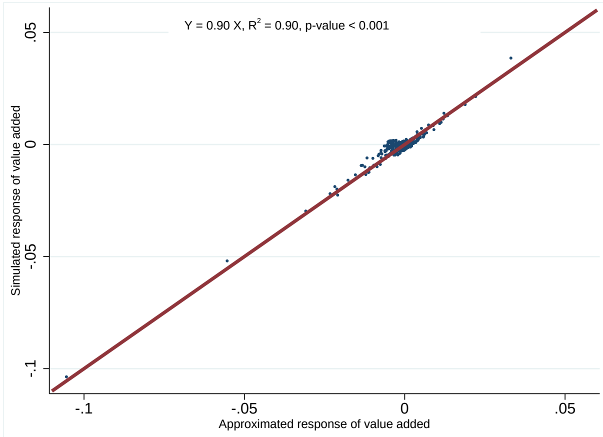

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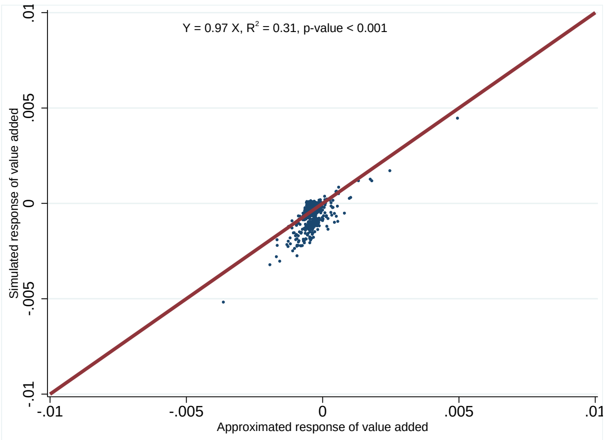

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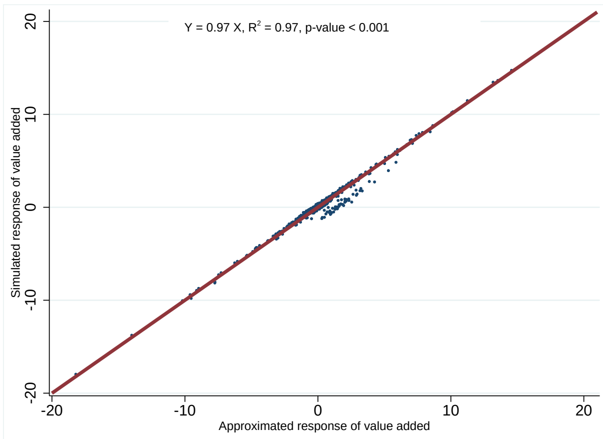

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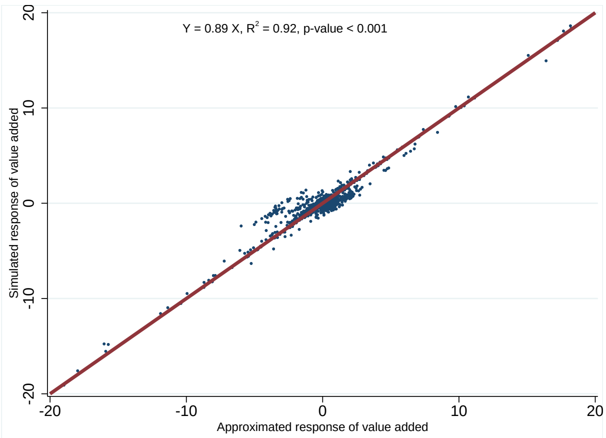

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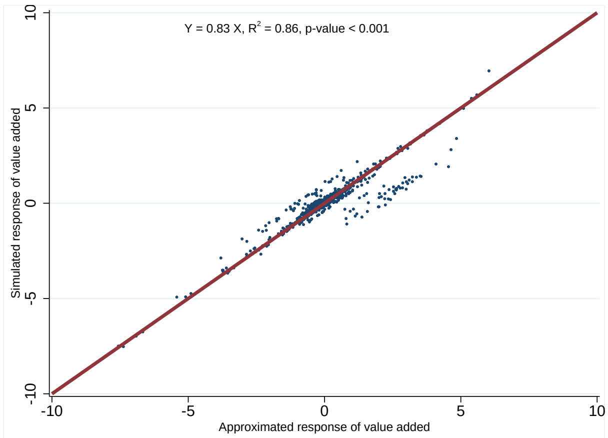
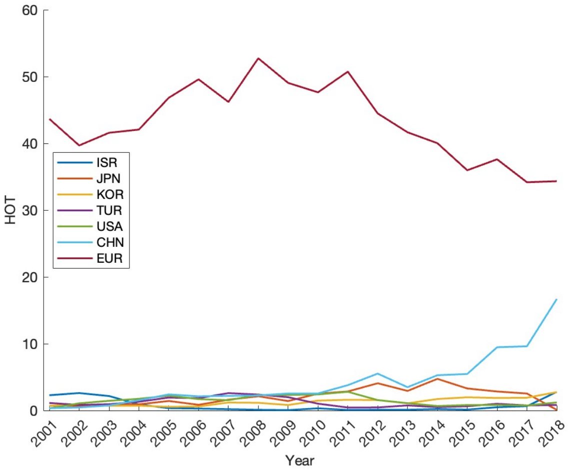
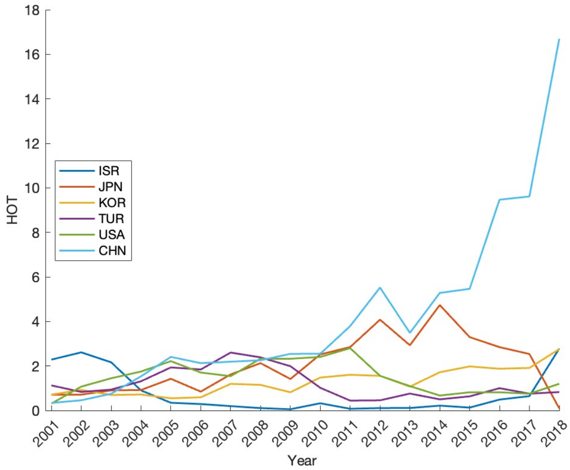


(f) $\rho = 0.1$, $\epsilon = 0.1$, and $\psi = 2$

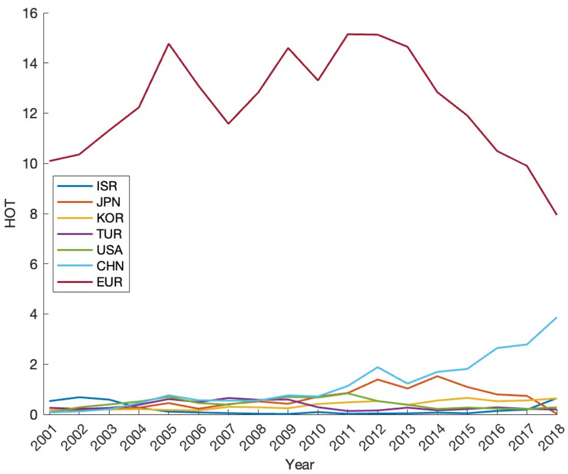
Figure 1: Response of value added to a Russian Oil shock



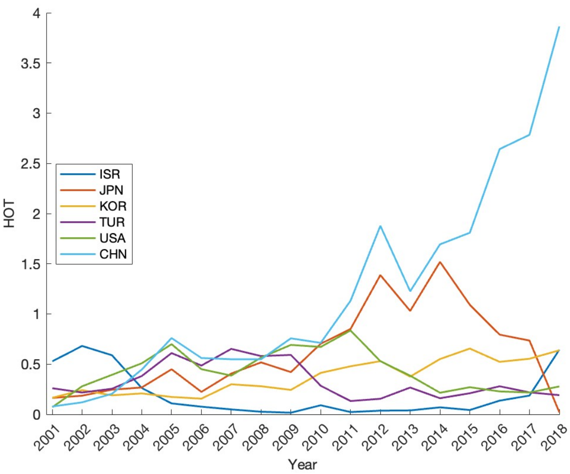
(a) Energy producing products



(b) Energy producing products (without Europe)

