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RESEARCH ARTICLE

International Economic Sanctions and Third-Country Effects

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Abstract

This paper studies international trade and macroeconomic dynamics triggered by economic sanctions, and the associated welfare losses, in a calibrated, asymmetric, three-country model of the world economy. We assume that there are two production sectors in each country, and the sanctioned country has a comparative advantage in production of a commodity (for convenience, gas) needed to produce final, differentiated consumption goods. We consider three types of sanctions: sanctions on trade in final goods, financial sanctions, and gas trade sanctions. We calibrate the model to an aggregate of countries that are currently imposing sanctions on Russia (the European Union, the UK, and the USA), Russia, and an aggregate of third countries (China, India, and Turkey). We show that, instead of reflecting the success of sanctions, exchange rate movements reflect the type of sanctions and the direction of the resulting within-country sectoral reallocations. Our welfare analysis demonstrates that the sanctioned country's welfare losses are significantly mitigated, and the sanctioning country's losses are amplified, if the third country does not join the sanctions, but the third country benefits from not joining. These findings highlight the necessity, but also the challenge, of coordinating sanctions internationally.

JEL Classification F31 · F41 · F42 · F51

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1 Introduction

The debate on the effectiveness of economic sanctions as an instrument to induce policy change in targeted countries has been reinvigorated by Russia's large-scale invasion of Ukraine in February of 2022 and the imposition of severe sanctions on Russia by many Western countries.[1] Arguments in favor of sanctions (e.g., those discussed in Blackwill and Harris 2016) have been met with two main objections: First, Russia is a large enough economy, especially for its role in energy markets, that sanctions can backfire through their effects on the global economy. Second, sanctions that target Russia's trade and financial relationships with the West do not prevent Russia from replacing these relationships with stronger ties to other nations.[2] This brings us back to Friedman (1980)'s Cold-War-era claim that sanctions would ultimately result in losses for the nations imposing them because of substitution in global trade.

In this paper, we assess the effectiveness of sanctions in an interdependent global economy by using a calibrated three-country model that allows us to capture both the nature of Russia as an economy of significant size and its ability to trade with countries that are not part of the Western bloc. To this end, we calibrate the sanctioning country in our model (Home) to an aggregate of the European Union, United Kingdom, and United States, the sanctioned country (Foreign) to Russia, and the third country (RoW, for Rest of the World) to an aggregate of China, India, and Turkey. Consistent with evidence, we set parameter values so that, when measured in purchasing power parity (PPP) terms, the gross domestic product (GDP) of our model-Russia represents approximately 10% of the combined GDPs of the European Union, United Kingdom, and United States. The structure of the model also allows us to capture Russia's comparative advantage and exporter role in production of mineral fuels. In this context, we show that sanctions can succeed at lowering the targeted economy's income and welfare, even when global effects and third-country behavior are taken into account.

The model that we use in our analysis shares several features with Ghironi and Melitz (2005)—henceforth, GM—which uses Melitz (2003) as the microeconomic underpinning of a two-country model of international trade and macroeconomics. We extend GM by adding an upstream energy-production sector that combines labor with a natural resource endowment (for convenience, natural gas) to produce energy. We assume that Foreign has a comparative advantage in this sector in the form of a larger endowment of natural gas. In the downstream sector, heterogeneous, monopolistically competitive firms combine labor and usable gas to produce differentiated consumption goods. Home enjoys a comparative advantage in this sector in the form of higher productivity in production of existing goods and creation of new ones. Producers in this sector face sunk entry costs in the domestic market, and fixed and iceberg trade costs in the export market. As is well known, fixed trade costs imply that

[1] We take a broad view of the West as including traditional allies, for instance, Japan.

[2] Schott (2023), among others, documents that Western sanctions compelled Russia to increase its trade with some Middle Eastern and Asian nations.

only producers whose productivity is above an endogenously determined threshold find it profitable to export. We also assume that international financial markets are incomplete, so that movements in current accounts have an impact on cross-border consumption allocations. This setup provides a rigorous environment for the assessment of international trade and macroeconomic effects of sanctions in dynamic general equilibrium.

We design trade and financial sanctions on Foreign as forced exits at extensive margins.[3] Financial sanctions are introduced by assuming that a fraction of Foreign agents are excluded from participation in international financial markets.[4] Trade sanctions on downstream producers are implemented by forcing firms that exceed a certain productivity threshold to exit the export market. This approach allows us to account for the fact that the sanctioned products from the West to Russia are typically those that require advanced technology for production.[5] Trade sanctions on Foreign gas exports are introduced in the form of a ban on gas trade.[6]

We find that all the sanctions we consider cause Foreign GDP and consumption to fall. The Home and RoW economies contract too, but by less than Foreign. Prohibiting Home firms from exporting consumption goods to Foreign generates the most noticeable changes in Foreign GDP and consumption. This type of sanction induces Foreign to increase its production of consumption goods, even if it is less efficient at producing them. Foreign reallocates resources toward industries in which it does not have a comparative advantage, and this inefficient reallocation amplifies the effects of sanctions. The cost of producing consumption goods in Foreign rises, putting upward pressure on domestic prices and causing the Foreign exchange rate to appreciate. In contrast, a ban on gas trade causes the Home exchange rate to appreciate by pushing Home to reallocate resources toward its gas sector, where it has a comparative disadvantage, and putting upward pressure on the cost of producing Home consumption goods. These findings show that the direction of exchange rate movements triggered by sanctions is associated with that of the within-country producer composition that sanctions cause. Moreover, our results show that exchange

[3] We model sanctions as permanent. As pointed by a referee, considering a shorter duration of sanctions might dampen their impact.

[4] Western nations have placed a variety of financial sanctions on Russia. These range from freezing central bank reserves to interruptions in international messaging systems such as SWIFT. A comprehensive analysis of financial sanctions necessitates modeling a more sophisticated financial sector, which is beyond the scope of this paper.

[5] Western countries that extensively introduced trade sanctions on Russia released guidance notes that give a list of the goods that were sanctioned, and these notes highlighted that sanctions are not blanket bans. See https://www.consilium.europa.eu/en/policies/sanctions/ and https://crsreports.congress.gov/product/pdf/R/R45415. The industries targeted by the sanctions- when compared to non-sanctioned sectors such as non-durable goods-exhibit higher productivity levels. We also conduct a robustness analysis by modeling trade sanctions on downstream producers through a random exclusion of firms from trade.

[6] This is the case for UK and US gas imports from Russia. The European Union has not stopped importing gas from Russia yet but has been taking steps in this direction. See Fig. 2 in Sect. 4 for details.

rate movements do not reflect the effectiveness of sanctions at generating economic contraction and welfare loss.[7]

To replicate Russia's trade flows after February 2022, we investigate a scenario in which Home imposes all three types of sanctions on Foreign, but RoW refrains from imposing sanctions. Our calibrated model shows that sanctions are effective at causing the targeted economy to contract and its households to suffer welfare losses regardless of what third countries do. The impact of the sanctions on Foreign is magnified if RoW imposes them. Additionally, if RoW joins the effort, Home GDP and welfare losses are smaller. However, RoW's GDP is higher and its welfare losses are smaller if RoW does not join Home's effort. These findings highlight the importance of international coordination of sanctions and the difficulty of accomplishing it.

Our study relies on critical features of the GM model, particularly the distinction in productivity between exporters and non-exporters. First, this distinction allows us to analyze how changes in producer composition within the downstream sector impacts real exchange rate dynamics. For example, under consumption-good export sanctions and gas sanctions, labor moves into the consumption-good sector in both cases. But, the exchange rate is responding to movements in the producer composition in the consumption-good sector and it depreciates under export sanctions and appreciates under gas sanctions. Second, our setup generates imperfect substitution towards the third-country in response to sanctions. Only more productive producers are able to cover the fixed export costs and therefore enter into export markets. This makes trade substitution imperfect for the country under sanctions as the third country cannot fulfill the additional demand from the sanctioned economy perfectly. These effects of sanctions could not be captured within an Armington model.

Additionally, we explore an alternative type of sanction where firms' exclusion is independent of their productivity. Both our benchmark and alternative sanctions lead to households needing to shift their expenditure from imported products to domestically produced ones, resulting in inefficient resource reallocations across sectors and countries.[8] Under the benchmark trade sanctions, these effects are amplified because we exclude the most productive exporters from trade. As a result, the benchmark trade sanctions have a stronger impact on welfare compared to the alternative sanctions. However, the disparity in dynamics and welfare losses between the benchmark and alternative scenarios is quantitatively small.

Our paper mainly contributes to two strands of literature. The Russia-Ukraine war triggered a wave of papers on the effects of sanctions, including (Albrizio and others 2022; Bachmann et al. 2022; Bianchi and Sosa-Padilla 2022; de Souza et al. 2022; Eichengreen et al. 2022; Itskhoki and Mukhin 2022; Lorenzoni and Werning 2022).[9]

[7] This echoes Eichengreen et al. (2022)'s and Itskhoki and Mukhin (2023)'s observation that exchange rates are not a good metric of the effectiveness of sanctions.

[8] In the model, exporters tend to be more productive than non-exporters, leading to lower prices for their products.

[9] Work that pre-dates Russia's large-scale invasion of Ukraine includes (Korhonen 2019; van Bergeijk 2021), and references therein.

Our main contribution is to develop a dynamic, general equilibrium analysis that accounts for the consequences of imposing sanctions on a large economy and for their extensive margin effects. Our paper also contributes to the literature on international trade and macroeconomics that developed following GM.[10] We contribute to this literature by using a three-country, two-sector, asymmetric framework to study the effects of sanctions.

