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Abstract

We propose a data-based approximation of the effects of trade sanctions. We validate the approximation by comparing it with exact responses simulated from a canonical multi-country multi-sector model. The approximation is palatable for a broad range of elasticities of substitution, except for extremely low ones. It is based on a decomposition of high order trade according to destination or inputs markets and can readily be computed on the basis of international input-output data. As such it provides a practical shortcut to evaluating the consequences of trade sanctions without having to make difficult calibration choices. We implement our approximation to evaluate the consequences of trade sanctions between Europe and Russia. Our approximated effects are within the range of existing estimates, but they mask vast asymmetries. First, the effects of sanctions are about fifteen times larger on Russia than on Europe. Second, the effects within Europe are enormously asymmetric, with much larger consequences on ex-"satellite" countries of the Soviet Union than on large Western European economies. We then adapt our approach to show that the most affected European countries do not typically have access to substitute markets and are in fact highly dependent on Russia. We show that this extreme dependence on Russia is at least partly explained by the existence of specific energy transporting infrastructure (pipelines) that appear to constrain tightly the production of electricity in those heavily affected East European economies. These findings illustrate the practical potentiality of our approximation in a variety of different contexts.

Keywords

European Energy Imports, Russian Sanctions, Economic Consequences of Sanctions, Global Value Chain

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Abstract

We propose a data-based approximation of the effects of trade sanctions. We validate the approximation by comparing it with exact responses simulated from a canonical multi-country multi-sector model. The approximation is palatable for a broad range of elasticities of substitution, except for extremely low ones. It is based on a decomposition of high order trade according to destination or inputs markets and can readily be computed on the basis of international input-output data. As such it provides a practical shortcut to evaluating the consequences of trade sanctions without having to make difficult calibration choices. We implement our approximation to evaluate the consequences of trade sanctions between Europe and Russia. Our approximated effects are within the range of existing estimates, but they mask vast asymmetries. First, the effects of sanctions are about fifteen times larger on Russia than on Europe. Second, the effects within Europe are enormously asymmetric, with much larger consequences on ex-"satellite" countries of the Soviet Union than on large Western European economies. We then adapt our approach to show that the most affected European countries do not typically have access to substitute markets and are in fact highly dependent on Russia. We show that this extreme dependence on Russia is at least partly explained by the existence of specific energy transporting infrastructure (pipelines) that appear to constrain tightly the production of electricity in those heavily affected East European economies. These findings illustrate the practical potentiality of our approximation in a variety of different contexts.

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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 a sanction. The numerator is computed allowing for the indirect linkages that emerge from the embargoed direct trade flows. The model-based response of sector-level value added to a sanction is approximated by this ratio. We establish this result in a canonical multi-country multi-sector model due to Huo et al. (2021) and related to Baqaee and Farhi (2019). We show through simulations that the approximation holds best for high substitutability between inputs, but is still palatable for reasonably 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 rough estimates of the consequences of sanctions, as in the quote by Ursula von Der Leyen in her 2022 State of the Union speech cited in this paper's opening.

[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).

We illustrate the differences between direct and indirect measures of trade linkages between Russia and European countries. They 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. The ratio of indirect to direct trade captures the intensity of the value chain: It takes low values when most trade is direct and high values when supply chains are long. 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, 0.64 percent decrease in GDP. The effect on the European economy is 16 times smaller, a decrease of 0.04 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 3.6 percent fall in GDP; The effect on the European economy is still small, 0.22 percent fall in the European GDP, still about 16 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 minuscule effect on the European economy, about 0.01 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 0.5 percent of Russian GDP, about 40 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, Russia sells the equivalent of 25 percent of its coke and refined petroleum to European-based supply chains. Its next highest export market is the US, but the share of that market in Russia output is 5 to 6 times smaller.

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. Large European economies have access to alternative supply chains from which to source energy inputs. Small, Eastern European countries, however, do not: the largest alternatives to Russian energy inputs available to Bulgaria for instance are South Africa or Turkey, whose shares are considerably smaller than Russia's. The diversity of available supply chains is much smaller for small, ex-satellite countries in Europe than it is for large western European economies.

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. 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. 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 parametrization of the substitutability across inputs is essential in determining the consequences of trade disruptions. 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. Our main contribution is to propose an approximation of the effects of trade disruptions that can be readily computed from international input-output tables and that bypasses the need for the precise calibration of elasticities of substitution provided they do not take extreme values. We establish the validity of the approximation in simulation exercises for a variety of parametrizations of the relevant elasticities of substitution.

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 $\mathrm{P}_i^c\,\mathrm{C}_i =$

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

$\sum_r \mathrm{W}_i^r \, \mathrm{H}_i^r + \sum_r \mathrm{R}_i^r \, \mathrm{K}_i^r$, where

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

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

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 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 transport 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, which 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 complementary 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 $\ln \mathbf{PY}_t - \ln \mathbf{P}_t^c$. In what follows we describe well-known empirical models of sector-level nominal output $\ln \mathbf{PY}_t$ that help approximate the response of value added.

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

$a_{ij}^{rs} = \frac{\mathrm{P}_{ij}^{rs}\,\mathrm{M}_{ij}^{rs}}{\mathrm{P}_j^s\,\mathrm{Y}_j^s}$. Solving recursively gives

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

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 $\mathrm{P}_{ik}^r\,\mathrm{C}_{ik}^r$ and direct intermediate demand $a_{ik}^{rs}\,\mathrm{P}_{kk}^s\,\mathrm{C}_{kk}^s$ (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.

[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.

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

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

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 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.

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 $\frac{\ln \text{V}^r_{\text{RUS},t}}{\ln \tau^r_{\text{RUS,EUR}}}$ 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 $\frac{\ln \text{V}^s_{\text{EUR},t}}{\ln \tau^r_{\text{RUS,EUR}}}$ 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 $\frac{\ln \text{V}^r_{\text{EUR},t}}{\ln \tau^r_{\text{EUR,RUS}}}$ 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 $\frac{\ln \text{V}^s_{\text{RUS},t}}{\ln \tau^r_{\text{EUR,RUS}}}$ and we propose to approximate it using $\text{SHOT}^{rs}_{\text{EUR,RUS}}$.

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.[4]

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.[5] 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

[4]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.

[5]In Appendix B we consider instead a shock to $\tau^r_{\text{EUR,RUS}}$, an embargo on European exports of sector r.

implies similarly very large responses.[6]

Figure 2 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. 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. We also note that CPI is a country-level aggregate: To the extent that sector-level price responses to the disruption are idiosyncratic, the response of CPI can be relatively small. 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 3 (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 perhaps when ρ and ϵ are both extremely low. Figure 3 (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.[7] 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 very low effects: Indeed the average simulated response is 0.01 percent.

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

3 The Approximate Effects of Trade Sanctions

3.1 Computing the measures

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.[8] 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 than WIOD or EXIOBASE 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.

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 $\mathrm{HOT}_{\mathrm{RUS},j}^{\mathrm{OIL}}$, 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

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

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 approximation we introduce in this paper.

Table 1 suggests that the ratio between indirect and direct trade is largest for ex "satellite" countries of the Soviet Union, including the Baltic states, 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 × 45 = 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-sectors, ranked according to the ratio of indirect to direct trade. 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 ratio is much smaller in Table 2 than in Table 1, which suggests short supply chains using Russian energy as an input.

Table 2 suggests the ratio of indirect to direct trade with Russia's energy sector is largest for a few specific sectors, which are the ones where the European supply chain using Russian energy is the longest. The most important one is Electricity, Gas, Steam, and Air Conditioning Supply in seven European countries (Austria, Britain, Slovakia, Malta, Portugal, France, and Italy), which confirms the importance of Russian oil in utility-related supply chains in Europe. The distribution of gas or electricity in Europe often depends on the supply of Russian energy, so that an embargo has indirect consequences down the supply chain. These supply chains are, however, relatively short in the sense that the ratios do not take very high values. The second European sector using Russian energy as an input is Construction, in five European countries (Latvia, Belgium, Cyprus, Slovenia, and Slovakia): There, too, European supply chains need Russian oil.