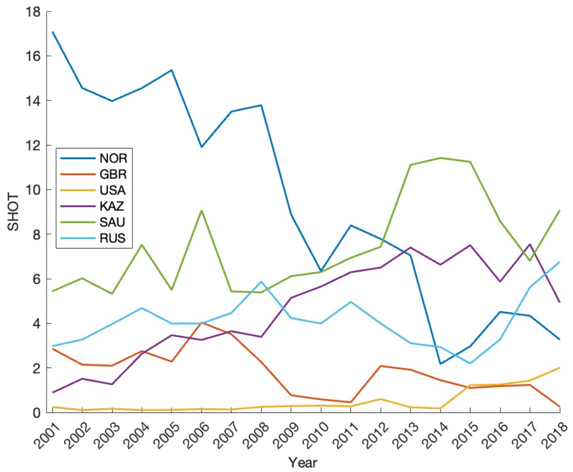


(c) Mining support services

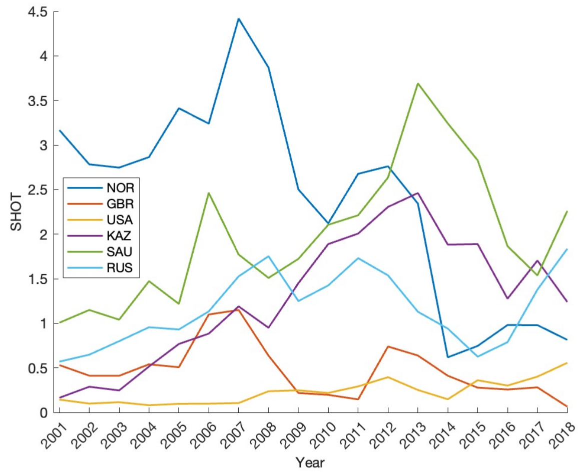


(d) Mining support services (without Europe)

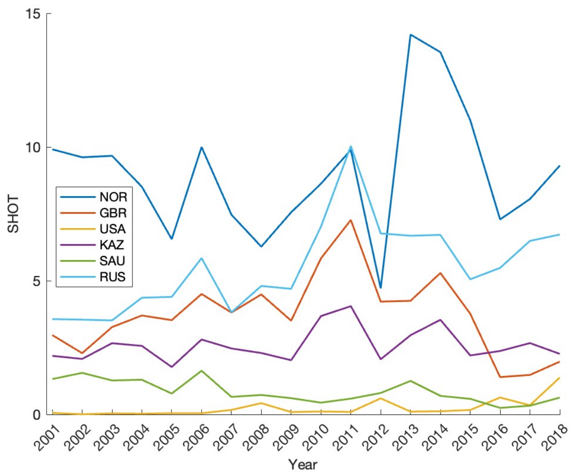
Figure 2: HOT Russia (in %)



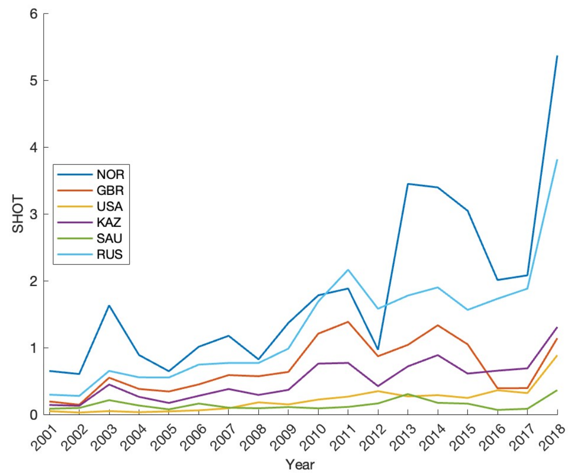
(a) France: Refined petroleum products



(b) France: Electricity, gas, steam

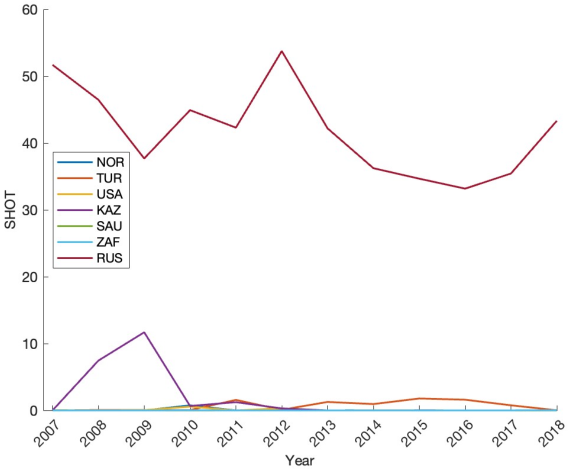


(c) Germany: Refined petroleum products

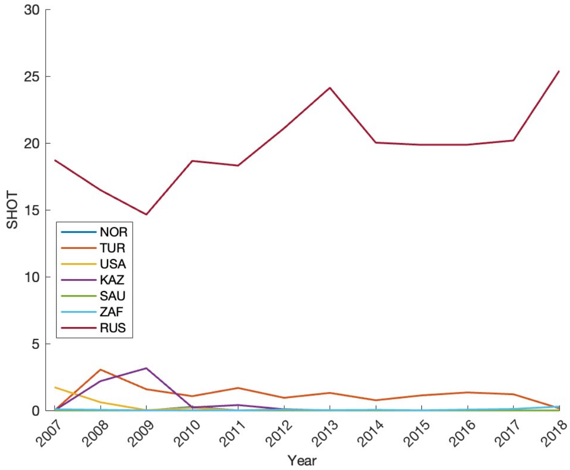


(d) Germany: Energy producing products

Figure 3: SHOT France and Germany (in %)

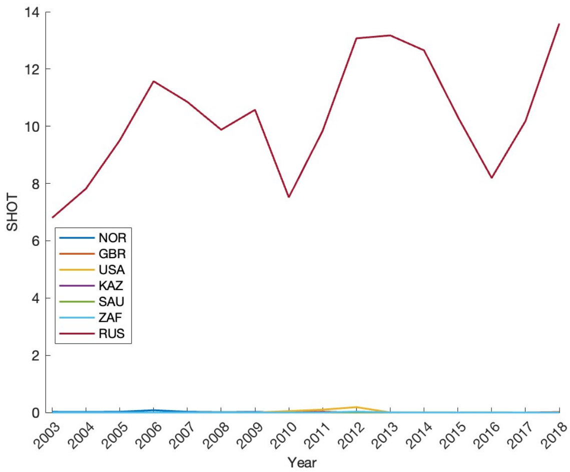


(a) Bulgaria: Refined petroleum products

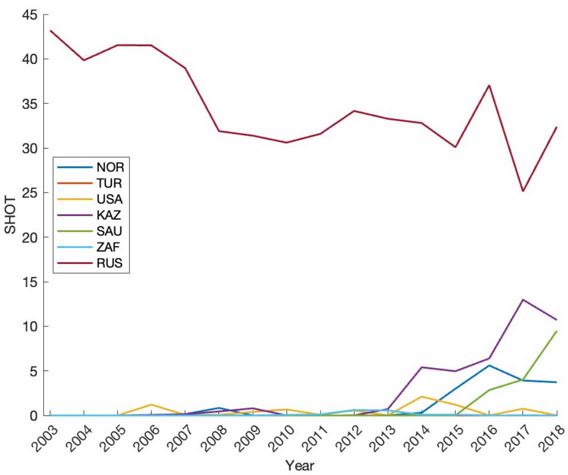


(b) Bulgaria: Electricity, gas, steam

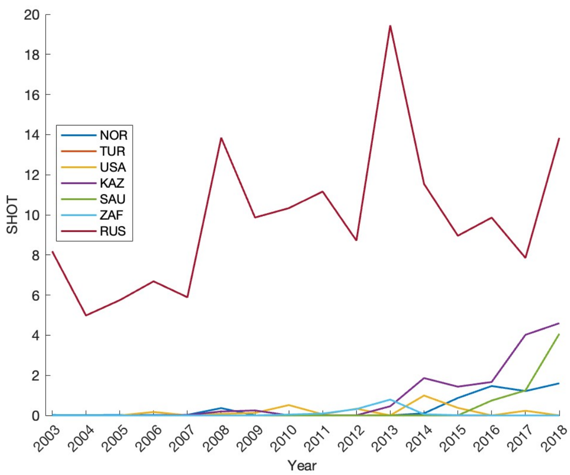
(c) Latvia: Refined petroleum products



(d) Latvia: Electricity, gas, steam



(e) Lithuania: Refined petroleum products



(f) Lithuania: Electricity, gas, steam

Figure 4: SHOT Lithuania, Latvia, and Bulgaria (in %). Note that the time-series start on the date of each country's accession to the European Union.