The rest of the paper is organized as follows: Sect. 2 presents the model and its key environments. Section 3 discusses the calibration. Section 4 examines the effects of sanctions. Section 5 presents the welfare results. Section 6 provides robustness of our results with alternative designs of trade and financial sanctions. Section 7 concludes.

2 The Model

We consider a three-region world economy in which the regions are labeled as Home (H), Foreign (F), and the Rest of the World (RoW, R). The baseline model structure is similar to Ghironi et al. (2022), which employs Ghironi and Melitz (2005)'s monopolistic competition and heterogeneous producer framework as the microeconomic foundation for the consumption goods production sector. One important distinction from GM is the asymmetry between the regions in terms of size and production structure (Fig. 1). We denote the populations as χ_i, with i representing country $\{H, F, R\}$. Home and RoW countries are populated by a unit mass of atomistic households (i.e., $\chi_H = \chi_R = 1$). However, the size of the Foreign country is smaller, i.e., $\chi_F \in (0, 1)$. There is a representative household in each country before the introduction of sanctions. The representative household consists of two types of workers who supply labor to consumption goods producers and gas producers, respectively. Home and RoW are importers of gas, whereas Foreign is an exporter of gas.

2.1 Household Preference

In each country $i \in H, F, R$, households derive utility from the consumption of a basket of goods, $C_{i,t}$, and experience disutility from supplying labor, $L^i t$, to the sector that produces consumption goods and $L^i_{G,t}$ to the sector that produces gas. Specifically, we assume the Frisch elasticity to be one. Following Horvath (2000), we use a constant elasticity of substitution specification, where the parameter, $\varrho > 0$, represents the degree of labor mobility between sectors.

The individual household's expected intertemporal utility function, which they aim to maximize, is as follows:

[10] An incomplete list includes (Auray and Eyquem 2011; Bergin et al. 2021; Bergin and Corsetti 2019; Cacciatore 2014; Cacciatore and Ghironi 2021; Corsetti et al. 2007, 2013; Dekle et al. 2015; Hamano and Zanetti 2017; Imura and Shukayev 2019; Kim 2021; Kim et al. 2021; Lanteri et al. 2023; Rodriguez-Lopez 2011; Zlate 2016).

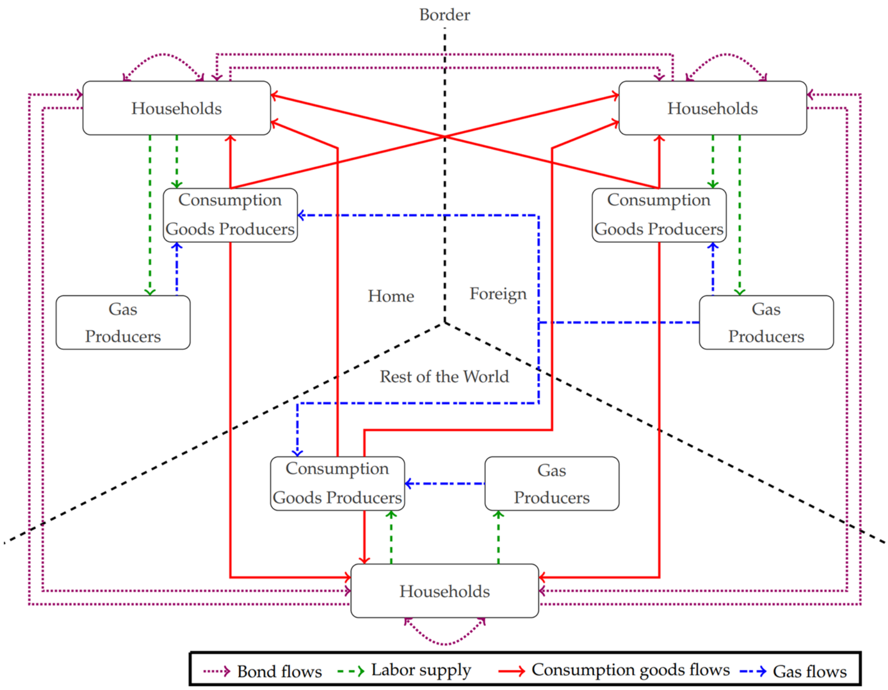


Fig. 1 Model architecture

$$\mathbb{E}_0\left[\sum_{t=0}^{\infty}\beta^t\left\{\ln C_{i,t}-\frac{\kappa}{2}\left[(L_t^i)^{\frac{1+\varrho}{\varrho}}+(L_{G,t}^i)^{\frac{1+\varrho}{\varrho}}\right]^{\frac{2\varrho}{1+\varrho}}\right\}\right], \tag{1}$$

where β is a discount factor between 0 and 1, and κ is a positive parameter and represent disutility from labor. The consumption basket in country i is defined over a continuum of goods represented by Ω: $C_{i,t} = \{\int_{\omega\in\Omega}[c_{i,t}(\omega)]^{\frac{\theta-1}{\theta}}d\omega\}^{\frac{\theta}{\theta-1}}$ where $\theta > 1$ is the symmetric elasticity of substitution across goods. At any time t, only a subset of goods $\Omega_{i,t} \subset \Omega$ is available in country i. Demand for individual goods in country i is given by $\chi_i c_{i,t}(\omega) = [p_{i,t}(\omega)/P_{i,t}]^{-\theta}\chi_i C_{i,t}$, where $p_{i,t}(\omega)$ is the country i currency price of a good $\omega \in \Omega_{i,t}$ and $P_{i,t} = \{\int_{\omega\in\Omega_{i,t}}[p_{i,t}(\omega)]^{1-\theta}d\omega\}^{\frac{1}{1-\theta}}$. We define $\rho_{i,t}(\omega)$ as the relative price of good ω compared to the price of the basket in country i. Using this definition, the demand for good ω is expressed as $\chi_i c_{i,t}(\omega) = [\rho_{i,t}(\omega)]^{-\theta}\chi_i C_{i,t}$.

2.2 Gas Production

Each country is endowed with a certain level of natural gas, denoted as G_N^i. We assume that Foreign has a larger endowment, i.e., $G_N^F > G_N^H$ and $G_N^F > G_N^R$. A perfectly competitive upstream sector in each country produces usable gas by combining labor and natural gas:

$$G_t^i = G_N^i(\chi_i L_{G,t}^i). \tag{2}$$

This gas can be used domestically ($G_{i,t}^i$) or exported ($G_{j,t}^i$) for $i \neq j$. Hence, in equilibrium, it will be $G_N^i \chi_i L_{G,t}^i = \sum_{j=H,F,R} G_{j,t}^i$. First-order conditions for optimal labor demand in gas production yields $w_{G,t}^i = \rho_{G,t}^i G_N^i$, where $w_{G,t}^i$ is the real (per unit) wage paid to workers in this sector, and $\rho_{G,t}^i$ is the real price of usable gas in country i (both wages and prices are in units of the country's consumption basket).

Foreign exports gas to Home and RoW but does not import from them. The produced gas is perfectly substitutable, and thus the determination of the gas market price ensures that $\rho_{G,t}^H = \tau_{G,t} Q_{F,t}^H \rho_{G,t}^F$ and $\rho_{G,t}^R = \tau_{G,t} Q_{F,t}^R \rho_{G,t}^F$, where $\tau_{G,t}$ represents iceberg gas import costs, and $Q_{j,t}^i$ is the consumption-based real exchange rate (units of country i consumption per unit of country j).

2.3 Consumption Good Production

Consumption goods producer Monopolistically competitive firms produce differentiated consumption goods by combining gas and labor. Home, Foreign, and RoW gases are perfect substitutes in the production of consumption goods. Firm ω in country $i \in H, R$ produces output $y_t^i(\omega)$ with the following production function:

$$y_t^i(\omega) = zZ_t^i \left\{ \alpha \left[g_{i,t}^i(\omega) + \frac{g_{i,t}^F(\omega)}{\tau_{G,t}} \right]^\rho + (1-\alpha)\left[l_t^i(\omega)\right]^\rho \right\}^{\frac{1}{\rho}}. \tag{3}$$

Hence, the elasticity of substitution between factors, ϵ, is given by $\epsilon \equiv 1/(1-\rho)$. The firm-specific productivity, denoted as z and ranging from z_{min} to infinity, is determined at the time of entry. Also, $Z_t^i > 0$ is a sector-wide productivity level, $l_t^i(\omega)$ is labor, and the relative share of gas in the production function is α where $0 \leq \alpha < 1$.

We define the firm's total gas demand by $g_{i,t}(\omega) = g_{i,t}^i(\omega) + g_{i,t}^F(\omega)/\tau_{G,t}$. The demand is split between domestically produced gas and imported gas, where the latter is subject to an iceberg cost. Foreign does not import gas from other countries. Firm optimization equates the gas prices due to the perfect substitutability assumption. In country $i = H$ and R,

$$\rho_{G,t}^i = \tau_{G,t} Q_F^i \rho_{G,t}^F. \tag{4}$$

Foreign firms use only domestic gas, $G_{F,t}^H(\omega) = G_{F,t}^R(\omega) = 0$ and $G_{F,t}(\omega) = G_{F,t}^F(\omega)$.