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 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.

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 (repair of vehicles, repair and installation of machinery), and some transport services (land and pipeline transport, support activities for transportation, 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 fall 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 0.64 percent.

The right panel of Table 3 reports the approximate effects of the same embargo on European countries, European sectors, 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, Finland, Slovakia, or the Czech Republic).[9] 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 (coke and refined petroleum, mining and quarrying of non-energy producing products), heavy manufacturing (basic metals, chemical products, non-metallic products), and transport services (air and 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 16 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 (machinery and equipment, repair and installation of machinery). Once again the sector-level effects fall very rapidly: The mining and quarrying of energy products is the only sector with large

[9] 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.

effects above 2.5 percent. The key difference with refined petroleum however is the size of the total effect, which is twice larger, 1.37 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.[10]

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), although this is still close to negligible and about 17 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 12 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 3.6 percent of GDP. This is a large number, but perhaps surprisingly "only" two and a half times larger than what is implied by an embargo on the extractive sector, which presumably reflects the extreme specialization of the Russian economy. On the other hand, 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

[10]It is also not clear what values they 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.

European Union's GDP. This is about three times larger than the effect of an embargo focused on Russian energy producing sectors and still 17 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).

Baqaee et al. (2022) conduct a similar analysis with a focus on France. They simulate the response of the French GDP to a stop on Russian energy imports 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 17 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 minuscule, about 0.012 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, Latvia, Estonia, Cyprus, Finland, Slovakia, Czech Republic, Slovenia, and Bulgaria. These are the countries that trade most intensely with Russia, and so they stand to lose most from a ban on those exports, although even Cyprus, which is the most heavily affected, would see its GDP fall by only 0.12 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, 0.5 percent of Russian GDP, which is still about 40 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 3.5 percent vs. only 0.5 percent. The cost to the European Union, however, would be larger in the case of an embargo on Russian exports - a fall by 0.23 percent vs. only 0.01 percent in the case of an embargo on European exports to Russia. In the next section we explore the existence of alternative suppliers and alternative markets for both parties, which would 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 could be used to obtain access to alternative destination markets or alternative sources of inputs to the ones that are embargoed.

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 exports. 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 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 both parties affected by the embargo to redirect their trade.

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 most affected sectors in Russia in response to embargoes on Russian exports to Europe in sector r. From Sections 3.3.1 and 3.3.2 we know which sectors are most affected in Russia by the three different European embargoes we have considered, i.e. an embargo on Russia's "Coke and Refined Petroleum" exports, an embargo on Russia's "Mining and Quarrying of Energy Producing Products", and an embargo on all Russian exports to the European Union. 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.

The top panel of Table 7 lists the three sectors in Russia most affected by a European embargo on Russia's Coke and Refined Petroleum exports. They are: (i) the Coke and Refined Petroleum sector itself, for which more than 25 percent of output is sold into European value chains; (ii) Mining support service activities, which exports 12 percent of its output into European value chains; and (iii) Mining and Quarrying of energy producing products, which exports 4 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 all three cases, the runner-up country (outside of the EU) is the US; But in all three cases the value of downstream linkages with the US are more than five times smaller than what they are with Europe: the US is Russia's second buyer of energy products, but it is a far second behind the European Union. China is right behind the US, with just slightly smaller values of HOT. The third one is Turkey. 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.[11]

The second panel of Table 7 repeats the same exercise for the three sectors in Russia most affected by a European embargo on Russia's Mining and Quarrying of Energy Producing Products, which are: (i) Mining and quarrying of energy producing products (34 percent sold into the EU, directly and indirectly), (ii) Mining support service activities (8 percent), and (iii) Land

[11]Interestingly the first EU export market is Germany, which constitutes about 1/4 of Russian output in these three sectors.

and pipeline transport (3.5 percent). In all three sectors the first runner up is China, but in each case the share of Russian output sold to China is less than half that sold to the EU. We need to go far down the list to find another non-EU destination for exports in these three sectors, which would be Israel with output shares of 2.7 percent in sector (i), 0.6 percent in sector (ii), and 0.3 percent in sector (iii).[12] The runner-up after Israel is South Korea. The same conclusion ensues: In response to a European embargo on Russia's Mining and Quarrying of Energy Producing Products, it will be difficult for Russia to find substitute export markets of comparable size to the EU.

The third panel of Table 7 considers now a blanket embargo on Russian exports to the European Union, whose effects are largest in the following Russian sectors: (i) Mining and quarrying of energy producing products (40 percent of Russia's output sold into the EU, directly or indirectly), (ii) Coke and refined petroleum (29.5 percent), and Mining support service activities (24.8 percent). These constitute very large shares of Russian output for all three sectors, and it is unlikely any alternative export market could provide a substitute. The first non-European runner-up export market for these sectors is China, but once again its share of Russian output is a fraction of that of the EU, between half and a fifth depending on which of the three sectors is considered. The next non-EU export market is South Korea, with output shares of 3.4 percent of sector (i), 3.6 percent of sector (ii), and 2.4 percent of sector (iii).[13] The next runner-up is Israel. These numbers suggest finding a replacement to EU export markets is very difficult for Russia.

3.4.2 Substitute Input Sourcing

We now consider the importance of 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 the embargoes we consider, since Sections 3.3.1 and 3.3.2 only reported average country and average sector effects. For each country-sector (j, s) we first report the values of $\mathrm{SHOT}^{rs}_{\mathrm{RUS},j}$ where r denotes the type of embargo considered (on Russia's "Coke and Refined Petroleum" exports, on Russia's "Mining and Quarrying of Energy Producing Products", and on all Russian exports to the European Union). We compare this value with $\mathrm{SHOT}^{rs}_{\mathrm{K},j}$, computed for the most affected sectors s in European country j to European embargoes on Russian exports in sector r for all K located outside of the EU.[14] 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.

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

[13] The export markets after China are Germany, Italy, and Poland.

[14] 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.

In order to focus the analysis on the key aspects of input trade between Russia and the EU, we limit the approach to four countries j: two countries that are heavily affected by the embargo on Russian inputs, Latvia and Bulgaria, and two countries that are not, France and Germany. Table 8 presents the values of $\mathrm{SHOT}^{rs}_{\mathrm{RUS},j}$ where r is Russia's Mining and Quarrying in Energy Producing Products, for the four countries j and the three most affected sectors s in each one of them. Unsurprisingly Coke and Refined Petroleum is the sector most affected in all four countries, followed by Electricity, Gas, Steam and Air-conditioning, presumably because both are very energy intensive. The third most affected sectors are manufacturing activities (basic metals, other non-metallic mineral products). What is interesting is the difference in magnitudes between small and large countries: $\mathrm{SHOT}^{rs}_{\mathrm{RUS},j}$ takes much smaller values in France and Germany (a maximum of 6.8 percent) than in Latvia and Bulgaria (about 4 to 6 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 $\mathrm{SHOT}^{rs}_{\mathrm{K},j}$, i.e., whose input supply of the embargoed sector r to country-sector (j, s) constitutes a large share of output there. 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 their most affected sectors. For example, 1.8 percent of the production of electricity, gas, steam and air-conditioning in France is associated with Russian coke and refined petroleum, but Saudi Arabia's constitutes more (2.25 percent), Kazakhstan's constitutes almost as much (1.2 percent), and Norway's is about half as important (0.8 percent). Similarly, 3.7 percent of Germany's output in mining of energy producing products is used to purchase Russian coke and refined petroleum, but 5.2 percent is used to purchase the Norwegian sourced version, 1.3 percent is used to purchase it from Kazakhstan, and 1.1 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 two Russian "satellite" countries we consider: Both Latvia and Bulgaria are heavily dependent on inputs from Russia. For example, 45 percent of Bulgaria's inputs in Coke and Refined Petroleum actually come (directly or indirectly) from the mining of energy producing products in Russia. Strikingly, there is no clear alternative to these inputs, since the "runners-up" countries provide much smaller proportions of Bulgaria's input in this sector: mining of energy products from South Africa represents 0.02 percent of Bulgarian output, 0.017 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, while they come from plausible exporters of energy (Britain, Norway, the US). The countries that are the most affected by an embargo on mining energy products from Russia seem to also be the ones that have very little alternative input suppliers.