Table 1: Comparing direct and indirect costs under an embargo on Russian Petroleum (in %)

Country	HOT	Direct Exports	Ratio	Country	HOT	Direct Exports	Ratio
CZE	0.35	0.01	40.71	LVA	0.09	0.02	4.13
SVK	0.36	0.03	14.32	HRV	0.05	0.01	4.11
LTU	0.29	0.03	9.35	AUT	0.06	0.02	4.04
BGR	0.70	0.08	9.19	DNK	0.96	0.27	3.56
MLT	0.01	<0.01	7.67	IRL	0.23	0.07	3.38
LUX	<0.01	<0.01	6.51	GRC	1.52	0.46	3.30
FIN	0.79	0.14	5.45	EST	0.13	0.04	3.23
POL	2.08	0.39	5.31	ROU	0.38	0.12	3.11
HUN	0.66	0.13	5.01	SVN	0.08	0.03	3.06
SWE	0.84	0.17	4.87	FRA	2.23	0.78	2.86
NLD	1.05	0.24	4.47	DEU	5.78	2.19	2.64
BEL	0.64	0.15	4.22	ESP	0.70	0.27	2.55
ITA	1.98	0.47	4.18	GBR	3.18	1.37	2.32
PRT	0.25	0.06	4.14	CYP	0.01	<0.01	2.11

Table 2: Comparing direct and indirect costs under an embargo on Russian Petroleum (in %)

Country	SHOT	Direct Imports	Ratio	Country	SHOT	Direct Imports	Ratio
MLT	0.08	0.04	2.14	SVK	0.36	0.22	1.61
ITA	0.11	0.06	1.87	EST	0.35	0.22	1.60
LVA	0.31	0.17	1.79	HRV	0.09	0.05	1.58
POL	0.40	0.22	1.79	SVN	0.12	0.08	1.55
ROU	0.15	0.09	1.78	BGR	1.16	0.75	1.55
CZE	0.17	0.10	1.74	SWE	0.17	0.11	1.53
FIN	0.34	0.20	1.73	BEL	0.10	0.07	1.52
CYP	0.03	0.02	1.73	GRC	0.71	0.47	1.52
ESP	0.04	0.02	1.72	HUN	0.40	0.27	1.52
DEU	0.13	0.07	1.70	LUX	<0.01	<0.01	1.39
AUT	0.01	0.01	1.69	NLD	0.10	0.07	1.39
GBR	0.09	0.05	1.68	LTU	0.61	0.44	1.38
FRA	0.07	0.04	1.66	DNK	0.24	0.17	1.36
PRT	0.11	0.07	1.63	IRL	0.04	0.03	1.24

Table 3: Approximate effects of an embargo on Russian Petroleum (in %)

Effects on Russia		Effects on European sectors		EU countries	
Refined petroleum products	5.00	Air transport	0.43	BGR	0.26
Mining support service activities	3.11	Refined petroleum products	0.30	GRC	0.16
Transport by land & pipelines	1.18	Water transport	0.27	HUN	0.13
Energy producing products	1.10	Transport by land & pipelines	0.19	POL	0.12
Warehouse & transport services	0.90	Basic metals	0.13	EST	0.12
Administrative services	0.88	Chemical products	0.13	LTU	0.11
Wholesale & retail trade	0.49	Other non-metallic minerals	0.11	LVA	0.11
Water transport	0.41	Postal & courier activities	0.09	FIN	0.08
Manufacturing nec	0.39	Fishing	0.09	SVK	0.08
Finance & insurance	0.36	Non-energy producing products	0.09	CZE	0.06
Total Effect	**0.60**	Total effect	**0.04**		

Table 4: Approximate effects of an embargo on Russian Energy (in %)

Effects on Russia		Effects on European sectors		EU countries	
Energy producing products	8.70	Refined petroleum products	1.43	BGR	1.13
Mining support service activities	2.01	Basic metals	0.51	LTU	0.52
Transport by land & pipelines	1.21	Electricity, gas, steam	0.42	SVK	0.43
Administrative services	1.01	Air transport	0.40	HUN	0.40
Manufacturing nec	0.80	Other non-metallic minerals	0.31	LVA	0.33
Warehouse & transport services	0.78	Chemical products	0.28	CZE	0.30
Water transport	0.72	Non-energy producing products	0.26	POL	0.29
Non-energy producing products	0.52	Transport by land & pipelines	0.26	FIN	0.20
Machinery & equipment, nec	0.45	Water transport	0.21	ROU	0.17
Rubber & plastics products	0.40	Rubber & plastics products	0.17	SVN	0.13
Total Effect	**1.17**	Total effect	**0.08**		

Table 5: Approximate effects of an embargo on all Russian sectors (in %)

Effects on Russia		Effects on European sectors		EU countries	
Energy producing products	10.22	Refined petroleum products	2.19	BGR	1.87
Air transport	9.19	Basic metals	1.51	LTU	1.25
Mining support service activities	6.32	Air transport	1.19	CYP	1.04
Postal & courier activities	6.25	Water transport	0.76	LVA	1.03
Basic metals	6.20	Other non-metallic minerals	0.69	EST	0.99
Warehouse & transport services	6.18	Chemical products	0.69	SVK	0.84
Water transport	6.01	Electricity, gas, steam	0.66	HUN	0.79
Refined petroleum products	5.84	Fabricated metal products	0.63	FIN	0.68
Transport by land & pipelines	5.73	Transport by land & pipelines	0.63	POL	0.68
IT	5.69	Wood products	0.61	CZE	0.65
Total effect	**3.40**	Total effect	**0.23**		

Table 6: Approximate effects of an embargo on all European sectors (in %)

Effects on EU countries		Effects on Russia	
CYP	2.14	Motor vehicles	6.34
LTU	0.93	Rubber & plastics products	5.26
EST	0.83	Machinery & equipment, nec	4.56
LVA	0.80	Other transport equipment	4.31
BGR	0.71	Electrical equipment	3.97
FIN	0.61	Manufacturing nec	3.49
SVN	0.53	Paper products & printing	3.25
IRL	0.52	Air transport	3.01
SVK	0.52	Fabricated metal products	2.97
CZE	0.50	Pharmaceutical products	2.92
Total effect	**0.24**	Total effect	**1.31**

Table 7: Substitute market for Russia ranked by HOT (in %)

European embargo on Russia's Energy sectors						
		Substitute countries				
Most affected Russian sectors	EUR	CHN	ISR	KOR	USA	TUR
Energy producing products	34.33	16.70	2.78	2.76	1.20	0.83
Mining support services	7.95	3.86	0.64	0.64	0.28	0.19

Table 8: Substitute market for Europe ranked by SHOT (in %)

European embargo on Russia's Energy						
		Substitute countries				
Most affected French sectors	RUS	SAU	KAZ	CHN	NOR	USA
Refined petroleum products	6.76	9.07	4.93	3.47	3.27	2.01
Electricity, gas, steam	1.84	2.26	1.24	0.87	0.81	0.56
Most affected German sectors	RUS	NOR	KAZ	GBR	USA	SAU
Refined petroleum products	6.73	9.31	2.26	1.97	1.38	0.63
Energy producing products	3.82	5.37	1.31	1.14	0.88	0.36
Most affected Latvian sectors	RUS	GBR	CHN	NOR	USA	
Refined petroleum products	23.09	0.03	<0.01	<0.01	<0.01	
Electricity, gas, steam	13.59	0.02	<0.01	<0.01	<0.01	
Most affected Lithuanian sectors	RUS	KAZ	SAU	NOR	CHN	ZAF
Refined petroleum products	32.37	10.71	9.48	3.72	0.93	<0.01
Electricity, gas, steam	13.84	4.60	4.07	1.60	0.40	<0.01
Most affected Bulgarian sectors	RUS	ZAF	TUR	CHN	USA	
Refined petroleum products	43.32	0.03	0.02	0.01	<0.01	
Electricity, gas, steam	25.40	0.29	0.15	<0.01	<0.01	

Appendix A

This appendix summarizes the key steps in the derivation of the influence matrix in response to trade shocks. All equilibrium conditions are expressed in deviations from the steady state, denoted with time subscripts and ln-deviations. We start with some definitions:

Definition 1.