We drop the identifier ω and replace it with the heterogeneous productivity z. Using w_t^i to denote the real wage paid to consumption-sector workers (in units of consumption), the expressions for labor and gas demand by firm z are

$$l_{i,t}^P(z) = \left(\frac{1-\alpha}{w_t^i} \right)^\epsilon \frac{y_t^i(z)}{\alpha^\epsilon (\rho_{G,t}^i)^{1-\epsilon} + (1-\alpha)^\epsilon (w_t^i)^{1-\epsilon}}, \tag{5}$$

$$g_{i,t}(z) = \left(\frac{\alpha}{\rho^i_{G,t}}\right)^{\epsilon} \frac{y^i_t(z)}{\alpha^{\epsilon}(\rho^i_{G,t})^{1-\epsilon} + (1-\alpha)^{\epsilon}(w^i_t)^{1-\epsilon}}. \tag{6}$$

It is straightforward to express the firm's marginal cost as

$$\mathrm{mc}^i_t(z) = \frac{1}{zZ^i_t}\left[\alpha^{\epsilon}(\rho^i_{G,t})^{1-\epsilon} + (1-\alpha)^{\epsilon}(w^i_t)^{1-\epsilon}\right]^{\frac{1}{1-\epsilon}}. \tag{7}$$

Considering Dixit-Stiglitz preferences and iceberg trade costs, the real price charged by a firm located in country i for sales in market j can be expressed as

$$\rho^i_{j,t}(z) = \left(\frac{\theta}{\theta-1}\right)\frac{\tau^i_{j,t}\mathrm{mc}^i_t(z)}{Q^i_{j,t}}. \tag{8}$$

Exporting is costly, and producers are subject to an iceberg export cost, $\tau^i_{j,t} > 1$ for $i \neq j$ (and $\tau^i_{i,t} = 1$), as well as a per-period fixed export cost, $f_{X,t}$. The fixed export cost requires the use of consumption-sector labor, with its effectiveness determined by the aggregate shock Z^i_t. We assume that $f_{X,t}$ is measured in units of effective labor when $i \neq j$. Therefore, the fixed export cost, measured in units of consumption, is $w^i_t f_{X,t}/Z^i_t$ for firms located in country i. The fixed export cost implies that only firms with sufficiently high productivity z will export. In other words, there exists a cutoff $\underline{z}^i_{j,t}$ such that a firm located in country i sells its product and turns a positive profit in market j if $z > \underline{z}^i_{j,t}$, with $\underline{z}^i_{i,t} = z_{min}$.

Number of firms, exporters, and their averages In line with Melitz (2003), we define the market-share weighted productivity average $\tilde{z}^i_j$ for firms in country i that have non-negative sales in market j as follows.[11]

$$\tilde{z}^i_{j,t} \equiv \left[\frac{1}{\Phi(\overline{z}^i_{j,t}) - \Phi(\underline{z}^i_{j,t})}\int_{\underline{z}^i_{j,t}}^{\overline{z}^i_{j,t}} z^{\theta-1}\mathrm{d}\Phi(z)\right]^{\frac{1}{\theta-1}}, \tag{9}$$

where $\overline{z}^i_{j,t} \to \infty$ and $\Phi(\overline{z}^i_{j,t}) \to 1$. When $i = j$, the market-share weighted productivity average $\tilde{z}_D$ for all producing firms ($\underline{z}^i_{i,t} = z_{min}$ and $\overline{z}^i_{i,t} \to \infty$) is

$$\tilde{z}^i_{i,t} = \tilde{z}_D \equiv \left(\int_{z_{min}}^{\infty} z^{\theta-1}\mathrm{d}\Phi(z)\right)^{\frac{1}{\theta-1}}. \tag{10}$$

As shown by Melitz (2003), the model is isomorphic to one in which $N^i_{D,t}$ firms with productivity $\tilde{z}^i_D$ produce in country i, and $N^i_{j,t}$ firms with productivity $\tilde{z}^i_{j,t}$ export to country $j \neq i$. The expression for country i's price index P^i_t implies that $\sum_{j\in H,F,R} N^i_{j,t}(\tilde{\rho}^j_{i,t})^{1-\theta} = 1$, where $\tilde{\rho}^j_{i,t} \equiv \rho^j_{i,t}(\tilde{z}^j_{i,t})$ represents the average relative prices of producers of origin country j and destination country i.

[11] See Zlate (2016), Kim (2021) for a case with both the upper and lower bounds of exporting firms.

Additionally, the average profits of country i firms from market j is $\tilde{d}^i_{j,t} \equiv \theta^{-1}(\tilde{\rho}^i_{j,t})^{1-\theta} Q^i_{j,t} C_{j,t}$. Thus, average total profits of country i firms are $\tilde{d}^i_t = \sum_{j=H,F,R}[\Phi(\overline{z}^i_{j,t}) - \Phi(\underline{z}^i_{j,t})]\tilde{d}^i_{j,t}$, where $\Phi(\overline{z}^i_{j,t}) - \Phi(\underline{z}^i_{j,t})$ is the proportion of firms that export, $N^i_{j,t}/N^i_{D,t}$.

Firm entry and exit There is an unbounded mass of potential entrants in each country. Entry requires use of consumption-sector labor with effectiveness determined by the aggregate shock Z^i_t. Prior to entry, all firms are identical and face a sunk entry cost $f_{E,t}$ in units of effective labor. Hence, the sunk entry cost in units of consumption is $w^i_t f_{E,t}/Z^i_t$. When firms enter the market, they randomly draw their individual productivity level, denoted as z, from a cumulative distribution function $\Phi(z)$ with support $[z_{min}, \infty)$. This productivity level remains fixed thereafter. We assume that $f_{E,t}/Z^F_t > f_{E,t}/Z^H_t$, allowing for the possibility that the gas-rich country features fewer consumption-sector firms as a consequence of inefficiencies of various type that can characterize the firm creation process.

We make an assumption of a one-period time-to-build requirement, meaning there's a gap of one period between a firm's entry and its actual production and profit generation. Every firm in the economy, whether established or newly entered, faces an external shock that could lead to their exit with a probability of $\delta \in (0, 1)$ at the end of each period. Therefore, the mass $N^i_{D,t}$ of producing Home firms in period t is determined by $N^i_{D,t} = (1-\delta)(N^i_{D,t-1} + N^i_{E,t-1})$, where $N^i_{E,t-1}$ is the number of firms that entered in period t-1.

Given these definitions, firm entry decisions are determined as follows. Potential entrants take a forward-looking approach, calculating the anticipated sequence of average total profits they can generate after entering the market. This calculation defines the average value of a new entrant, denoted as $\tilde{v}^i_t$.

$$\tilde{v}^i_t \equiv \mathbb{E}_t \left\{ \sum_{s=t+1}^{\infty} [\beta(1-\delta)]^{s-t} \left(\frac{C_{i,s}}{C_{i,t}} \right)^{-1} \tilde{d}^i_s \right\}. \tag{11}$$

Entry occurs until this value is equated to the sunk entry cost, implying the free-entry condition $\tilde{v}^i_t = w^i_t f_{E,t}/Z^i_t$. We assume that macroeconomic shocks are never large enough to cause zero entry in any period (or $\tilde{v}^i_t < w^i_t f_{E,t}/Z^i_t$) so that the entry condition always holds with equality (in other words, there is always a positive number of entrants). Since both new entrants and incumbent firms face the same probability of exit, δ, at the end of each period regardless of their firm-specific productivity, $\tilde{v}^i_t$ is also the average value of incumbent firms after production has occurred.

2.4 Household Budget Constraint and Asset Holdings

International financial markets are incomplete as only non-contingent, riskless real bonds are traded internationally. The representative country i household's holdings of country j bonds entering period t are denoted with $B^j_{i,t}$. The household receives the risk-free real interest rate r^j_t on these bonds during period t. (Country j bonds and interest rate are in units of country j consumption). We assume that firms are fully domestically owned. Specifically, the country i representative household enters the period with share holdings x_t^i in a mutual fund of $N_{D,t}^i$ producing firms in country i. During period t, the household receives dividends from its share holdings, $\tilde{d}_t^i$ per share, and the value of selling its share portfolio at the price $\tilde{v}_t^i$ per share. Besides its financial assets and the income they generate, the representative household's resources in period t also include the income from labor supplied in the gas production sector ($w_{G,t}^i L_{G,t}^i$) and in the consumption sector ($w_t^i L_t^i$). Finally, the household also receives a lump-sum rebate of fees that it pays to financial intermediaries in order to enter period $t+1$ (these fees serve the purpose of pinning down holdings of Home and Foreign bonds at their steady-state values in the deterministic steady state of the model). During period t, the household uses its resources to buy consumption, to buy bonds with which it will enter period $t+1$ ($\{B_{i,t+1}^j\}_{j=H,F,R}$), to pay fees $\sum_{j=H,F,R} 0.5 Q_{j,t}^i (B_{i,t+1}^j - B_j^i)^2$, with $\eta > 0$, and to buy share holding x_{t+1}^i in a mutual fund of $N_t^i \equiv N_{D,t}^i + N_{E,t}^i$ firms. Only $1-\delta$ of these N_t^i firms will be around to produce and generate profits in period $t+1$. The household does not know which firms will be hit by the exit-inducing shock. Therefore, it finances continued operations by all currently producing firms and entry by all producers who choose to enter the market, with the risk of firm exit at the end of period t reflected in the share price that will be determined by the Euler equation for optimal share holdings. Here's the budget constraint for the typical household in country i.

$$\begin{aligned} C_{i,t} + \tilde{v}_t N_t^i x_{t+1}^i + \frac{\eta}{2}\left(x_{t+1}^i - \frac{1}{\chi_i}\right)^2 + \sum_{j=H,F,R} Q_{j,t}^i \left[B_{i,t+1}^j + \frac{\eta}{2}(B_{i,t+1}^j - B_i^j)^2\right] \\ = w_{G,t}^i L_{G,t}^i + w_t^i L_t^i + (\tilde{d}_t^i + \tilde{v}_t^i) N_{D,t}^i x_t^i + T_t^f + \sum_{j=H,F,R} Q_{j,t}^i (1 + r_t^i) B_{i,t}^j. \end{aligned} \tag{12}$$

where $T_t^f = 0.5\eta\left[(x_{t+1}^i - \chi_i^{-1})^2 + \sum_{j=H,F,R} Q_{j,t}^i (B_{i,t+1}^j - B_i^j)^2\right]$, in equilibrium.