This is a common feature across the shocks we consider. Table 9 now illustrates the availability of alternative inputs to Russian coke and refined petroleum in the most affected sectors of France, Germany, Latvia, and Bulgaria. France has options from Saudi Arabia, the US, and India, and Germany from Norway, Britain, and the US. However, alternative suppliers of coke and refined petroleum are smaller than for raw energy materials in Table 8. For example air transport in France sources 0.66 percent of its output in Russian coke and refined petroleum, as against 0.42 percent from India or 0.37 percent from Saudi Arabia. Germany is a bit more captive as air transport there source 1.4 percent of its fuel from Russia, as against 0.18 percent from the US, the largest runner-up supplying country. These differences however are dwarfed by Latvia and Bulgaria, where the largest runner-up suppliers outside of the EU constitute a tiny fraction of the share of Russian input in production. For example in Bulgaria fuel from Russia constitutes 4.1 percent of the production in the electricity, gas, and air-conditioning sector: The largest runner-up is Turkey, whose share is about 100 times smaller.

Table 10 considers a blanket embargo on all Russian inputs into Europe. Now the values of $\mathrm{SHOT}^{rs}_{\mathrm{RUS},j}$ are very large in Latvia and Bulgaria (between 20 and 65 percent for the three most affected sectors there, Coke and refined petroleum products Electricity, gas, steam and air conditioning supply, and Other non-metallic mineral products). The comparable numbers are all below 10 percent in France and Germany. Interestingly, France and Germany historically both have had access to runners-up suppliers whose inputs constitute similar fractions of their production as Russian inputs. For example, Russian inputs constitute 10.8 percent of the production of coke and refined petroleum products in Germany: The runner-up is Norway, whose inputs also constitute 10 percent of that production. In other words these countries have access to upstream suppliers that have historically been as large as Russia. In addition, second and third runners-up suppliers are not negligible either. For instance, Kazakhstan and Britain constitute each more than 2.5 percent of German output of coke and refined petroleum products.

Once again Latvia and Bulgaria face a very different choice set of suppliers. While they are much more exposed to a Russian embargo, they are also close to captive in the sense that runners-up suppliers are considerably smaller. For example 48 percent of Latvian coke and refined petroleum production comes from Russian inputs: The second largest supplier to this sector is the US, whose share is 100 times smaller.

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. While it is true that these effects 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. A potential avenue is the possibility of value chains within Europe that the satellite countries could turn to, which our approach is assuming away because we do not know whether prospective alternative suppliers in Europe also source inputs from Russia. Another possibility would be some redistributive mechanisms within the Union that could be designed to compensate for the dependence on the embargoed market.

3.5 Pipelines and Energy Infrastructure

A potentially important determinant of the availability of substitute markets for European countries is the existence of energy transport infrastructure. From the previous section, we know that Eastern European economies appear to be extremely specialized in their trade with Russia, in terms of both exports and imports markets. One explanation to this fact is history; Another is available infrastructure (which presumably also finds its roots in history). We now present a version of our approximation that helps evaluating this possibility.

By definition SHOT_{ij}^{rs} captures the fraction of output in (j, s) that remunerates inputs in (i, r). It also approximates the effects on value added in (j, s) of an embargo on inputs purchased from (i, r). With available data on the value of inputs coming from Russian pipelines across using country-sectors (j, s), it will be possible to get a sense of how important Russian pipelines are for country-sector (j, s), for all j and s. For example, we can explore how important Russian pipelines are for the production of energy (e.g., electricity) using gas in a cross-section of European countries j.

This is the exercise we conduct now. We exploit international input-output data put together by the European consortium EXIOBASE, which provide multi-regional input-output tables for 44 countries and a rest of the world aggregate separated into 5 regions. There are 163 industries in the hybrid version 3 that we use.[15] Information is very granular, with separate data on the values of input trade and exports for such sectors as Poultry Farming or Re-processing of secondary wood material into new wood material. Two sectors are particularly interesting for the question at hand: Transport via Pipelines on the one hand, and Production of Electricity by Gas on the other.[16] The data are available from 1995 to 2022. In what follows we use the 2021 vintage, the last year available before the invasion of Ukraine, and also to preserve broad enough coverage that would not be available in 2022.

For each European country j we compute $\mathrm{SHOT}_{\mathrm{RUS},j}^{\mathrm{PIP,ELEC}}$, where PIP denotes Transport via Pipelines, and ELEC denotes Production of Electricity by Gas. This approximates the response of the production of electricity by gas in country j to an embargo on Transport via Pipelines in Russia. In other words, it measures how much that sector responds to Russia shutting down its pipelines towards its European markets. Table 11 presents the results for

[15] See Merciai and Schmidt (2016) and Merciai and Schmidt (2018).

[16] We cannot use EXIOBASE for this paper's other exercises because we are lacking other important data at that level of disaggregation, such as the labor share.

all 28 EU member countries ranked by decreasing order of $\text{SHOT}^{\text{PIP,ELEC}}_{\text{RUS},j}$. We also include a column reporting the ratio of $\text{SHOT}^{\text{PIP,ELEC}}_{\text{RUS},j}$ to *direct* imports from the Russian Transport via Pipeline sector. When this ratio takes high values, so will $\text{SHOT}^{\text{PIP,ELEC}}_{\text{RUS},j}$ and this happens because country j is downstream from a long value chain emerging from Russian pipelines: The large effect of a pipeline shutdown in Russia comes from this long value chain being disrupted. If $\text{SHOT}^{\text{PIP,ELEC}}_{\text{RUS},j}$ is high but the ratio of indirect to direct trade is close to one, then the large effect of a pipeline shutdown in Russia comes from the exposure of country j to energy inputs from Russia.

The ranking on Table 11 once again singles out Eastern European countries: Lithuania, the Czech Republic, Roumania, Hungary, Croatia, Slovenia, Latvia, Poland are all in the most affected countries. They also all have Russian pipelines crossing their territory, and they are located relatively upstream of these value chains (i.e., the ratio column takes values relatively close to one). Most large European economies are relatively low in this ranking - e.g., Germany, Spain, Britain, the Netherlands: They are relatively immune from shocks to this very infrastructure from Russia. Two exceptions are Sweden and France, that we find would be affected by a shutdown of Russian pipelines. That is because they are far downstream of these Russian inputs, i.e., the ratio column takes high values.

This exercise provides an illustration of one of the practical benefits of the approximation we propose. With adequately granular data, we can quantify at relatively low cost the importance of specific transport infrastructure for different trading partners. The results in Table 11 confirm the asymmetric effect a shutdown of Russian pipelines would have on European countries in a way that is useful and plausible since it largely reflects the locations of these pipelines. This suggests the asymmetries within Europe documented in Sections 3.3 and 3.4 are due for a significant part to existing transport infrastructures.