$\mathbf{A}^m$ *is the matrix with typical element the direct requirement coefficient* $a^{rs}_{ij} = \frac{\mathrm{P}^{rs}_{ij}\,\mathrm{M}^{rs}_{ij}}{\mathrm{PY}^s_j} = (1-\eta^s)\frac{\mathrm{P}^{rs}_{ij}\,\mathrm{M}^{rs}_{ij}}{\mathrm{P}^s_j\,\mathrm{M}^s_j}$ *the share of output in* (j,s) *that is produced using intermediate inputs from* (i,r).

$\mathbf{A}^c$ *is the matrix with typical element* $ac^r_{ij} = \frac{\mathrm{P}^r_{ij}\,\mathrm{C}^r_{ij}}{\mathrm{P}_j\,\mathrm{C}_j}$ *the expenditure share of country* j*'s final consumption that is spent on final goods produced in* (i,r).

$\mathbf{B}^m$ *is the matrix with typical element the allocation coefficient* $b^{rs}_{ij} = \frac{(1-\eta^s)\,\mathrm{PY}^s_j\,\xi^{rs}_{ij}}{\mathrm{PY}^r_i} = \frac{\mathrm{P}^{rs}_{ij}\,\mathrm{M}^{rs}_{ij}}{\mathrm{PY}^r_i}$ *the share of output in source sector* (i,r) *that is used as intermediate input in* (j,s).

$\mathbf{B}^c$ *is the matrix with typical element* $bc^r_{ij} = \frac{\pi^r_{ij}\,\mathrm{P}_j\,\mathrm{C}_j}{\mathrm{PY}^r_i} = \frac{\mathrm{P}^r_{ij}\,\mathrm{C}^r_{ij}}{\mathrm{PY}^r_i}$ *the share of output in source sector* (i,r) *used as final consumption in country* j.

$\mathbf{\Upsilon}$ *is the matrix with typical element* $\upsilon^r_i = \frac{\eta^r\,\mathrm{PY}^r_i}{\mathrm{P}_i\,\mathrm{C}_i}$ *the share of nominal value added in* (i,r) *in total nominal consumption in country* i.

Market clearing in deviations from the steady state is given by

$$\begin{aligned}\ln \mathrm{P}^r_{i,t} + \ln \mathrm{Y}^r_{i,t} &= \sum_j \sum_s \frac{ac^r_{ij}\,\mathrm{P}_j\,\mathrm{C}_j}{\mathrm{P}^r_i\,\mathrm{Y}^r_i}\frac{\eta^s\,\mathrm{P}^s_j\,\mathrm{Y}^s_j}{\mathrm{P}_j\,\mathrm{C}_j}(\ln \mathrm{P}^s_{j,t} + \ln \mathrm{Y}^s_{j,t} + \ln \pi^r_{ij,t}) \\ &+ \sum_j \sum_s \frac{\mathrm{P}^s_j\,\mathrm{Y}^s_j\,a^{rs}_{ij}}{\mathrm{P}^r_i\,\mathrm{Y}^r_i}(\ln \mathrm{P}^s_{j,t} + \ln \mathrm{Y}^s_{j,t} + \ln \xi^{rs}_{ij,t}),\end{aligned}$$

where in addition

$$\begin{aligned}\ln \pi^r_{ij,t} &= (1-\rho)(1-ac^r_{ij})\ln \tau^r_{ij,t} + (1-\rho)\sum_{k,l} ac^l_{kj}(\ln \mathrm{P}^r_{i,t} - \ln \mathrm{P}^l_{k,t}), \\ \ln \xi^{rs}_{ij,t} &= (1-\epsilon)(1-\frac{a^{rs}_{ij}}{1-\eta^s})\ln \tau^r_{ij,t} + (1-\epsilon)\sum_{k,l}\frac{a^{ls}_{kj}}{1-\eta^s}(\ln \mathrm{P}^r_{i,t} - \ln \mathrm{P}^l_{k,t}).\end{aligned}$$

Rewriting the resource constraint in matrix algebra making use of the definitions summarized in Definition 1 yields

$$\begin{aligned}\ln \mathbf{P}_t + \ln \mathbf{Y}_t = (\mathbf{B}^c \boldsymbol{\Upsilon} + \mathbf{B}^m)(\ln \mathbf{P}_t + \ln \mathbf{Y}_t) \\ + (1-\rho)\Big[\mathrm{diag}(\mathbf{B}^c \mathbf{1}_{\mathrm{N}}) - \mathbf{B}^c (\mathbf{A}^c)^\top\Big] \ln \mathbf{P}_t \\ + (1-\rho)\Big[\mathbf{B}^c \odot (\mathbf{1}_{\mathrm{NR}} - \mathbf{A}^c) \odot \ln \boldsymbol{\tau}_t\Big] \mathbf{1}_{\mathrm{N}} \\ + (1-\epsilon)\Big[\mathrm{diag}(\mathbf{B}^m \mathbf{1}_{\mathrm{NR}}) - \mathbf{B}^m (\mathbf{I}-\boldsymbol{\eta})^{-1} (\mathbf{A}^m)^\top\Big] \ln \mathbf{P}_t \\ + (1-\epsilon)\Big[\mathbf{B}^m \odot (\mathbf{1}_{\mathrm{NR}} - (\mathbf{I}-\boldsymbol{\eta})^{-1} \mathbf{A}^m) \odot (\ln \boldsymbol{\tau}_t \otimes \mathbf{1}_{\mathrm{R}})\Big] \mathbf{1}_{\mathrm{NR}},\end{aligned} \tag{A.4}$$

where $\ln \boldsymbol{\tau}_t$ denotes the vector of changes in transport costs $\ln \tau^r_{ij}$ between any location of production (i, r) and location of use j.

In deviations from the steady state, the production function can be rewritten as

$$\ln \mathbf{Y}_t = \boldsymbol{\eta}\boldsymbol{\alpha} \ln \mathbf{H}_t + (\mathbf{I}-\boldsymbol{\eta}) \ln \mathbf{M}_t. \tag{A.5}$$

Equilibrium labor input is given by

$$\ln \mathbf{H}_t = \frac{\psi}{1+\psi} \ln \mathbf{Y}_t + \frac{\psi}{1+\psi} (\mathbf{I} - (\mathbf{A}^c)^\top \otimes \mathbf{1}_{\mathrm{R}}) \ln \mathbf{P}_t. \tag{A.6}$$

Market clearing in the intermediate input market implies

$$\ln \mathbf{M}_t = \ln \mathbf{P}_t - \ln \mathbf{P}^{\mathrm{M}}_t + \ln \mathbf{Y}_t, \tag{A.7}$$

where $\ln \mathbf{P}^{\mathrm{M}}_t$ denotes the deviations from the steady state of the material price index

$$\mathrm{P}^{r\,\mathrm{M}}_i = \left(\sum_{j,s} \mu^{sr}_{ji} (\mathrm{P}^{sr}_{ji})^{1-\epsilon} \right)^{\frac{1}{1-\epsilon}}.$$