The Euler equation for the optimal holdings of country j bonds by the representative household in country i can be expressed as

$$C_{i,t}^{-1}\left[1 + \eta(B_{i,t+1}^j - B_i^j)\right] = \beta\left(1 + r_{t+1}^j\right)\mathbb{E}_t\left[\frac{Q_{j,t+1}^i}{Q_{j,t}^i} C_{i,t+1}^{-1}\right], \tag{13}$$

for each $j = H, F, R$. Similarly, the Euler equation for the optimal share holdings suggests that:

$$\tilde{v}_t^i\left[1 + \eta\left(x_{t+1}^i - \frac{1}{\chi_i}\right)\right] = \beta(1-\delta)\mathbb{E}_t\left[\left(\frac{C_{i,t+1}}{C_{i,t}}\right)^{-1}\left(\tilde{v}_{t+1}^i + \tilde{d}_{t+1}^i\right)\right]. \tag{14}$$

Forward iteration of this equation and the relevant transversality condition imply the expression for $\tilde{v}_t^i$ in the free-entry condition of Eq. (11), thus establishing the general equilibrium link between firm entry decisions and household decisions regarding the financing of entry.

2.5 Market Clearing and Aggregate Accounting

The price of usable gas, $\rho^i_{G,t}$, is determined by the gas market clearing condition in a gas import country $i = H$ and R:

$$G^i_N(\chi_i L^i_{G,t}) = G^i_{i,t}, \tag{15}$$

and also, the gas demand satisfies

$$N^i_{D,t} \int_{z_{min}}^{\infty} g_{i,t}(z)\mathrm{d}\Phi(z) = G^i_{i,t} + \frac{G^F_{i,t}}{\tau_{G,t}}. \tag{16}$$

In a gas export country (F), the followings hold.

$$G^F_N(\chi_F L^F_{G,t}) = \sum_{j=H,F,R} G^F_{j,t} \tag{17}$$

$$N^i_{D,t} \int_{z_{min}}^{\infty} g_{i,t}(z)\mathrm{d}\Phi(z) = G^F_{F,t} \tag{18}$$

The labor supply decision in gas production in country i requires

$$L^i_{G,t} = \left(\frac{w^i_{G,t}}{\kappa C^i_t}\right)^{\varrho} \left[(L^i_t)^{\frac{1+\varrho}{\varrho}} + (L^i_{G,t})^{\frac{1+\varrho}{\varrho}}\right]^{\frac{\varrho(1-\varrho)}{1+\varrho}}. \tag{19}$$

Let country i be a gas importer (H or R) and $\varrho = 1$. Then, $L^i_{G,t} = \rho^i_{G,t} G^i_N/(\kappa C_{i,t})$ and $L^F_{G,t} = \rho^i_{G,t} G^F_N/(\tau_{G,t}\kappa Q^i_{F,t} C_{F,t})$, where the relationships use the fact that $\rho^i_{G,t} = \tau_{G,t} Q^i_{F,t} \rho^F_{G,t}$ and $w^i_{G,t} = \rho^i_{G,t} G^i_N$. Ceteris paribus, the amount of labor employed in gas production in each country increases as the country's endowment of natural gas increases. Additionally, it increases as the price of gas increases. Instead, labor in the gas sector decreases as the country's consumption increases, and intuitively, as the weight of the disutility of labor increases. Because a real depreciation of the country i's currency (an increase in $Q^i_{F,t}$) causes a higher real price of usable gas in gas import country i, it causes a decrease in gas-sector employment in Foreign, as there is an incentive to shift production to country i.

Market clearing for individual goods requires $y_{i,t}(z) = c_{H,t}(z) + c_{F,t}(z) + c_{R,t}(z)$ for the product of a Home firm with specific productivity z. Market clearing conditions for individual goods of Foreign and RoW firms are analogous.

Labor market clearing in the consumption good sectors of country $i = H, F, R$ requires

$$\chi_i L^i_t = N^i_{D,t} \int_{z_{min}}^{\infty} l^P_{i,t}(z)\mathrm{d}\Phi(z) + N^i_{E,t}\frac{f_{E,t}}{Z^i_t} + \sum_{j\neq i} N^i_{j,t}\frac{f_{X,t}}{Z^i_t}, \tag{20}$$

where the labor satisfies

$$L_t^i = \left(\frac{w_t^i}{\kappa C_{i,t}}\right)^{\varrho}\left[(L_t^i)^{\frac{1+\varrho}{\varrho}} + (L_{G,t}^i)^{\frac{1+\varrho}{\varrho}}\right]^{\frac{\varrho(1-\varrho)}{1+\varrho}}. \tag{21}$$

Market clearing for bonds issued by country i requires $\sum_{j=H,F,R}\chi_j B_{j,t+1}^i = 0$ in every period. Stock market clearing in each country requires $x_{t+1}^i = x_t^i = 1/\chi_i$ in every period. Because costs of adjusting bond holdings are rebated back to households in equilibrium, imposing equilibrium conditions on the household budget constraint yields:

$$C_{i,t} + \tilde{v}_t^i N_{E,t}^i \chi_F^{-1} + TB_{i,t} = GDP_{i,t}, \tag{22}$$

where $TB_{i,t} = \sum_{j=H,F,R} Q_{j,t}^i [B_{i,t+1}^j - (1 + r_t^j)B_{i,t}^j]$ and $GDP_{i,t} = w_{G,t}^i L_{G,t}^i + w_t^i L_t^i + N_{D,t}^i \tilde{d}_t^i \chi_i^{-1}$ are country i's trade balance and GDP per capita, respectively.

2.6 Sanctions

We consider three types of sanctions and their combinations: trade sanctions affecting the export/import of consumption goods, financial sanctions, and gas trade sanctions. These sanctions are modeled as exit measures at the extensive margin, rather than solely manipulating the prices of existing traded goods, as observed in the case of sanctions imposed on the Russian market.[12] We provide more details on the modelling of sanctions below.

Consumption good trade sanctions We model consumption good trade sanctions by imposing exit from trade for consumption good producers with productivity above a certain threshold. The underlying concept is that sanctions lead to a reduction in trade involving the most productive producers. We adopt this modeling approach because the sanctioned products from the EU and the US to Russia are those requiring sophisticated technology for production, such as quantum computers, sensors, lasers, space industry goods, maritime navigation goods, and luxury cars.[13]

Despite the narrative evidence, detailed data are unavailable to identify whether sanctions specifically target the most productive or largest firms. Therefore, in Sect. 6, we will explore alternative designs for trade sanctions that are independent of productivity. In these alternative scenarios, we will exclude firms from international trade with an exogenous probability, which is identical across all firms. Both

[12] The evidence shows that sanctions were in the form of exit from the Russian market. It is documented that more than 1000 companies voluntarily curtailed operations in Russia in an attempt to add to what was being imposed by governments. See Sonnenfeld et al. (2022) and https://som.yale.edu/story/2022/over-1000-companies-have-curtailed-operations-russia-some-remain for more details and discussion.

[13] See a description of the goods from the EU and the US that are subject to sanctions: http://www.consilium.europa.eu/en/policies/sanctions/restrictive-measures-against-russia-over-ukraine/sanctions-against-russia-explained/#trade and "Russia's War on Ukraine Financial and Trade Sanctions," Congressional Research Service, February 22, 2023.

our benchmark and alternative consumption good trade sanctions result in households needing to shift their expenditure from imported products to domestically produced products. It is worth noting that exporters tend to be more productive than non-exporters, leading to lower prices for their products.

We introduce sanctions on consumption good trade by imposing a productivity upper bound, $\bar{z}_S$, which we call the sanction productivity limit. Either Home consumption good producers with higher productivity levels than the sanction productivity limit level stop exporting to Foreign ($\bar{z}^H_{F,t} = \bar{z}_S$), or Home stops importing from Foreign producers with productivity levels above the sanction productivity limit ($\bar{z}^F_{H,t} = \bar{z}_S$). Under consumption good trade sanctions, the share of exporting firms from country i (sanctioning region) to country j (sanctioned region) reads as follows:

$$\frac{N^i_{j,t}}{N^i_{D,t}} = (1 - \mathbb{1}^S) + \mathbb{1}^S \Phi(\bar{z}_S) - \Phi(\underline{z}^i_{j,t}). \tag{23}$$

where $\mathbb{1}^S$ is an indicator function and takes the value 1 when sanctions are introduced and 0 under normal times. Our choice of the sanction cut-off level reflects Russia's non-mineral fuel goods trade flows with the European Union, the UK, and the USA after the Russian-Ukrainian war. (See Sect. 3 for the details.) Specifically, we pin down the threshold sanction productivity level by imposing that the top 0.5% most productive consumption good producers are participating in sanctions. Although the top 0.5% Home firms represent 78% of aggregate exports to Foreign in our model's initial steady state, there is an increase in the export participation of lower productive firms. Therefore, the total decrease in aggregate exports is less than 78%.[14] The increase in lower productivity firms entering the export market does not quantitatively affect our results. The average exporter productivity drops after the sanctions, irrespective of whether there is further entry by lower productivity firms into the export market or lack thereof.