4 Conclusion

We propose a data-based approach to approximate 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 for extremely low ones. 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 sanction - one that will never 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 consequences of trade sanctions between Europe and Russia, in three steps. First, we consider embargoes imposed on Russian energy or more generally Russian exports to Europe, and embargoes imposed on European exports to Russia. The approximate magnitudes we compute are within the range of existing estimates obtained by simulation for reasonably plausible values of the elasticities of substitution. The effects of either embargo are about fifteen times larger on Russia than on Europe, even though they are both quite low. Interestingly 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. This contributes to explaining why the overall effects on Europe are low. Second, we exploit historical (but recent) data on input-output linkages to identify existing supply chains that constitute substitutes to embargoed markets, upstream or downstream. This reveals the large asymmetries within European are compounded by the fact that the most affected (small) countries do not typically have access to substitute downstream markets or upstream inputs: They are highly dependent on Russia. Third, still using our approximation, we show that this extreme dependence on Russia is at least partly explained by the existence of specific pipelines, which appear to constrain tightly the production of electricity in those heavily affected East European economies. These three steps illustrate the practical potentiality of our approximation in a variety of different contexts. We intend to make available online a complete set of high order trade decompositions, which can be used to approximate the effects of a wide range of shocks on sector-level domestic activity.

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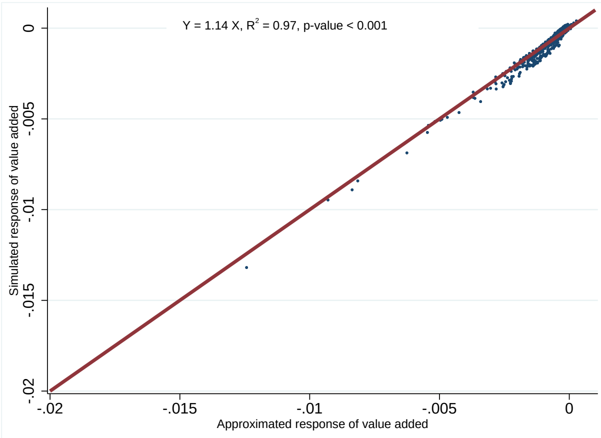
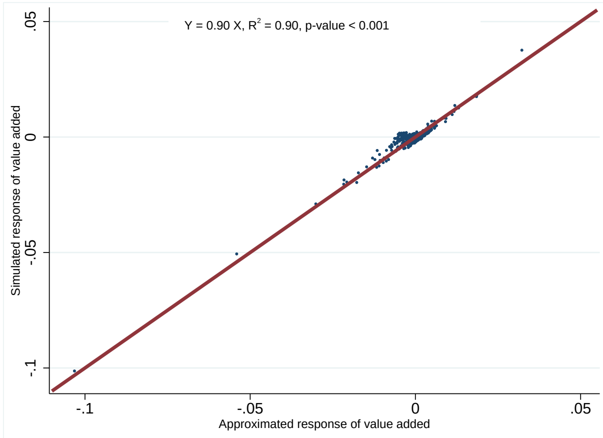
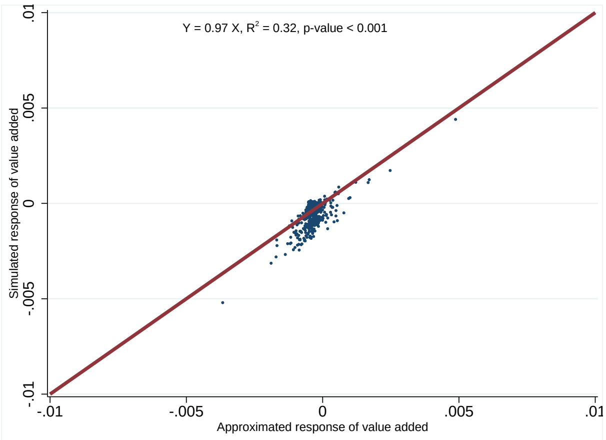


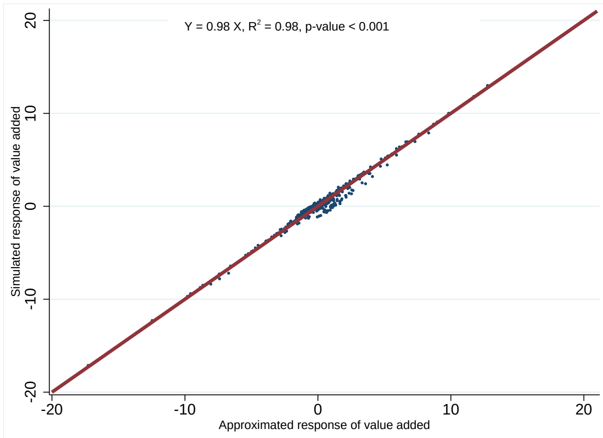
(a) $\rho = 2.5$, $\epsilon = 1.5$, and $\psi = 2$



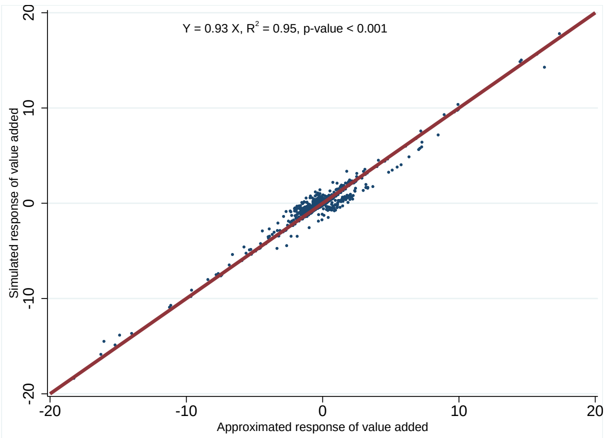
(b) $\rho = 2.5$, $\epsilon = 0.05$, and $\psi = 2$



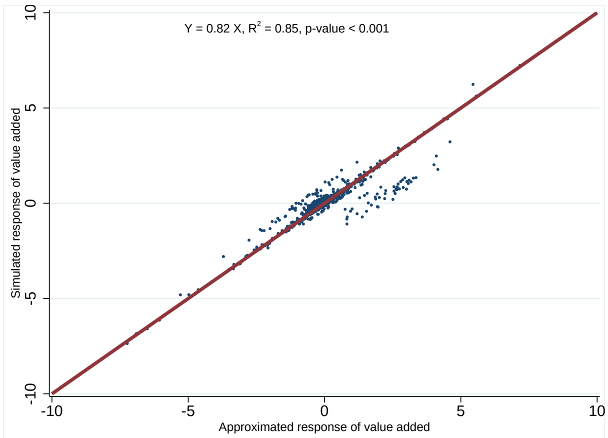
(c) $\rho = 0.05$, $\epsilon = 1.5$, and $\psi = 2$