It follows that

$$\ln \mathbf{M}_t = \ln \mathbf{Y}_t + \Big[\mathbf{I} - (\mathbf{I}-\boldsymbol{\eta})^{-1} (\mathbf{A}^m)^\top\Big] \ln \mathbf{P}_t - \Big[(\mathbf{I}-\boldsymbol{\eta})^{-1} (\mathbf{A}^m)^\top \odot (\ln \boldsymbol{\tau}_t \otimes \mathbf{1}_{\mathrm{R}})^\top\Big] \mathbf{1}_{\mathrm{NR}}. \tag{A.8}$$

Combining equations (A.4), (A.5), (A.6), and (A.8) yields the expression in the text for the response of real output $\ln \mathbf{Y}_t$:

$$\ln \mathbf{Y}_t = \boldsymbol{\Lambda}^{-1} \ln \mathbf{T}_t,$$

where we define:

$$\boldsymbol{\Lambda} = \Big[\mathbf{I} - \frac{\psi}{1+\psi} \boldsymbol{\eta}\boldsymbol{\alpha} \Big(\mathbf{I} + \Big(\mathbf{I} - (\mathbf{A}^c)^\top \otimes \mathbf{1} \Big) \mathcal{P} \Big) - (\mathbf{I}-\boldsymbol{\eta}) \Big(\mathbf{I} + \Big(\mathbf{I} - (\mathbf{I}-\boldsymbol{\eta})^{-1} (\mathbf{A}^m)^\top \Big) \mathcal{P} \Big) \Big],$$

$$\mathcal{P} = -\Big(\mathbf{I} - \mathcal{M}\Big)^{+}\Big(\mathbf{I} - \mathbf{B}^c\boldsymbol{\Upsilon} - \mathbf{B}^m\Big),$$

$$\mathcal{M} = \mathbf{B}^c\boldsymbol{\Upsilon} + \mathbf{B}^m + (1-\rho)\Big(\mathrm{diag}(\mathbf{B}^c\mathbf{1}_N) - \mathbf{B}^c(\mathbf{A}^c)^\top\Big) + (1-\epsilon)\Big(\mathrm{diag}(\mathbf{B}^m\mathbf{1}_{NR}) - \mathbf{B}^m(\mathbf{I}-\boldsymbol{\eta})^{-1}(\mathbf{A}^m)^\top\Big),$$

and

$$\begin{aligned}
\ln \mathbf{T}_t =& \Big[\frac{\psi}{1+\psi}\boldsymbol{\eta}\boldsymbol{\alpha}\Big(\mathbf{I} - (\mathbf{A}^c)^\top \otimes \mathbf{1}_{\mathrm{R}}\Big) + (\mathbf{I}-\boldsymbol{\eta})\Big(\mathbf{I} - (\mathbf{I}-\boldsymbol{\eta})^{-1}(\mathbf{A}^m)^\top\Big)\Big]\Big(\mathbf{I} - \mathcal{M}\Big)^{+} \\
& \Big[(1-\rho)\Big(\mathbf{B}^c \odot (\mathbf{1}_{\mathrm{N}} - \mathbf{A}^c) \odot \ln \boldsymbol{\tau}_t\Big)\mathbf{1}_{\mathrm{N}} \\
& + (1-\epsilon)\Big(\mathbf{B}^m \odot (\mathbf{1}_{\mathrm{NR}} - (\mathbf{I}-\boldsymbol{\eta})^{-1}\mathbf{A}^m) \odot (\ln \boldsymbol{\tau}_t \otimes \mathbf{1}_R)\Big)\mathbf{1}_{\mathrm{NR}}\Big] \\
& - (\mathbf{A}^m)^\top \odot (\ln \boldsymbol{\tau}_t \otimes \mathbf{1}_{\mathrm{R}})^\top \mathbf{1}_{\mathrm{NR}}.
\end{aligned} \tag{A.9}$$

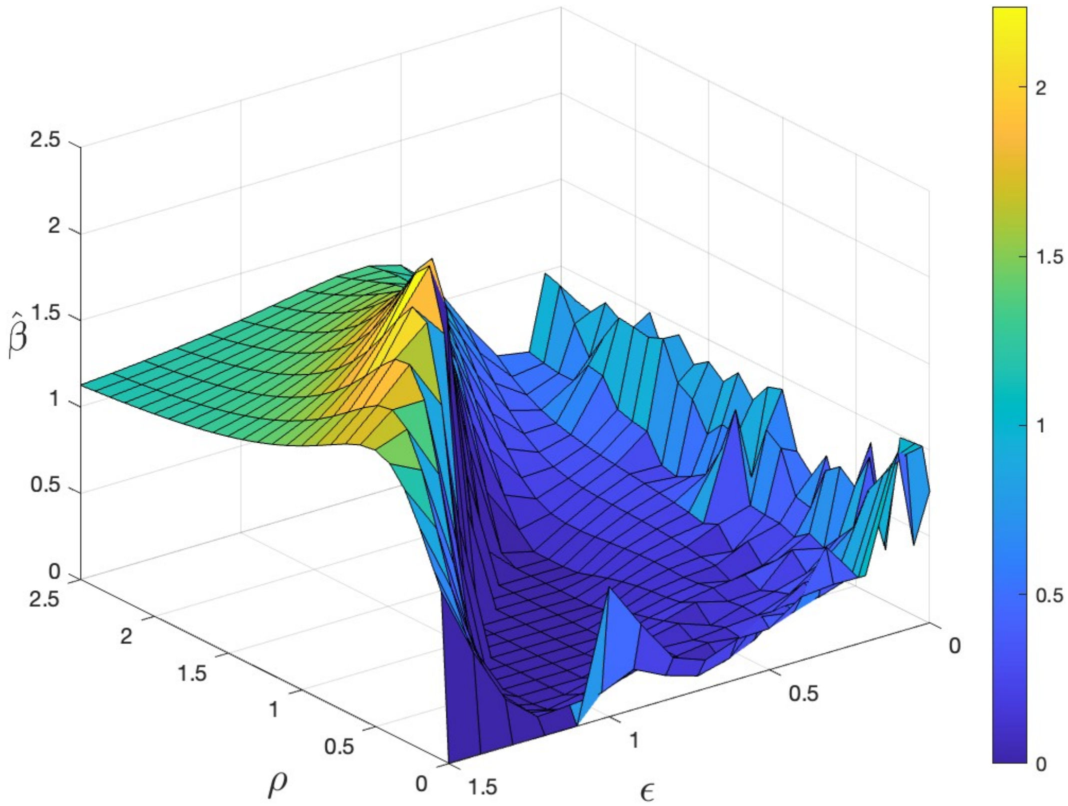
The + sign stands for the Moore-Penrose inverse as $\mathbf{I} - \mathcal{M}$ is not invertible. See Huo et al. (2021). The response of sector-level prices is given by