Gas sanctions With respect to gas trade sanctions, we conduct simulations involving a permanent halt of gas imports from Foreign. These sanctions are modeled by introducing a permanent reduction in demand for gas imports from Foreign, effective from period $t = 1$ onwards. When these sanctions are imposed, the market clearing condition for usable gas in Foreign undergoes the following modification:

$$G^F_N \chi_F L^F_{G,t} = \min\left\{\overline{G}^S_{H,t}, G^F_{H,t}\right\} + \min\left\{\overline{G}^S_{R,t}, G^F_{R,t}\right\} + G^F_{F,t}. \tag{24}$$

In the above equation, $\overline{G}^F_{H,t}$ and $\overline{G}^F_{R,t}$ denote the quota imposed by Home and RoW to gas imports from Foreign, respectively. We consider that under gas sanctions, sanctioning economies reduce their demand for Foreign gas to zero, i.e., $\overline{G}^F_{H,t} = 0$. If

[14] Due to asymmetry between Home and Foreign, the top 0.5% Foreign firms represent 60% of aggregate exports from Foreign to Home in the initial steady state. Section 3 provides the details.

RoW participates in sanctions, the gas import quota is $\overline{G}^F_{R,t} = \overline{G}^F_{H,t}$. Otherwise, there is no quota, $\overline{G}^F_{R,t} \to \infty$.

Financial sanctions We introduce financial market sanctions by modeling the exclusion of a fraction of Foreign households from international bond trading, with the extreme case being the exclusion of all Foreign households. Sanctioned households' internationally traded bonds are captured by sanctioning economies and they cannot cash in those savings. This modeling approach is motivated by the Biden administration's sanctions on Russian bonds.[15] There are other forms of financial sanctions, including freezing central bank reserves, restricting transactions of Russian financial institutions, and imposing restrictions on international financial messaging systems like SWIFT; however we limit our focus on the international bond trade.

When Home imposes financial sanctions against Foreign, a fraction $\lambda > 0$ of Foreign households are excluded from international financial markets. These households can only trade Foreign bonds and shares with RoW households and other Foreign households.[16] When RoW joins the financial sanctions and the entire Foreign economy is subject to financial sanctions with $\lambda = 1$, Foreign operates under financial autarky.

The budget constraint of the representative sanctioned household reads for $t = 1, 2, \dots, \infty$:

$$\begin{aligned} C^*_{F,t} &+ \frac{\eta}{2}\tilde{v}^F_t N^F_t (x^{F*}_{t+1} - \chi^{-1}_F)^2 + \tilde{v}^F_t N^F_t x^{F*}_{t+1} \\ &+ \sum_{j=F,R} Q^j_{F,t}\left[B^{j*}_{F,t+1} + \frac{\eta}{2}(B^{j*}_{F,t+1} - B^{j*}_F)^2\right] \\ &= w^F_{G,t} L^{F*}_{G,t} + w^F_t L^{F*}_t + (\tilde{d}^F_t + \tilde{v}^F_t) N^F_{D,t} x^{F*}_t + T^*_{F,t} + \sum_{j=F,R} (1 + r^j_t) Q^j_{F,t} B^{j*}_{F,t}. \end{aligned} \tag{25}$$

The asterisk denotes Foreign households that are subject to sanctions. The sanctioned households cannot trade Home bonds along the transitional path, and their terminal steady-state holdings are zero, i.e., $B^F_{H,t+1} = B^{F*}_H = 0$.[17] Therefore, they do not need to pay adjustment costs on Home bond holdings.

The budget constraint of the representative non-sanctioned household is:

[15] See "Russia's War on Ukraine Financial and Trade Sanctions," Congressional Research Service, February 22, 2023.

[16] The resulting household structure after the introduction of financial sanctions is related with those in open economy HANK literature, such as Guo et al. (2023). This literature studies the effects of shocks given the heterogeneous structure of households, whereas our focus is on the variation of household heterogeneity along the transitional path between steady states.

[17] If the RoW joins sanctions, the holdings of RoW bonds by the households sanctioned in the terminal steady-state also drop to zero, i.e., $B^{F*}_{R,t+1} = B^{F*}_R = 0$.

$$
\begin{aligned}
& C_{F,t}^{**} + \frac{\eta}{2}\tilde{v}_t^F N_t^F (x_{t+1}^{F**} - \chi_F^{-1})^2 + \tilde{v}_t^F N_t^F x_{t+1}^{F**} \\
& \quad + \sum_{j=H,F,R} Q_{F,t}^j \left[B_{F,t+1}^{j**} + \frac{\eta}{2}(B_{F,t+1}^{j**} - B_F^{j**})^2 \right] \\
& = w_{G,t}^F L_{G,t}^{F**} + w_t^F L_t^{F*} + (\tilde{d}_t^F + \tilde{v}_t^F) N_{D,t}^F x_t^{F**} + T_{F,t}^{**} + \sum_{j=H,F,R} (1 + r_t^j) Q_{F,t}^j B_{F,t}^{j**},
\end{aligned}
\tag{26}
$$

where the terminal steady-state bond holdings are the same as the initial values: $B_F^{j**} = B_F^j$ for $j = H, F, R$. The doubled asterisk denotes non-sanctioned households. For $t \geq 1$, the market clearing conditions for bonds and shares in the presence of financial market sanctions are as follows:

$$
0 = \chi_F(1 - \lambda)B_{F,t+1}^{H**} + \sum_{j=H,R} B_{j,t+1}^H \tag{27}
$$

$$
0 = \chi_F[\lambda B_{F,t+1}^{F*} + (1 - \lambda)B_{F,t+1}^{F**}] + \sum_{j=H,R} B_{j,t+1}^F \tag{28}
$$

$$
1 = \chi_F[\lambda x_{t+1}^{*} + (1 - \lambda)x_{t+1}^{**}]. \tag{29}
$$

According to Eq. (25), when the sanctions begin, the sanctioned households lose the Home bonds they hold. While $B_{F,1}^{H*} > 0$ (determined at $t = 0$), they cannot receive any returns from them starting at $t = 1$. However, Sect. 6 will consider an alternative design of financial sanctions. Under these alternative financial sanctions, the sanctioned households are required to sell all their Home bonds at $t = 1$ and earn values $(1 + r_1^H)Q_{F,t}^H B_{F,1}^{H*}$ rather than loose them. Furthermore, under the alternative scenario of financial sanctions, non-sanctioned households' terminal steady-state of Home-issued bond holdings is zero, i.e., $B_H^{F**} = 0$ ($B_R^{F**} = 0$ if RoW joins sanctions). But, they can trade Home bonds along the transitional path.

3 Calibration

The model is calibrated by using the conventional values in the international trade and macroeconomics literature and through matching the steady-state values of several variables to the data. Steady-state values of Foreign GDP, Foreign exports and Foreign imports are matched to replicate the average of 2020–2021 Russian annual data, and the steady-state values of Home GDP, Home exports and Home imports are matched to replicate the combination of EU27, the UK, and the US averages in 2020–2021. We also match the Russian net foreign position and the amount of Russian external assets when setting the steady-state bond holdings of Foreign.

We first calibrate some parameters directly from the data or from the previous literature (Table 1). This approach allows us to assess the implications of sanctions without the risk of our findings being the product of an unusual calibration. We normalize the mass of Home households to one and set the mass of Foreign households to match the relative size of Russia's labor force. The data indicates that the relative size of Russian labor force is approximately 20% of the combination of EU27, the UK, and the US.[18] Therefore, we set χ_F to 0.20.

Following Kim et al. (2021), we set the cost share of gas to $\alpha = 0.05$ and we set a low elasticity of substitution between gas and labor, ϵ, to 0.3. The latter is in line with the suggested estimates in Bachmann et al. (2022). We set the discount factor and firm exit rates to $\beta = 0.99$ and $\delta = 0.025$, respectively. The former implies a steady-state real interest rate of 4% per annum. The latter is set using Ghironi and Melitz (2005), among others in this literature. The disutility parameter from working, κ, is set to 0.75 to normalize the consumption goods sector labor supply to one. We follow the sectoral labor mobility parameter of Horvath (2000).[19] The scale parameter for the costs of adjusting bond/share holdings, η, is 0.0025, which is sufficient to induce stationarity. This value pins down the non-stochastic steady state. Again, following Ghironi and Melitz (2005), we set the elasticity of substitution between varieties, θ, to 3.8. As in Melitz (2003), we assume that firm-level productivity z is drawn from a Pareto distribution with lower bound z_{min} and shape parameter k. We set k to 3.4 and normalize z_{min} and f_E to 1. Hence, the Pareto shape parameter of (domestic) sales distribution is 1.21. Our choice of calibration implies that the top 1% productive exporters constitute 71% of total exports when 35% of firms export. According to Mayer and Ottaviano (2008), the share of top 1% exporters in total exports is 81%, 73%, 69%, 59%, 73%, and 81% in Germany, France, the UK, Italy, Belgium, and Norway, respectively. Our model generates values that are within the range of their estimates.

We set the fixed cost of exporting to be $f_X = 0.0045$, which yields that the percent of Home producers that export their good to RoW is 34 in the initial steady state. Because of the small market size of Foreign, only 2% of Home firms export to Foreign. The percent of Foreign firms export to Home is 9 in the initial steady state.