(d) $\rho = 0.05$, $\epsilon = 0.05$, and $\psi = 2$

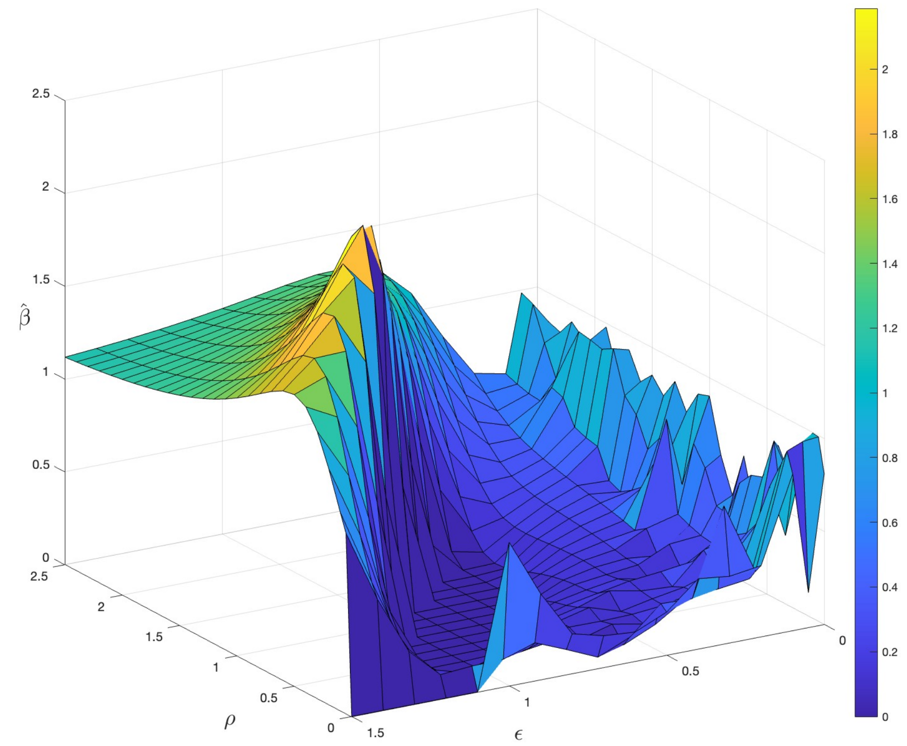


(e) $\rho = 0.05$, $\epsilon = 0.1$, and $\psi = 2$

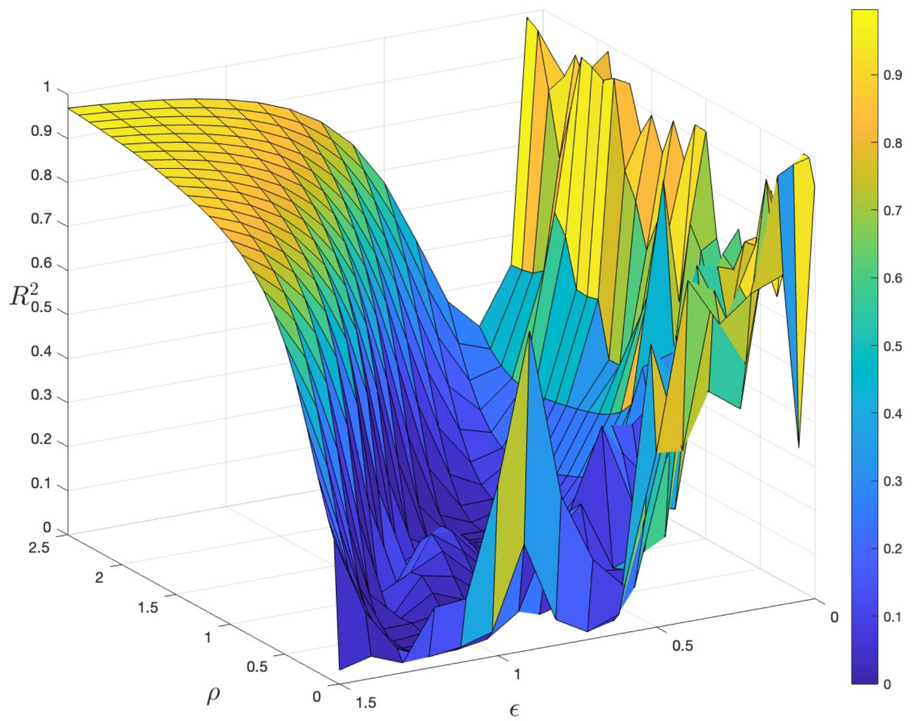


(f) $\rho = 0.1$, $\epsilon = 0.1$, and $\psi = 2$

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

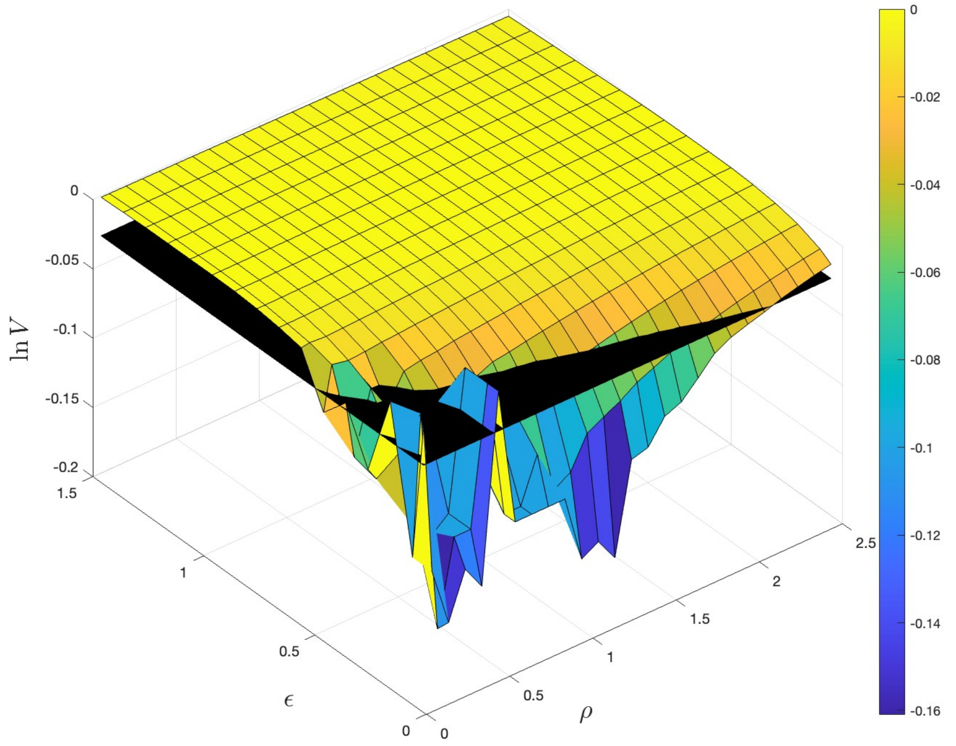


(a) $\hat{\beta}$ from regressing $\ln \mathbf{V}_t$ on $\frac{\alpha^r \psi}{1+\psi} \ln \mathbf{PY}_t$

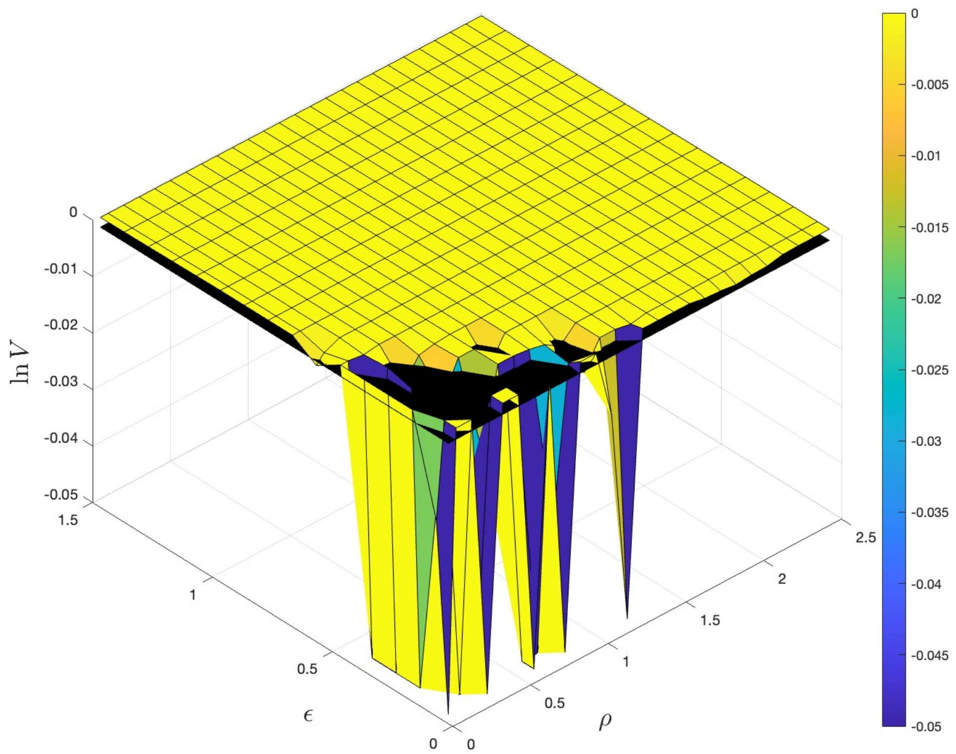


(b) R^2 from regressing $\ln \mathbf{V}_t$ on $\frac{\alpha^r \psi}{1+\psi} \ln \mathbf{PY}_t$