$$\ln \mathbf{P}_t = \mathcal{P} \ln \mathbf{Y}_t.$$

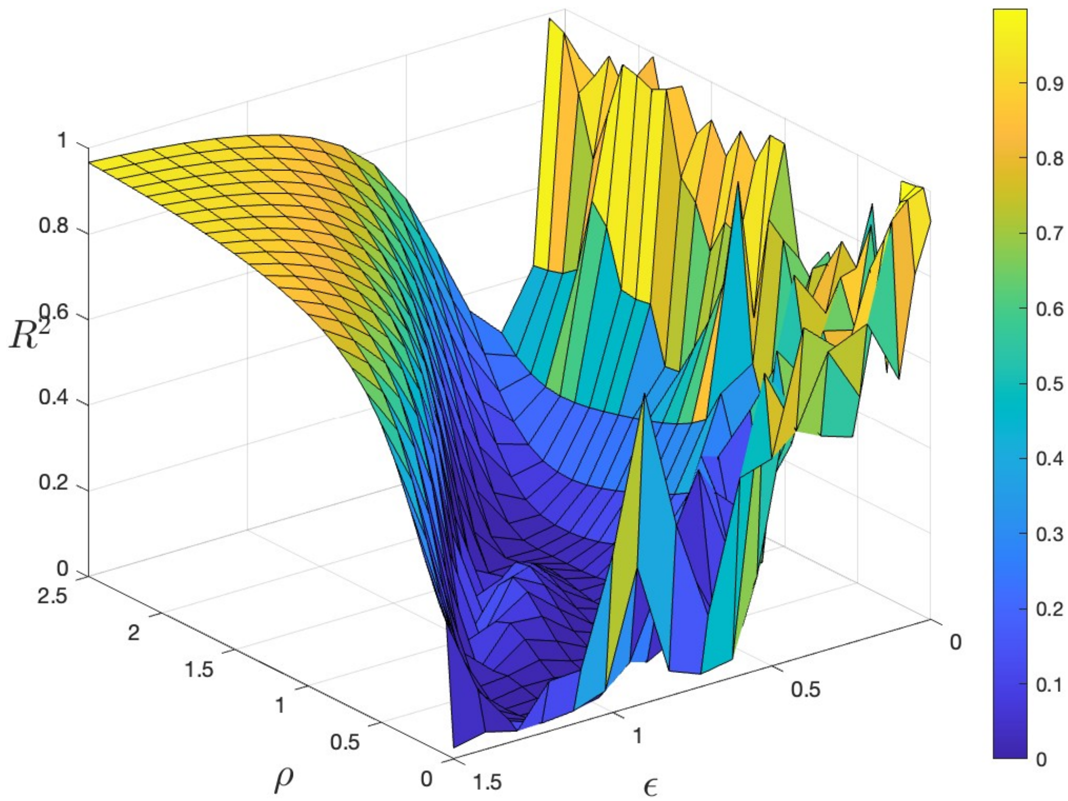
It follows the response of nominal output is given by

$$\ln \mathbf{PY}_t = (\mathcal{P} + \mathbf{I})\boldsymbol{\Lambda}^{-1} \ln \mathbf{T}_t.$$

Appendix B

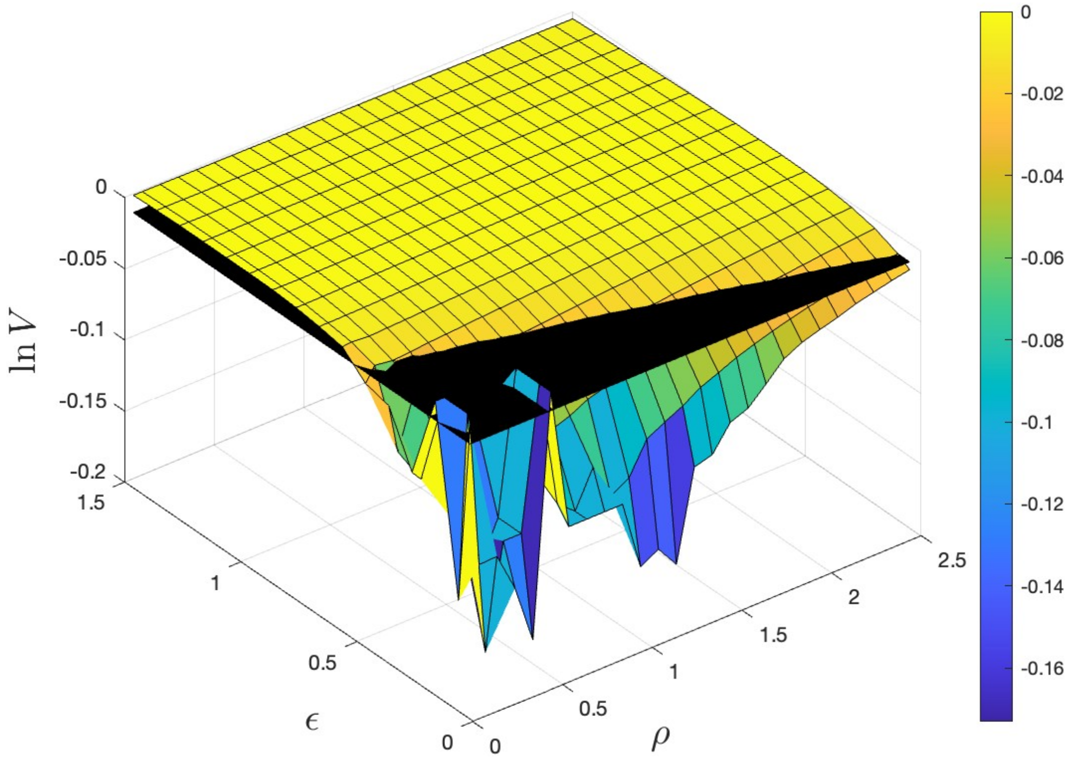


(a) $\hat{\beta}$ from regressing $\ln \mathbf{V}_t$ on $\frac{\alpha^r \psi}{1+\psi} \ln \mathbf{PY}_t$

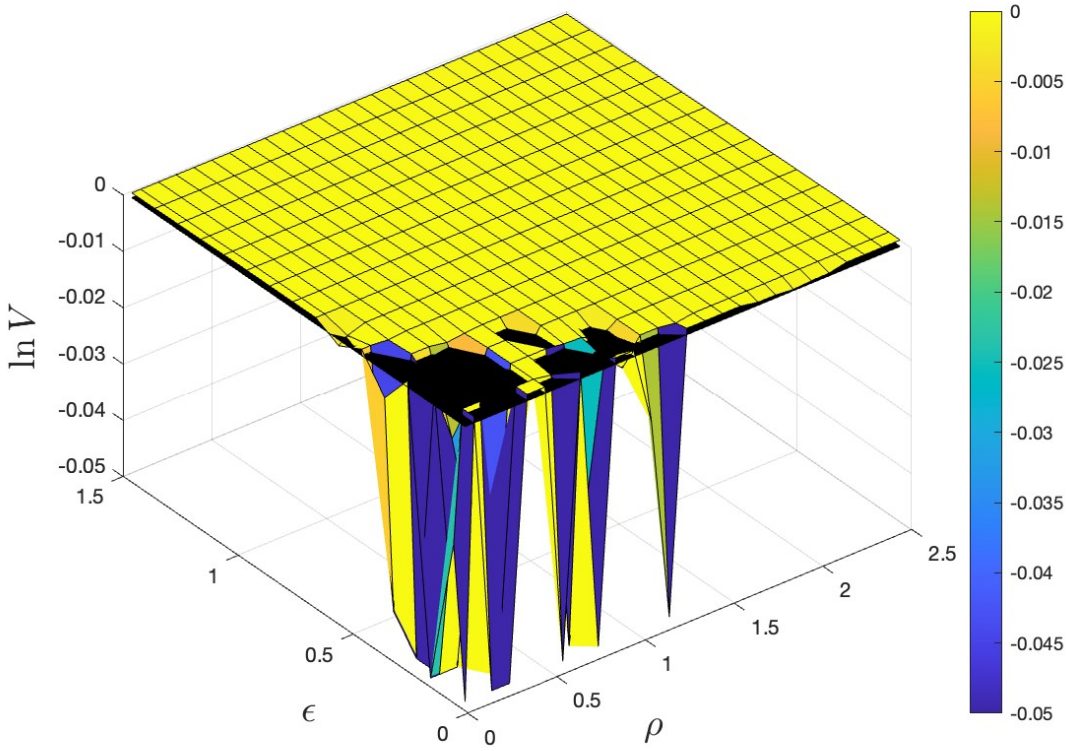


(b) R^2 from regressing $\ln \mathbf{V}_t$ on $\frac{\alpha^r \psi}{1+\psi} \ln \mathbf{PY}_t$

Figure B.1: Correlating $\ln \mathbf{V}_t$ with $\frac{\alpha^r \psi}{1+\psi} \ln \mathbf{PY}_t$