As previously highlighted, an important dimension of our model is the asymmetry between the three regions. We calibrate the consumption goods sector productivity, gas endowment, and trade cost of each region to reflect their respective economic sizes and export patterns before the Russia sanctions, as shown in the Panel B of Table 2.

Without loss of generality, we normalize Foreign productivity and Home natural gas endowments to one; $Z_t^F = 1$ and $G_N^H = G_N^R = 1$. Home and RoW are gas importers and Foreign is a gas exporter. We set Foreign gas endowment, G_N^F, to 1.2, and Home and RoW aggregate productivity of consumption good production, $Z_t^H = Z_t^R$, to 1.2. In the gas sector, Foreign has a comparative advantage, while Home and

[18] According to the World Bank's World Development Indicators, the 15-64 aged population of Russia is the 71% of the aggregates of EU27, the UK, and the US in 2020 and 2021. Labor force participation rates in total (% of total population ages 15+, modeled ILO estimate) are 61.9 (62.2), 56.6 (56.9), 62.8 (62.1), and 61.3 (62.2) in Russia, EU27, the UK, and the US, respectively, in 2020 (2021).

[19] See Cantelmo and Melina (2023) for more information on our parameter selection and the sectoral mobility literature.

Table 1 A priori parameters

Parameter	Notation	Value	Target
Mass of Foreign households	χ_F	0.2	Russian (relative) labor force size
Disutility from working	κ	0.75	Normalize $L_0^H = 1$
Sectoral labor mobility	ϱ	1	Labor mobility in the US
Discount factor	β	0.99	4% annual interest rate
Firm exit probability	δ	0.025	10% annual firm exit rate
Elasticity of substitution across products	θ	3.8	Markups
Pareto distribution			
Lower bound	z_{min}	1	Normalized
Shape	k	3.4	Firm domestic sales distribution shape
Production function (consumption goods sector)			
Gas share	α	0.05	Energy factor cost share
Elasticity of substitution (gas & labor)	ϵ	0.3	Elasticity b/w energy & other factors
Productivity (gas sector)			
Sunk entry costs	$f_{E,t}$	1	Normalized
Fixed Export costs	$f_{X,t}$	0.0045	Fraction of exporters in US manufacturers

RoW have a comparative advantage in the consumption goods sector.[20] In our calibration, Home's GDP is approximately ten times larger than Foreign's GDP in the initial steady state, without any sanctions. According to the World Bank's World Development Indicators–DataBank, this value is similar to the ratio of combined GDPs at purchasing power parity (PPP) of EU27, the UK, and the US to Russian GDP at PPP in 2020 and 2021. There is a small discrepancy between the model implied steady state and the data between the combined GDPs of EU27, the UK, and the US (indicative for Home) versus China, India, and Turkey (indicative for RoW). In the data, the former is 1.2 times larger than the latter, whereas, in the model, these regions are equal in size.

The calibration of iceberg trade costs enables us to match the export-to-GDP ratios of the steady state of the model to data. We set the iceberg trade costs to 30%, i.e., $\tau^H_{F,t} = \tau^R_{F,t} = \tau_{G,t} = 1.3$. The calibration of these parameters is within the estimates that are widely used in the literature.[21] We set lower trade costs between Home and RoW, i.e., $\tau^H_R = \tau^R_H = 1.2$, in order to match the model's Home exports-to-GDP

[20] In addition to comparative advantages from endowments and productivities, Home and RoW tend to be concentrated in the consumption goods sector because of their large market sizes. According to the home market effects of Krugman (1980), countries with large market sizes are more appealing as a firm location for producing differentiated goods and economies of scale. For further recent discussion on the home market effects of product differentiation, trade costs, and economies of scale, see Hanson and Xiang (2004); Bak et al. (2022), and many others.

[21] Anderson and van Wincoop (2004) summarize the literature on the estimation of tariff equivalent trade costs (i.e., iceberg trade costs) and our values are within the range provided in their paper as well, i.e., between 10 and 40%.

Table 2 Parameters from (Initial) steady state matching: GDP and trade

Panel A. Calibrated Parameter	Notation	Value
Natural gas endowments (gas sector productivity)		
Home	$G^H_{N,t}$	1.0
RoW	$G^R_{N,t}$	$G^H_{N,t}$
Foreign	$G^F_{N,t}$	1.2
Productivity (consumption goods sector)		
Home	Z^H_t	1.2
RoW	Z^R_t	Z^H_t
Foreign	Z^F_t	1.0
Export (iceberg) costs (consumption goods)		
between Home & RoW	$\tau^H_R = \tau^R_H$	1.2
from Home & RoW to Foreign	$\tau^H_F = \tau^R_F$	1.3
from Foreign to Home & RoW	$\tau^F_H = \tau^F_R$	3.0
Gas import (iceberg) costs	$\tau_{G,t}$	1.3
Panel B. Target	Data	Model
GDP ratio of Home to Foreign	10.09%	10.30%
Home exports/GDP	26.7%	29.6%
Foreign exports/GDP	28.2%	34.6%
Foreign gas export share in total exports	57.2%	64.5%

Notes: In Panel B's second column (data), we collect Russia, European Union, the UK, and the US data from the World Bank's World Development Indicators–DataBank. The GDP ratio of Foreign to Home is calculated by dividing the sum of the GDPs of the EU27, the UK, and the US by the GDP of Russia (PPP, current international $). Home and Foreign export to GDP ratios are from the USD nominal values of annual exports and GDP of the three countries (EU27, UK, and US) and Russia, respectively. We calculate the Foreign gas export share by dividing Russia's monthly mineral fuel exports by total goods exports, using data from Zsolt Darvas, Luca Lery Moffat, Catarina Martins, and Conor McCaffrey's Russian Foreign Trade Tracker (17 May 2023). All numbers are the average of 2020 and 2021. The third column reports the model values at the initial state without sanctions

ratio and the fraction of Home exporters to those of data.[22] Finally, the cost of trade for Foreign exporters is relatively higher in our calibration, i.e., $\tau^F_{H,t} = \tau^R_{H,t} = 3.0$. These values are higher with respect to trade costs between Home and RoW, but Foreign being subject to higher trade costs helps to match the Russian low exports of non-mineral fuel goods to our model's steady state, specifically, exports-to-GDP ratio and the share of gas exports in total exports. See Table 2 for the related data.

The fact that Russia is a net creditor on global markets is a crucial characteristic of the Russian economy. Therefore, to set the initial steady-state net foreign asset holdings of Foreign, we target the value of Russian net foreign position (NFA) and

[22] Setting low trade costs between Home and RoW is not an unusual calibration. The EU is Turkey's largest trade partner, the US is India's largest trade partner, and the EU and the US are top two largest trade partners of China in 2021.

Table 3 Parameters from (Initial) steady state matching: external assets

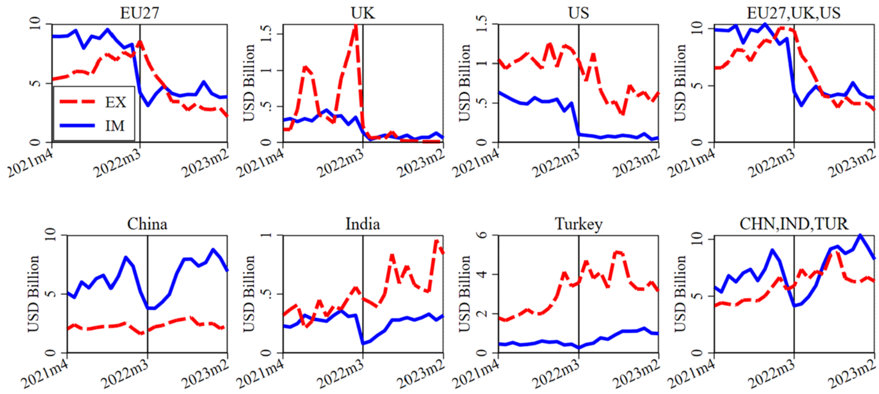
Panel A. Calibrated Parameter	Notation	Value
Foreign initial bond holdings		
Home bond	B_F^H	$1/\chi_F$
Foreign bond	B_F^F	$-1.3/\chi_F$
RoW bond	B_F^R	B_F^H
Home initial bond holdings		
Home bond	B_H^H	$-\chi_F B_F^H$
Foreign bond	B_H^F	$-\chi_F B_F^F/2$
RoW bond	B_H^R	0
RoW initial bond holdings		
Home bond	B_R^H	B_H^R
Foreign bond	B_R^F	B_H^F
RoW bond	B_R^R	B_H^H
Panel B. Target	Data	Model
Foreign's NFA/GDP	31.0%	29.4%
Foreign's External Assets/GDP	99.1%	98.8%

In the second column of Panel B, we collect Russia's annual external assets and net foreign assets (NFA) data for 2020 and 2021 from the International Monetary Fund's International Investment Position database. Russia's annually nominal GDP USD values for 2020 and 2021 are taken from the World Bank's World Development Indicators–DataBank. We compute the ratios for each year and average them. The third column reports the model values at the initial state without sanctions

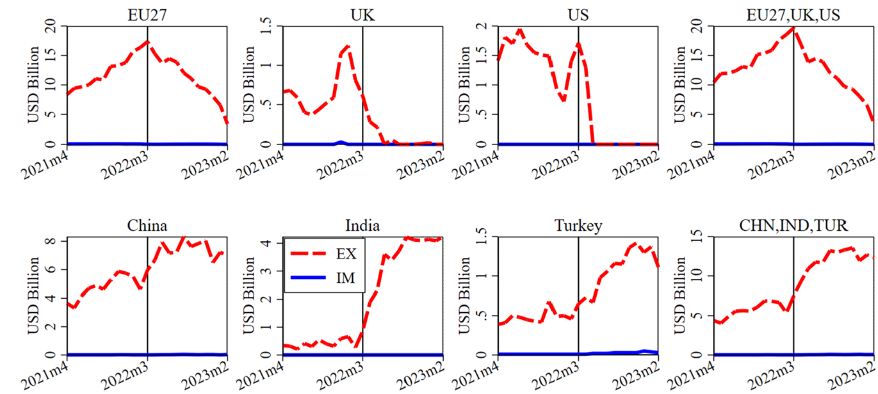
external assets.[23] In the data, the former is approximately 30% of Russian GDP in 2021, and the latter is approximately equal to the Russian GDP in 2021. Table 3 summarizes our calibration of steady-state asset holdings.