Figure 2: 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 3: Response of value added to a Russian Oil shock

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

Country	HOT	Direct Exports	Ratio	Country	HOT	Direct Exports	Ratio
CZE	0.35	0.01	40.63	HRV	0.05	0.01	4.05
SVK	0.36	0.03	14.32	BEL	0.64	0.16	4.02
LTU	0.29	0.03	9.00	AUT	0.06	0.02	3.93
BGR	0.70	0.08	8.72	DNK	0.96	0.27	3.56
MLT	0.01	<0.01	7.68	IRL	0.24	0.07	3.50
LUX	<0.01	<0.01	6.35	GRC	1.55	0.48	3.23
FIN	0.79	0.15	5.36	EST	0.13	0.04	3.18
POL	2.09	0.40	5.27	ROU	0.38	0.12	3.08
HUN	0.66	0.13	4.96	SVN	0.07	0.03	2.79
SWE	0.84	0.17	4.87	FRA	2.21	0.80	2.76
NLD	1.02	0.24	4.20	DEU	5.79	2.27	2.55
ITA	1.97	0.47	4.19	ESP	0.70	0.28	2.52
PRT	0.25	0.06	4.19	GBR	3.19	1.39	2.30
LVA	0.09	0.02	4.10	CYP	0.01	<0.01	2.10

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

Most affected country	Most affected industry	SHOT	Direct Imports	Ratio
AUT	Electricity, gas, steam	0.06	0.03	2.04
GBR	Electricity, gas, steam	0.07	0.04	1.87
LVA	Warehousing & transport services	0.19	0.10	1.86
PRT	Electricity, gas, steam	0.28	0.16	1.80
LUX	Basic metals	<0.01	<0.01	1.71
MLT	Electricity, gas, steam	1.28	0.76	1.68
SVK	Electricity, gas, steam	1.95	1.23	1.59
FRA	Electricity, gas, steam	0.28	0.18	1.55
LVA	Construction	0.09	0.06	1.53
SVK	Arts & entertainment	0.01	0.01	1.50
ITA	Electricity, gas, steam	0.38	0.25	1.50
PRT	Water supply & waste management	0.05	0.04	1.48
MLT	Fishing	0.07	0.05	1.48
BEL	Construction	0.05	0.03	1.48
CYP	Construction	0.01	<0.01	1.46
SVK	Construction	0.06	0.04	1.44
SVN	Construction	0.04	0.03	1.44
LUX	Financial & insurance	<0.01	<0.01	1.43
FRA	Financial & insurance	0.01	<0.01	1.43
SVK	Postal services	0.01	0.01	1.42

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

Effects on Russia		Effects on European countries			
Refined petroleum products	5.16	Air transport	0.44	BGR	0.25
Mining support service activities	3.77	Refined petroleum products	0.31	GRC	0.17
Energy producing products	1.34	Water transport	0.29	HUN	0.13
Transport by land & pipelines	1.19	Transport by land & pipelines	0.18	POL	0.12
Warehouse & transport services	0.91	Basic metals	0.13	EST	0.12
Administrative services	0.88	Chemical products	0.12	LTU	0.11
Wholesale & retail trade	0.49	Non-energy producing products	0.10	LVA	0.11
Water transport	0.44	Other non-metallic minerals	0.10	FIN	0.08
Manufacturing nec	0.41	Postal & courier activities	0.09	SVK	0.08
Finance & insurance	0.36	Fishing	0.09	CZE	0.06
Total Effect	**0.64**			Total effect	**0.04**

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

Effects on Russia		Effects on European countries			
Energy producing products	10.46	Refined petroleum products	1.47	BGR	1.09
Mining support service activities	2.42	Basic metals	0.50	LTU	0.50
Transport by land & pipelines	1.20	Electricity, gas, steam	0.42	SVK	0.43
Administrative services	1.00	Air transport	0.40	HUN	0.40
Manufacturing nec	0.82	Other non-metallic minerals	0.31	LVA	0.33
Warehouse & transport services	0.78	Non-energy producing products	0.31	CZE	0.30
Water transport	0.71	Chemical products	0.27	POL	0.29
Non-energy producing products	0.64	Transport by land & pipelines	0.25	FIN	0.20
Machinery & equipment, nec	0.45	Water transport	0.23	ROU	0.17
Rubber & plastics products	0.39	Energy producing products	0.20	SVN	0.13
Total Effect	**1.37**			Total effect	**0.08**

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

Effects on Russia		Effects on European countries			
Energy producing products	12.30	Refined petroleum products	2.25	BGR	1.82
Air transport	9.21	Basic metals	1.49	LTU	1.22
Mining support service activities	7.63	Air transport	1.19	LVA	1.03
Postal & courier activities	6.40	Water transport	0.80	EST	0.99
Basic metals	6.18	Other non-metallic minerals	0.68	CYP	0.89
Refined petroleum products	6.01	Chemical products	0.66	SVK	0.83
Water transport	5.96	Non-energy producing products	0.66	HUN	0.79
Warehouse & transport services	5.95	Electricity, gas, steam	0.65	POL	0.68
IT	5.65	Fabricated metal products	0.62	FIN	0.68
Transport by land & pipelines	5.65	Transport by land & pipelines	0.62	CZE	0.65
Total effect	**3.62**			Total effect	**0.23**

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

Effects on European countries		Effects on Russia	
CYP	0.12	Motor vehicles	6.32
LTU	0.06	Rubber & plastics products	5.23
EST	0.06	Machinery & equipment, nec	4.53
LVA	0.04	Other transport equipment	4.33
IRL	0.04	Electrical equipment	3.96
FIN	0.03	Manufacturing nec	3.53
SVK	0.02	Paper products & printing	3.22
CZE	0.02	Air transport	3.05
SVN	0.02	Fabricated metal products	2.96
BGR	0.02	Pharmaceutical products	2.89
Total effect	**0.01**	Total effect	**0.48**

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

European embargo on Russia's Petroleum				
		Substitute countries		
Most affected Russian sectors	EUR	USA	CHN	TUR
Refined petroleum products	25.39	4.51	4.30	3.53
Mining support service activities	12.27	2.18	2.08	1.71
Energy producing products	4.35	0.77	0.74	0.60
European embargo on Russia's Energy sectors				
		Substitute countries		
Most affected Russian sectors	EUR	CHN	ISR	KOR
Energy producing products	34.02	17.07	2.77	2.75
Mining support services	7.88	3.96	0.64	0.64
Transport by land & pipelines	3.47	1.74	0.28	0.28
European embargo on all Russian sectors				
		Substitute countries		
Most affected Russian sectors	EUR	CHN	KOR	ISR
Energy producing products	39.98	18.39	3.44	3.05
Refined petroleum products	29.56	5.98	3.63	1.56
Mining support services	24.80	6.85	2.39	1.39

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

European embargo on Russia's Energy		Substitute countries			
	FRA	SAU	KAZ	NOR	
Refined petroleum products	6.59	8.86	4.87	3.23	
Electricity, gas, steam	1.82	2.25	1.24	0.82	
Basic metals	0.64	0.56	0.31	0.21	
	DEU	NOR	KAZ	USA	GBR
Refined petroleum products	6.80	9.48	2.31		2.00
Energy producing products	3.67	5.24	1.28		1.11
Electricity, gas, steam	1.74	1.63	0.40	0.57	
	LVA	GBR	USA	NOR	
Refined petroleum products	32.64	0.03	<0.01	<0.01	
Electricity, gas, steam	13.20	0.02	<0.01	<0.01	
Other non-metallic minerals	12.58	<0.01	<0.01	<0.01	
	BGR	ZAF	TUR	USA	
Refined petroleum products	44.80	0.02	0.02	<0.01	
Electricity, gas, steam	25.69	0.26	0.16	<0.01	
Other non-metallic minerals	23.27	0.06	0.05	<0.01	