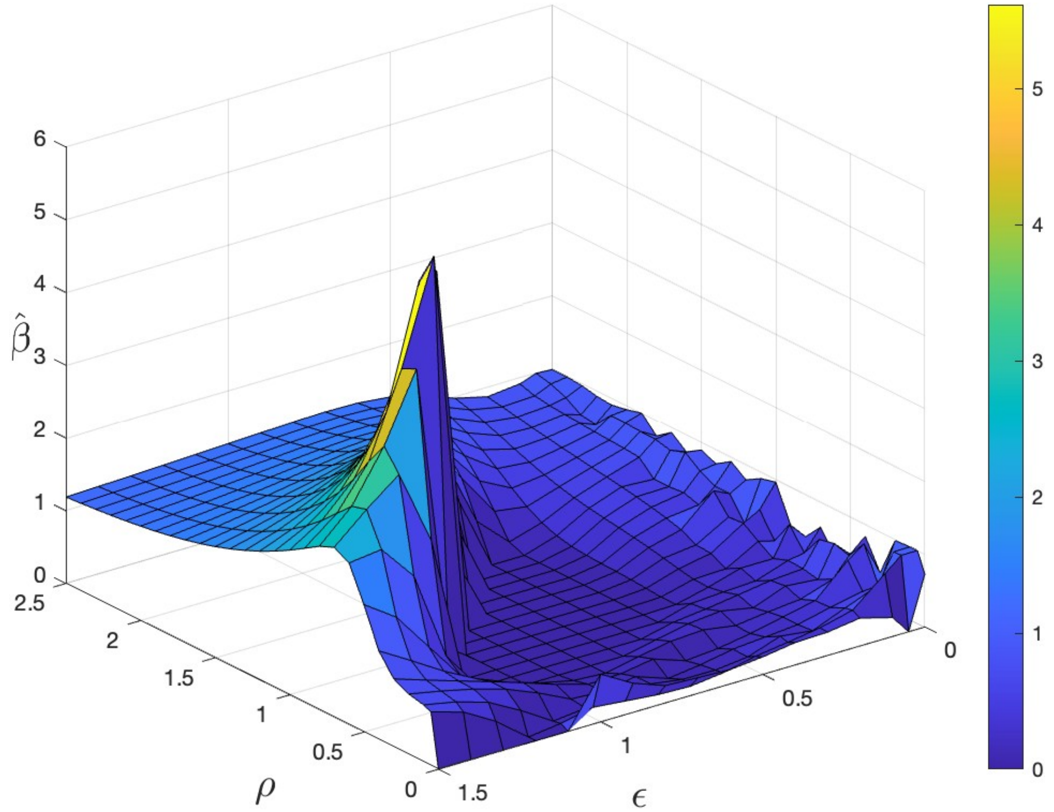


(a) Simulated $\ln \mathbf{V}_t$ vs. HOT implied approximation

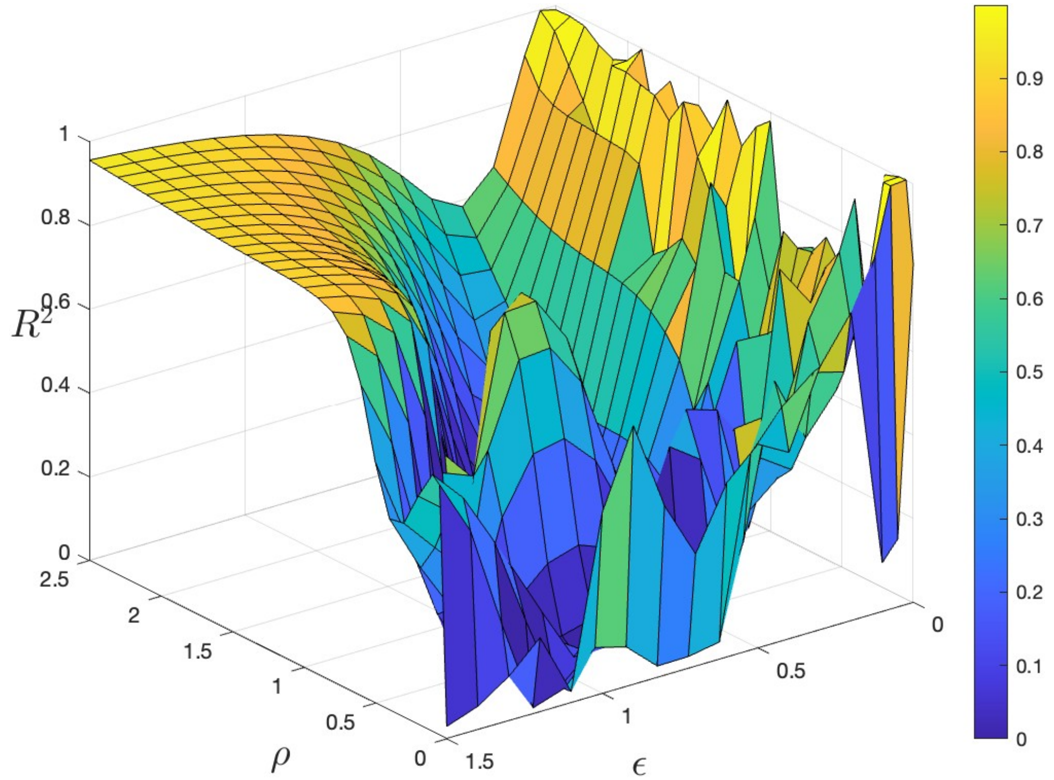


(b) Simulated $\ln \mathbf{V}_t$ vs. SHOT implied approximation

Figure B.2: Response of value added to a Russian Oil shock

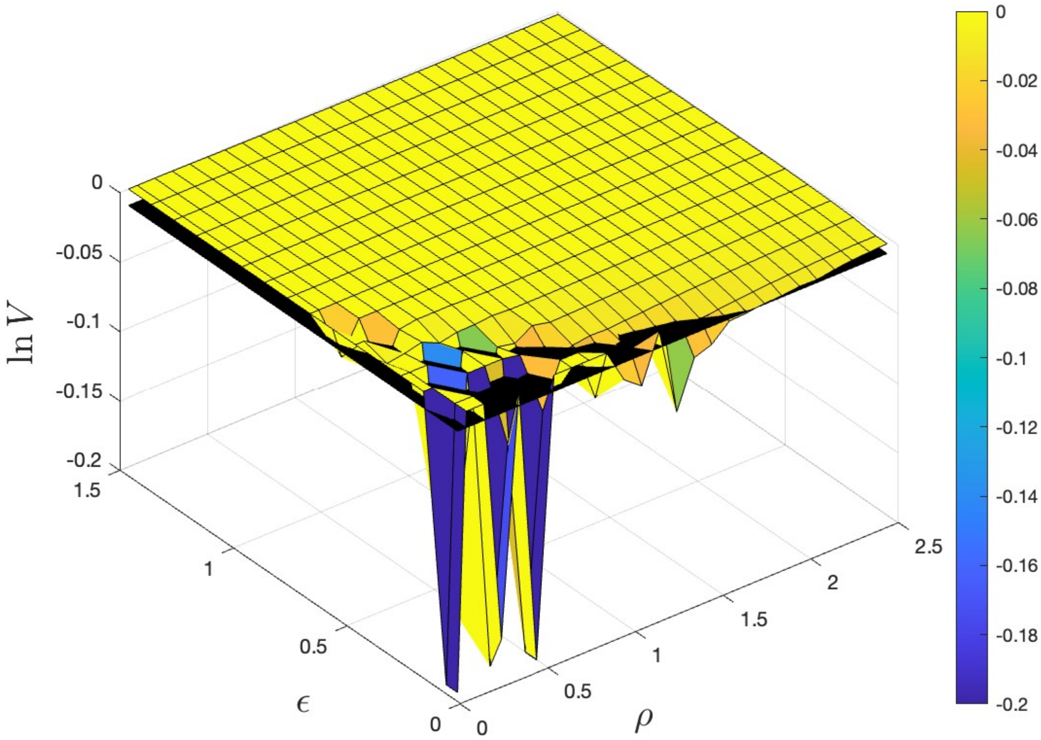


(a) $\hat{\beta}$ from regressing $\ln \mathbf{V}_t$ on $\frac{\alpha^r \psi}{1+\psi} \ln \mathbf{PY}_t$