Parameters related with sanctions We end this section by explaining the calibration related with sanctions. We set the sanction productivity limit for consumption good trade to match the observed changes in Russia's trade flows of goods (excluding mineral fuels) after the war that began in February 2022. (See Fig. 2 for the data.) The implied sanction productivity limit ($\bar{z}_S$) is $0.005^{-1/k}$, which translates into exclusion of the top 0.5% firms from export markets. Regarding financial and gas sanctions, our choices are suggestive. We set the percentage of Foreign households that are excluded from international bond trade after financial sanctions, λ, to 0.9. For gas sanctions, we consider a complete stop of gas imports from Foreign

[23] According to the International Monetary Fund's International Investment Position database, Russia's foreign assets are 1569 billion USD in 2020 and 1652 billion USD in 2021. In 2020 and 2021, its net foreign asset positions are 517 and 485 billion USD, respectively.



(a) Goods Other than Mineral Fuels



(b) Mineral Fuels

Fig. 2 Russia's exports and imports of goods. *Notes*: The figure plots Russia's monthly exports of goods to the selected countries from April 2021 to February 2023, as well as its monthly imports of these goods from those countries (blue solid lines and red dashed lines, respectively). Date source: Zsolt Darvas, Luca Lery Moffat, Catarina Martins, and Conor McCaffrey's Russian Foreign Trade Tracker (17 May 2023). (Color figure online)

($\overline{G}^{S}_{H,t} = 0$), which is in line with the data of the UK and the US mineral fuel imports from Russia in Fig. 2.[24]

Figure 2 illustrates the movement in Russia's exports (red dashed lines) and imports (blue solid lines) of goods excluding mineral fuels after the sanctions (in USD). Following the sanctions, Russia's non-mineral exports and imports with

[24] The EU27 mineral fuel imports from Russia did not fall to zero after the war, although there has a substantial decrease in these imports.

the EU, the UK, and the US decreased by 66% and 55%, respectively (in terms of year-to-year growths on average for December 2022-February 2023). Our choice of the sanction productivity limit ($\bar{z}_S$) is to match these values. In our calibrated model, when Home applies all of the sanctions without RoW's participation, the new steady-state values of Foreign exports and imports with Home are 62% and 64% lower than the initial values in terms of Home currency.[25] The corresponding sanction cut-off, $\bar{z}_S$, translates into the exclusion of the top 0.5% firms from export markets.

In contrast, Russia raises its non-mineral fuel exports and imports (USD) with China, India, and Turkey by 7% and 23%, respectively, in terms of year-to-year growth rates on average during December 2022–February 2023 (Fig. 2's subfigure a). Despite not being targeted, our model is successful in generating similar behavior, i.e., an increase in imports of the sanctioned economy from a third region in response to uncoordinated sanctions. Our model generates an increase of 23% (Home currency value) in Foreign imports from RoW after the uncoordinated sanctions imposed by Home. Following these sanctions, Foreign economy's imports from RoW and domestic productions of consumption goods increase to replace the sanctioned Home products. Increased domestic demand in Foreign implies reduction in exports to RoW. Furthermore, Foreign raises labor employment in firm entry and production to extensively and intensively boost final consumption good production.

In Fig. 2, the red dashed lines of the subfigure (b) illustrate that sanctions have reduced UK and US imports of mineral fuels from Russia to near-zero since the war. While European economies continue to import mineral fuels from Russia, their value has also steadily declined. China, India, and Turkey, on the other hand, increased their imports of mineral fuels from Russia. Specifically, Russia's mineral fuel exports (in USD) to the EU27, the UK, and the US fell by 65% year-on-year, but its mineral fuel exports (in USD) to China, India, and Turkey rose by 99%. We replicate these numbers in calibration of gas sanctions in our model. Our model generates that gas exports from Foreign to Home and RoW drop by –100% and 64%, respectively, in terms of Home currency. Note that our model does not allow Home or RoW to export gas because all six countries have zero or minimal exports of mineral fuels to Russia, as shown in the data.

4 The Impact of Sanctions

We solve our model numerically to investigate the short-, medium-, and long-term effects of sanctions. To be precise, at $t = 0$, the model is at the no-sanction equilibrium. Sanctions are introduced in $t = 1$ and the model converges to a new equilibrium, which we call the sanction equilibrium.[26] In the first subsection, we consider that Home sanctions Foreign and the RoW does not join the sanctions. Later in the

[25] Note that in Fig. 6 plots exports in terms of destination currency (consumption good unit).

[26] Using Dynare's nonlinear equation solver with line search, we solve the model as a nonlinear, forward-looking, deterministic system.

second subsection, we present and discuss dynamics when Home and RoW impose sanctions against Foreign together.

4.1 Types of Sanctions

We study three different types of sanctions: financial sanctions, trade sanctions on consumption goods, and trade sanctions on gas. All of the sanctions generate a fall in Home and RoW consumption and GDP, although the fall is not as large as in Foreign. The impact of consumption good export sanctions generates the most pronounced changes. We also find that real exchange rate movements are shaped by sectoral reallocations, but do not indicate effectiveness of sanctions.

Consumption good trade sanctions Figure 3 shows the transitional dynamics from the no-sanction equilibrium to the sanction equilibrium of several macroeconomic and trade variables after the introduction of consumption good trade sanctions at $t = 1$. Green dashed lines with triangles represent simulations in which the top 0.5% of productive Home and RoW firms stop exporting to Foreign markets after the introduction of export sanctions (labeled EXS). Blue dashed lines with circles indicate the simulations in which the top 0.5% of productive Foreign firms stop exporting to both Home and RoW (labeled IMS). Simulations with simultaneous import and export sanctions are shown with red solid lines, labeled trade sanctions (TS).

In response to import sanctions (IMS), less productive Foreign producers begin to export, indicating a decline in the least productive Foreign exporter's cutoff productivity level. The decline in the average productivity of Foreign exporters translate into more expensive Foreign consumption good exports. Increase in the Home consumption price index, due to more expensive imports from Foreign, generates an appreciation of Home real exchange rate as shown in Fig. 3. The drop in the supply of exported consumption goods of Foreign implies lower demand for labor in the consumption good sector. In turn, the number of producers in Foreign decreases. Resources in the Foreign economy is reallocated towards the gas sector to compensate for the loss of export revenues. Therefore the labor demand in Foreign gas sector goes up. The increase in the gas production of Foreign reduces the price of gas in Home and RoW.

In response to export sanctions (EXS), Foreign economy reallocates its resources from the gas sector to the consumption good sector. The resource allocation works in the opposite direction when compared with import sanctions (IMS). Foreign economy rebalances itself to produce more consumption goods in compensation to loss of imports from Home and RoW. In returns, labor demand in Foreign consumption good sector rises and entry in the consumption sector increases. The decrease in the labor supply towards gas production in Foreign implies an increase in the price of gas in Home and RoW due to lower global supply of gas. Foreign starts to import more from lower productivity firms in Home and RoW, which translates into a higher consumption price index. The latter generates the depreciation of Home real exchange rate.

When we focus on the effects of export and import sanctions on GDP and per capita consumption, we observe that Foreign suffers more than Home and RoW