Table 9: Substitute market for Europe ranked by SHOT (in %)

European embargo on Russia's Petroleum		Substitute countries			
	FRA	IND	SAU	USA	
Refined petroleum products	1.16	0.10	0.08	0.08	
Air transport	0.66	0.42	0.37	0.34	
Chemical and chemical products	0.41	0.24	0.19	0.20	
	DEU	NOR	USA	GBR	
Refined petroleum products	1.78	0.14	0.11	0.08	
Air transport	1.42	0.08	0.18	0.14	
Energy producing products	0.70	0.06	0.02	0.01	
	LVA	CHN	IND	CHE	GBR
Refined petroleum products	5.19	<0.01		<0.01	<0.01
Electricity, gas, steam	2.19	<0.01		<0.01	<0.01
Other non-metallic minerals	2.08	<0.01	<0.01	<0.01	
	BGR	TUR	IND	USA	KAZ
Refined petroleum products	7.42	0.08	0.03	0.02	
Electricity, gas, steam	4.08	0.05		0.01	<0.01
Other non-metallic minerals	3.99	0.09		<0.01	<0.01

Table 10: Substitute market for Europe ranked by SHOT (in %)

European embargo on all Russian sectors						
		Substitute countries				
	FRA	SAU	KAZ	USA	CHN	NOR
Refined petroleum products	9.75	8.98	5.75	2.87		3.42
Electricity, gas, steam	2.75	2.30	1.47	1.37		0.89
Basic metals	1.86		2.30		1.36	
	DEU	NOR	USA	KAZ	GBR	CHN
Refined petroleum products	10.80	10.02	2.41	2.74	2.59	
Energy producing products	5.87	5.65	2.16	1.52	1.82	
Basic metals	5.48	2.40	2.69		1.14	1.33
	LVA	USA	CHN	GBR	NOR	
Refined petroleum products	47.99	0.43	0.25	0.20		
Electricity, gas, steam	20.28	0.41	0.23	0.23		
Other non-metallic minerals	19.38	0.37	0.52		0.34	
	BGR	TUR	CHN	GBR	ZAF	
Refined petroleum products	65.37	0.96	0.46	0.29		
Electricity, gas, steam	37.08	0.49		0.18	0.30	
Other non-metallic minerals	34.35	1.46	0.61	0.25		

Table 11: Impact on Gas production of an Embargo on Russian pipelines (in %)

Country	SHOT	Ratio	Country	SHOT	Ratio
SWE	0.023	6089.22	LUX	0.003	11.39
LTU	0.019	1.44	SVK	0.002	31.55
CZE	0.019	15.23	EST	0.002	140.82
ROU	0.018	1.70	DEU	0.002	120.19
HUN	0.015	1.28	BGR	0.002	31.82
FRA	0.014	679.81	ESP	0.002	90.89
ITA	0.007	1.73	FIN	0.001	50.03
HRV	0.005	39.15	BEL	0.001	45.71
SVN	0.005	54.94	GRC	0.001	25.54
PRT	0.004	2427.31	IRL	0.001	2.86
DNK	0.004	9.23	GBR	0.001	1557.12
LVA	0.003	306.31	NLD	0.001	4.14
POL	0.003	89.01	CYP	-	-
AUT	0.003	2694.81	MLT	-	-

Notes: The Ratio reported is the ratio of SHOT to direct imports.

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 $a_{ij}^{rs} = \frac{\mathrm{P}_{ij}^{rs}\,\mathrm{M}_{ij}^{rs}}{\mathrm{PY}_j^s} = (1-\eta^s)\frac{\mathrm{P}_{ij}^{rs}\,\mathrm{M}_{ij}^{rs}}{\mathrm{P}_j^s\,\mathrm{M}_j^s}$ 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 $ac_{ij}^r = \frac{\mathrm{P}_{ij}^r\,\mathrm{C}_{ij}^r}{\mathrm{P}_j\,\mathrm{C}_j}$ 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 $b_{ij}^{rs} = \frac{(1-\eta^s)\,\mathrm{PY}_j^s\,\xi_{ij}^{rs}}{\mathrm{PY}_i^r} = \frac{\mathrm{P}_{ij}^{rs}\,\mathrm{M}_{ij}^{rs}}{\mathrm{PY}_i^r}$ 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 $bc_{ij}^r = \frac{\pi_{ij}^r\,\mathrm{P}_j\,\mathrm{C}_j}{\mathrm{PY}_i^r} = \frac{\mathrm{P}_{ij}^r\,\mathrm{C}_{ij}^r}{\mathrm{PY}_i^r}$ the share of output in source sector (i,r) used as final consumption in country j.

$\mathbf{\Upsilon}$ is the matrix with typical element $\upsilon_i^r = \frac{\eta^r\,\mathrm{PY}_i^r}{\mathrm{P}_i\,\mathrm{C}_i}$ 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

$$\ln \mathrm{P}_{i,t}^r + \ln \mathrm{Y}_{i,t}^r = \sum_j \sum_s \frac{ac_{ij}^r\,\mathrm{P}_j\,\mathrm{C}_j}{\mathrm{P}_i^r\,\mathrm{Y}_i^r}\frac{\eta^s\,\mathrm{P}_j^s\,\mathrm{Y}_j^s}{\mathrm{P}_j\,\mathrm{C}_j}(\ln \mathrm{P}_{j,t}^s + \ln \mathrm{Y}_{j,t}^s + \ln \pi_{ij,t}^r)$$
$$+ \sum_j \sum_s \frac{\mathrm{P}_j^s\,\mathrm{Y}_j^s\,a_{ij}^{rs}}{\mathrm{P}_i^r\,\mathrm{Y}_i^r}(\ln \mathrm{P}_{j,t}^s + \ln \mathrm{Y}_{j,t}^s + \ln \xi_{ij,t}^{rs}),$$

where in addition

$$\ln \pi_{ij,t}^r = (1-\rho)(1-ac_{ij}^r)\ln \tau_{ij,t}^r + (1-\rho)\sum_{k,l} ac_{kj}^l(\ln \mathrm{P}_{i,t}^r - \ln \mathrm{P}_{k,t}^l),$$
$$\ln \xi_{ij,t}^{rs} = (1-\epsilon)(1-\frac{a_{ij}^{rs}}{1-\eta^s})\ln \tau_{ij,t}^r + (1-\epsilon)\sum_{k,l}\frac{a_{kj}^{ls}}{1-\eta^s}(\ln \mathrm{P}_{i,t}^r - \ln \mathrm{P}_{k,t}^l).$$

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 $\ln \tau_{ij}^r$ 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

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

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

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

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:

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

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

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

and

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

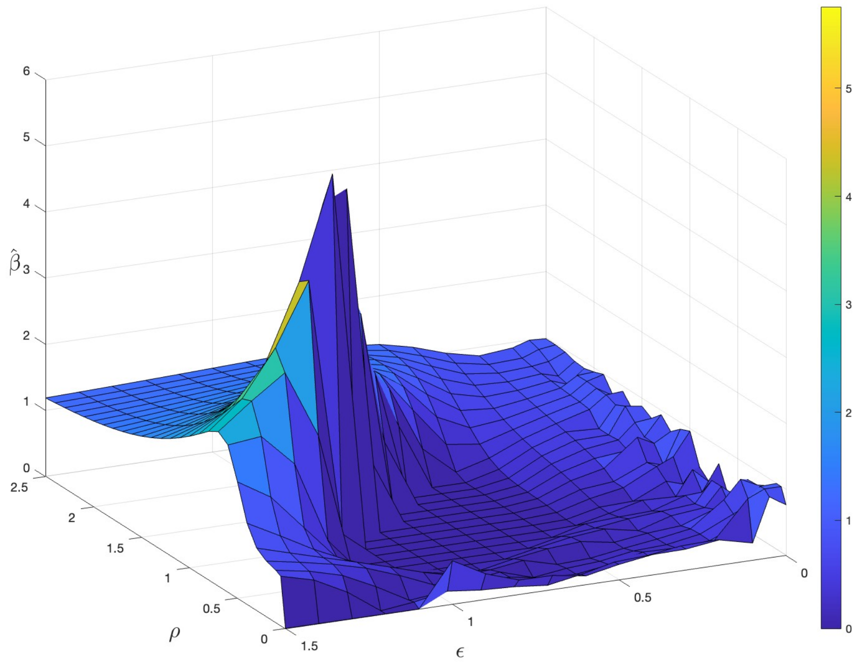
The + sign stands for the Moore-Penrose inverse as $\mathbf{I} - \mathcal{M}$ is not invertible. See Huo et al. (2021). The response of sector-level prices is given by