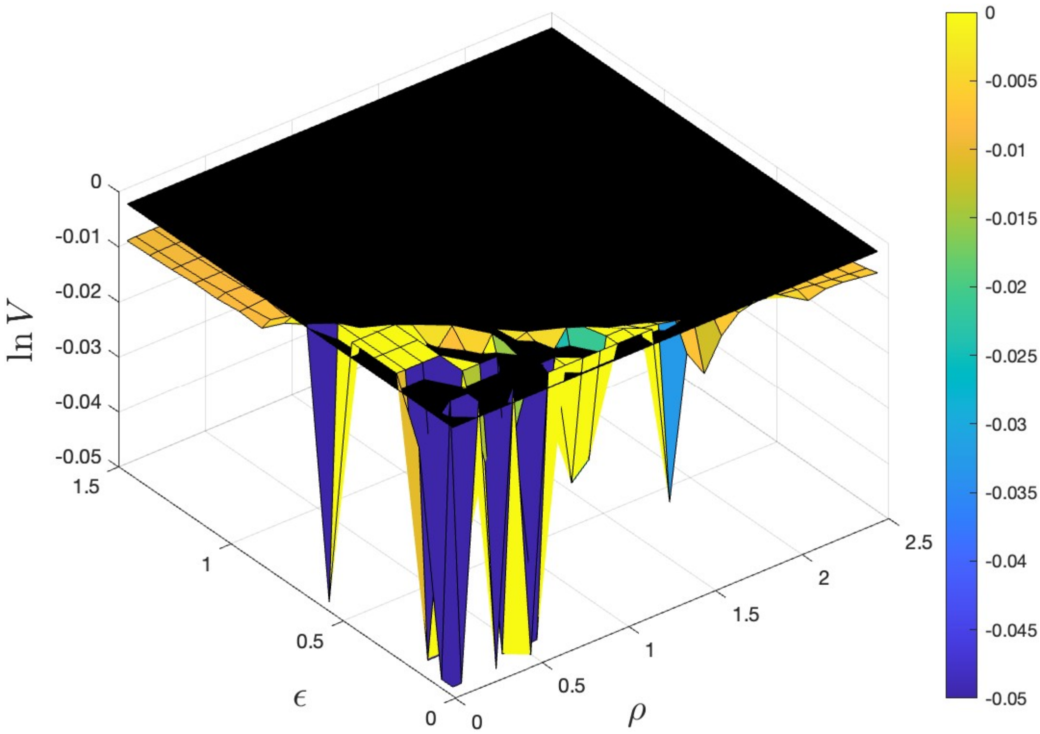


(b) R^2 from regressing $\ln \mathbf{V}_t$ on $\frac{\alpha^r \psi}{1+\psi} \ln \mathbf{PY}_t$

Figure B.3: Correlating $\ln \mathbf{V}_t$ with $\frac{\alpha^r \psi}{1+\psi} \ln \mathbf{PY}_t$ for a European Embargo on Russia in all sectors,



(a) Simulated $\ln \mathbf{V}_t$ vs. HOT implied approximation for German Chemicals



(b) Simulated $\ln \mathbf{V}_t$ vs. SHOT implied approximation for Russian Petroleum

Figure B.4: Value added response to a European Embargo on all sectors. The German Chemicals approximate response (HOT) is 1.18 percent, and the average simulated response is 0.64 percent. The Russian Petroleum approximate response (SHOT) is 0.28 percent and the average simulated response is 0.88 percent.

Appendix C

Table 9: OECD-ICIO Industry List

Industry	ISIC Rev. 4
Agriculture, hunting, forestry	01, 02
Fishing and aquaculture	3
Mining and quarrying, energy producing products	05, 06
Mining and quarrying, non-energy producing products	07, 08
Mining support service activities	9
Food products, beverages and tobacco	10, 11, 12
Textiles, textile products, leather and footwear	13, 14, 15
Wood and products of wood and cork	16
Paper products and printing	17, 18
Coke and refined petroleum products	19
Chemical and chemical products	20
Pharmaceuticals, medicinal chemical and botanical products	21
Rubber and plastics products	22
Other non-metallic mineral products	23
Basic metals	24
Fabricated metal products	25
Computer, electronic and optical equipment	26
Electrical equipment	27
Machinery and equipment, nec	28
Motor vehicles, trailers and semi-trailers	29
Other transport equipment	30
Manufacturing nec; repair and installation of machinery and equipment	31, 32, 33
Electricity, gas, steam and air conditioning supply	35
Water supply; sewerage, waste management and remediation activities	36, 37, 38, 39
Construction	41, 42, 43
Wholesale and retail trade; repair of motor vehicles	45, 46, 47
Land transport and transport via pipelines	49
Water transport	50
Air transport	51
Warehousing and support activities for transportation	52
Postal and courier activities	53

Continued on next page

Table 9 – *Continued from previous page*

Industry	ISIC Rev.4
Accommodation and food service activities	55, 56
Publishing, audiovisual and broadcasting activities	58, 59, 60
Telecommunications	61
IT and other information services	62, 63
Financial and insurance activities	64, 65, 66
Real estate activities	68
Professional, scientific and technical activities	69 to 75
Administrative and support services	77 to 82
Public administration and defence; compulsory social security	84
Education	85
Human health and social work activities	86, 87, 88
Arts, entertainment and recreation	90, 91, 92, 93
Other service activities	94,95, 96
Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use	97, 98

Table 10: WIOD Industry List

Industry	NACE 2
Crop and animal production, hunting and related service activities	A01
Forestry and logging	A02
Fishing and aquaculture	A03
Mining and quarrying	B
Manufacture of food products, beverages and tobacco products	C10-C12
Manufacture of textiles, wearing apparel and leather products	C13-C15
Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials	C16
Manufacture of paper and paper products	C17
Printing and reproduction of recorded media	C18
Manufacture of coke and refined petroleum products	C19
Manufacture of chemicals and chemical products	C20
Manufacture of basic pharmaceutical products and pharmaceutical preparations	C21
Manufacture of rubber and plastic products	C22
Manufacture of other non-metallic mineral products	C23
Manufacture of basic metals	C24
Manufacture of fabricated metal products, except machinery and equipment	C25
Manufacture of computer, electronic and optical products	C26
Manufacture of electrical equipment	C27
Manufacture of machinery and equipment n.e.c.	C28
Manufacture of motor vehicles, trailers and semi-trailers	C29
Manufacture of other transport equipment	C30
Manufacture of furniture; other manufacturing	C31-C32
Repair and installation of machinery and equipment	C33
Electricity, gas, steam and air conditioning supply	D35
Water collection, treatment and supply	E36
Sewerage; waste collection, treatment and disposal activities; materials recovery; remediation activities and other waste management services	E37-E39
Construction	F
Wholesale and retail trade and repair of motor vehicles and motorcycles	G45
Wholesale trade, except of motor vehicles and motorcycles	G46
Retail trade, except of motor vehicles and motorcycles	G47
Land transport and transport via pipelines	H49
Water transport	H50
Air transport	H51

Continued on next page

Table 10 – *Continued from previous page*

Industry	NACE 2
Warehousing and support activities for transportation	H52
Postal and courier activities	H53
Accommodation and food service activities	I
Publishing activities	J58
Motion picture, video and television programme production, sound recording and music publishing activities; programming and broadcasting activities	J59-J60
Telecommunications	J61
Computer programming, consultancy and related activities; information service activities	J62-J63
Financial service activities, except insurance and pension funding	K64
Insurance, reinsurance and pension funding, except compulsory social security	K65
Activities auxiliary to financial services and insurance activities	K66
Real estate activities	L68
Legal and accounting activities; activities of head offices; management consultancy activities	M69-M70
Architectural and engineering activities; technical testing and analysis	M71
Scientific research and development	M72
Advertising and market research	M73
Other professional, scientific and technical activities; veterinary activities	M74-M75
Administrative and support service activities	N
Public administration and defence; compulsory social security	O84
Education	P85
Human health and social work activities	Q
Other service activities	R-S
Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use	T
Activities of extraterritorial organizations and bodies	U