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

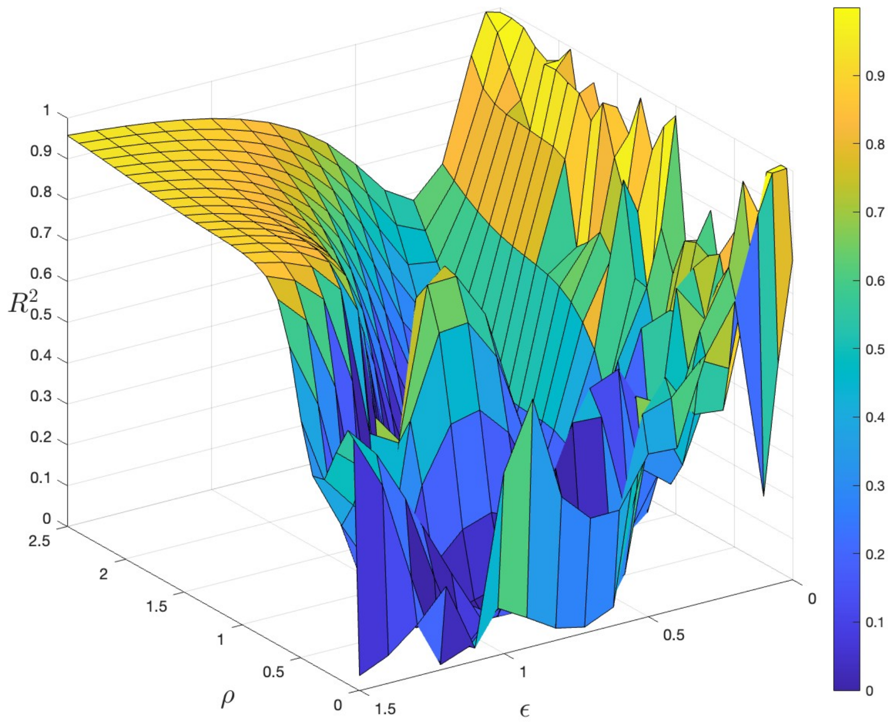
It follows the response of nominal output is given by

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

Appendix B

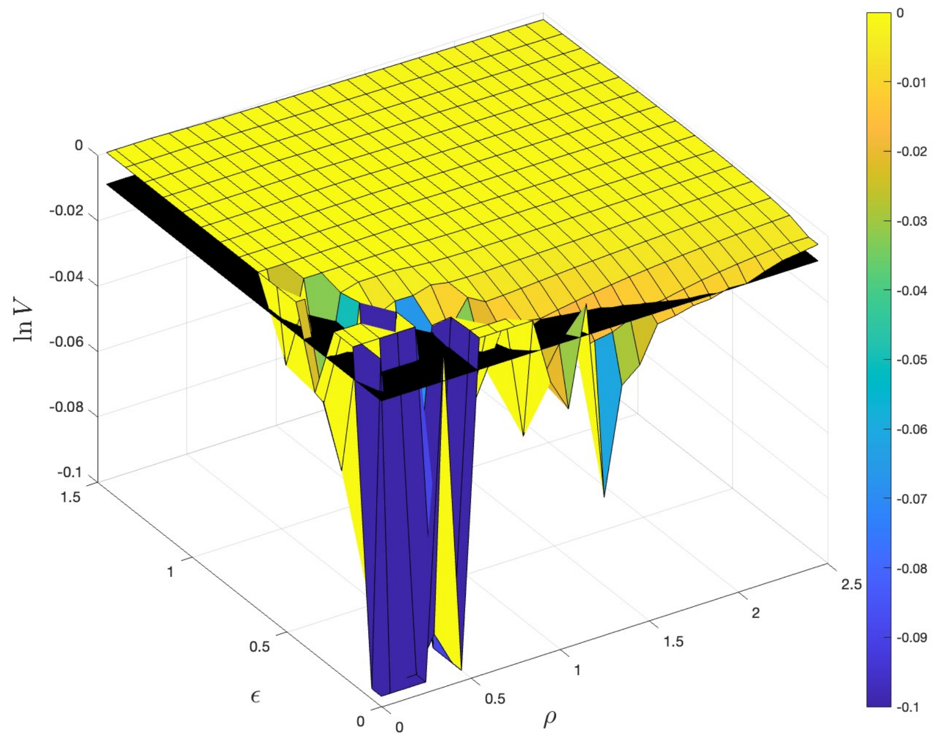


(a) $\hat{\beta}$ from regressing $\ln \mathbf{V}_t$ on $\frac{\alpha^r \psi}{1+\psi} \ln \mathbf{PY}_t$

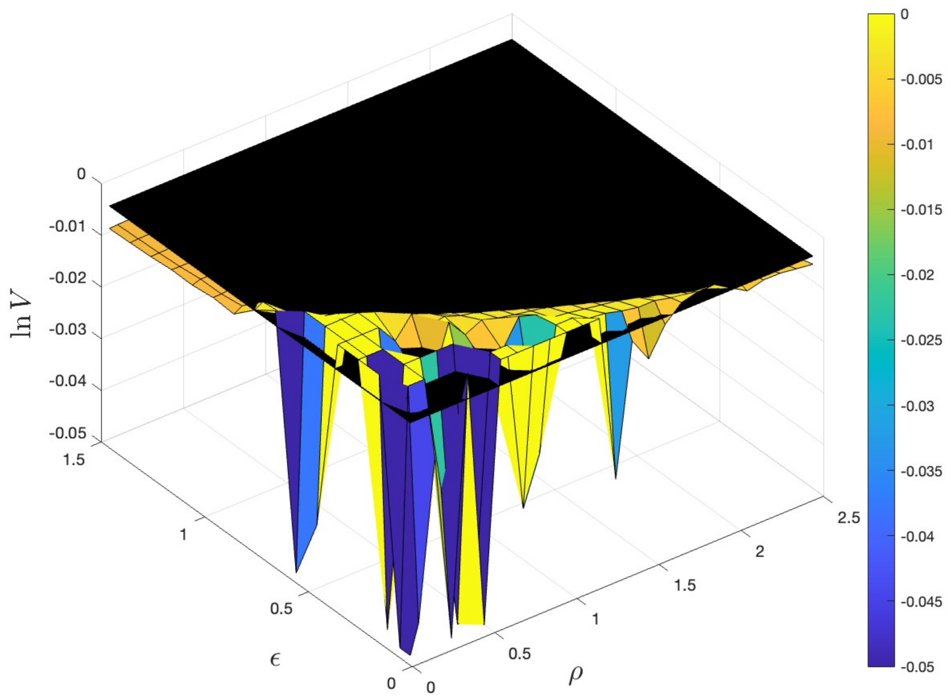


(b) R^2 from regressing $\ln \mathbf{V}_t$ on $\frac{\alpha^r \psi}{1+\psi} \ln \mathbf{PY}_t$

Figure 4: 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 5: Value added response to a European Embargo on all sectors. The German Chemicals approximate response (HOT) is 0.97 percent, and the average simulated response is 0.6 percent. The Russian Petroleum approximate response (SHOT) is 0.5 percent and the average simulated response is 0.9 percent.