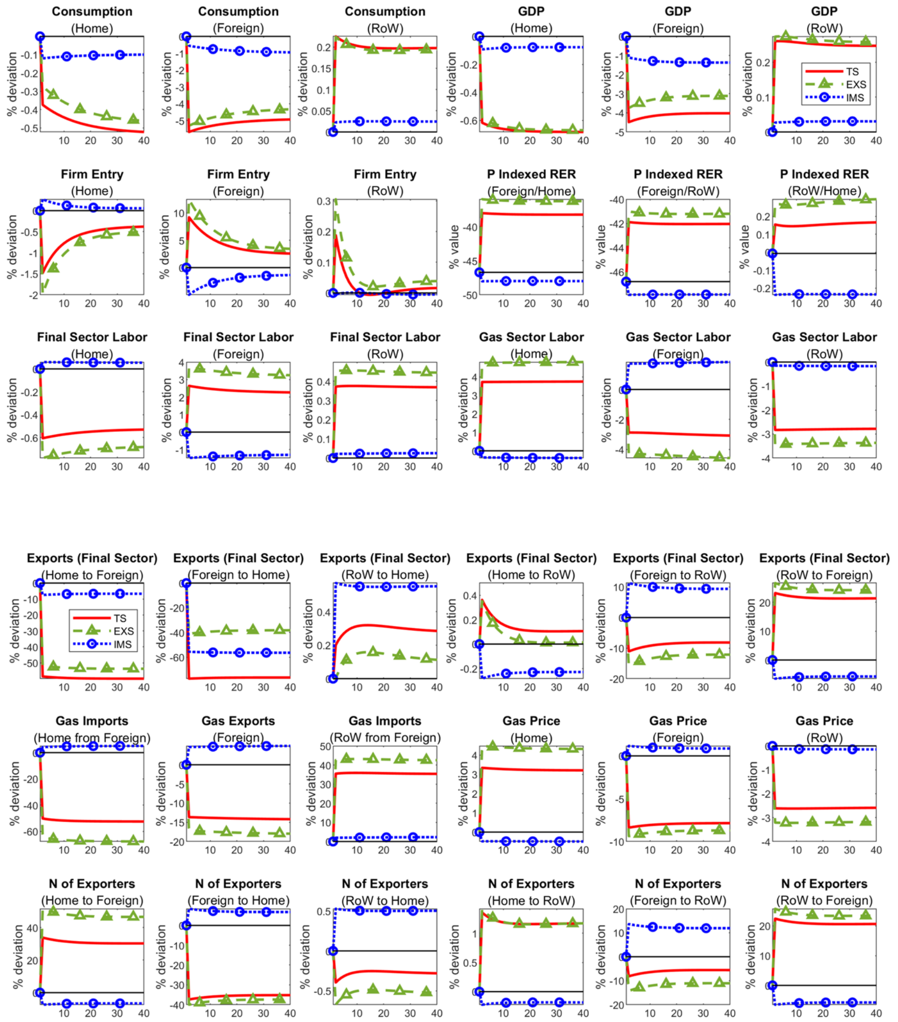


Fig. 3 Transitional dynamics under trade sanctions. *Notes*: The red solid lines plot the model transition dynamics when trade sanctions (TS, export and import sanctions) are imposed at $t = 1$. The green dashed lines with triangles plots the model transition dynamics when export sanctions (EXS) are imposed at $t = 1$. The blue dashed lines with circles plots the model transition dynamics when import sanctions (IMS) are imposed at $t = 1$. All deviations except for the figures titled P indexed RER are in units of percent deviation from the initial steady state without sanctions ($t = 0$). The figures of ratio, titled P indexed RER, are in units of percent deviation from one, i.e., $100 \times (x - 1)$. See Appendix Fig. 9 for the other variables' responses. (Color figure online)

combined in the short-, medium- and long-term.[27] Moreover, export sanctions (EXS) always generate a more pronounced drop in per capital consumption and GDP in

[27] It is important to note that Home and RoW combined is approximately 10 times larger than Foreign in size and this result is valid both for aggregate and per capita consumption dynamics.

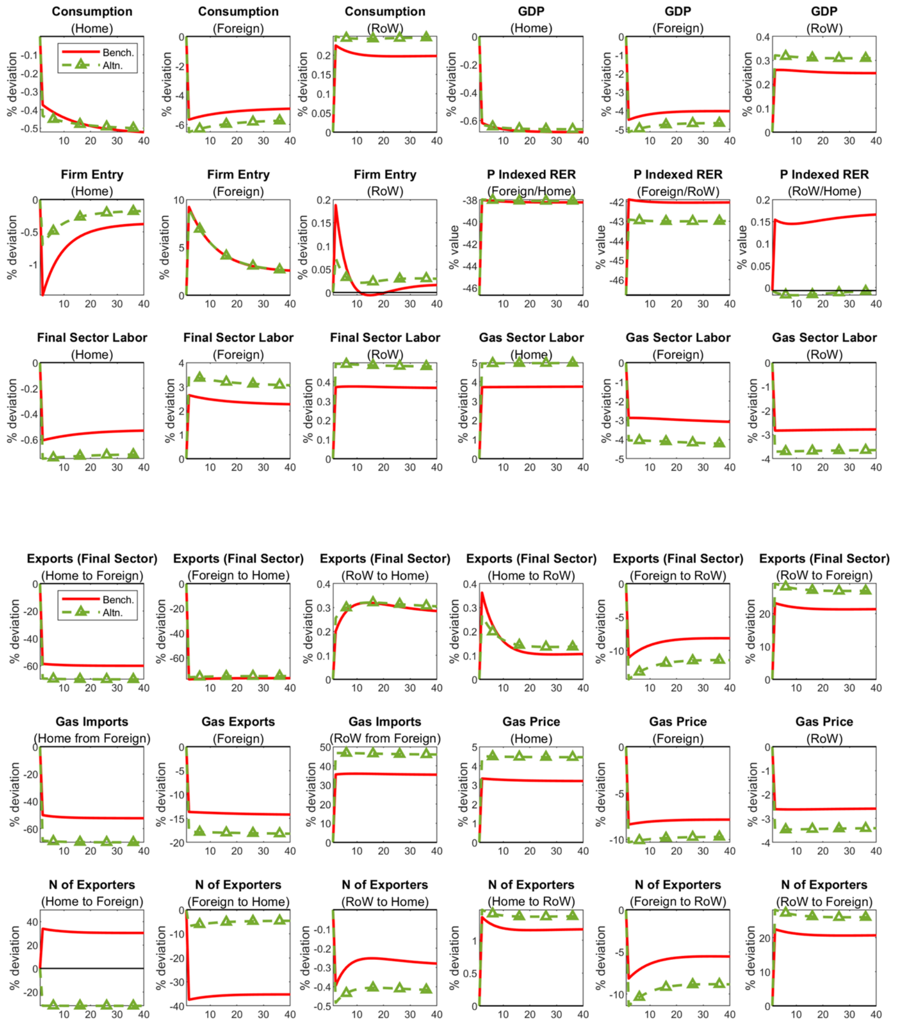


Fig. 4 Transitional dynamics under trade sanctions with invariant exporter productivity cutoffs. *Notes*: The red solid lines plot transitional dynamics in the benchmark model under combined trade sanctions. The green dashed lines with triangles plot transitional dynamics in the model with invariant exporter entry under combined trade sanctions. Sanctions are imposed at $t = 1$. All deviations except for the figures titled P indexed RER are in units of percent deviation from the initial steady state without sanctions ($t = 0$). The figures of ratio, titled P indexed RER, are in units of percent deviation from one, i.e., $100 \times (x - 1)$. See Appendix Fig. 10 for the other variables' responses. (Color figure online)

comparison with import sanctions (IMS). The asymmetric production structure in between the regions is at the heart of our results. Home and RoW has comparative advantage in producing consumption goods, and therefore, they rely on imported goods less than Foreign households. Losing the imports from Home and RoW forces the Foreign to move resources to its less advantageous sector and implies a loss of advantage in producing usable gas. This inefficient resource allocation squeezes the size of the Foreign economy. When we look at the combined effect of import and export sanctions, we also observe that the effects of export sanctions dominate due to the above reason (for instance, Foreign economy experiences an appreciation of real exchange rate and terms of labor under combined trade sanctions).

We conduct an additional simulation in Fig. 4 to understand the importance of entry into export markets by lower productivity consumption good producers after the sanctions. To the best of our knowledge, there is no firm-level data for Russian exporters for the period after sanctions and this exercise serves the purpose of understanding the impact of entry into export markets in assessing the overall impact of trade sanctions. The solid red lines indicate dynamics of the combined trade sanctions as before (TS in Fig. 3). The green dashed lines with triangles indicate dynamics when there is no changes in the export productivity cutoff of firms following trade sanctions. We label the former “Benchmark" and the latter “Alternative." We turn off the entry into export markets by fixing Home and RoW exporter productivity cutoff (lower bound) at the initial steady-state level. Thus, only Home and RoW producers with productivity between $\underline{z}^H_{F,0}$ and $\overline{z}_S$ export after the sanctions (i.e., $\underline{z}^i_{F,t} = \underline{z}^i_{F,0}$ and $\overline{z}^i_{F,t} = \overline{z}_S$ for $i = H, R$ and $t \geq 1$). Shutting down the movements in the lower bound of the export margin has no qualitative impact on our simulations. The average exporter productivity still drops when the most productive producers exit from the export market due to sanctions. Therefore, the responses of the prices and the exchange rate move in the same direction with the previous exercise. However, we see a significant amplification of the responses when we turn off entry into export markets by lower productivity producers. The reason is that the collapse in aggregate trade becomes more significant when we rule out the entry margins into export market by lower productivity firms. This trade collapse, in return, is reflected into other aggregates such as Foreign consumption and GDP. The only variable with a milder response under invariant exporter entry is Home GDP. The response is caused by the significant increase of wages in the gas sector. A more significant trade collapse in Foreign generates an amplified resource reallocation towards consumption good sector, which diminishes the gas exports of Foreign more significantly. Therefore, Home and RoW gas sectors demand more labor to produce their own gas, which translates into higher wages and a lower drop in GDP.

Gas sanctions Blue dashed lines with circles in Fig. 5 plot the transitional dynamics of several variables under gas sanctions (GS). Halting gas imports from Foreign implies a big negative demand shock to Foreign usable gas producers. Foreign gas sector gets smaller and reduces its labor demand. Labor supply shifts towards consumption good production sector. Foreign economy rebalances itself towards consumption goods production and generating more export revenue in this sector to compensate for the loss of export revenue in the gas production sector. The rebalancing economy facilitates higher entry in consumption good production sector and lower exporter entry cutoff. Less productive producers entering into Foreign consumption good export market implies a decrease in the average productivity of Foreign exporters, which translates into a higher consumption price index in Home and RoW. Therefore, Foreign real exchange rate depreciates against Home and RoW.

The fall in demand for Foreign gas induces a drop in gas production in Foreign and a subsequent jump in gas prices in Home and RoW. The gas price in Home and RoW economies rises because consumption good producing firms demand more

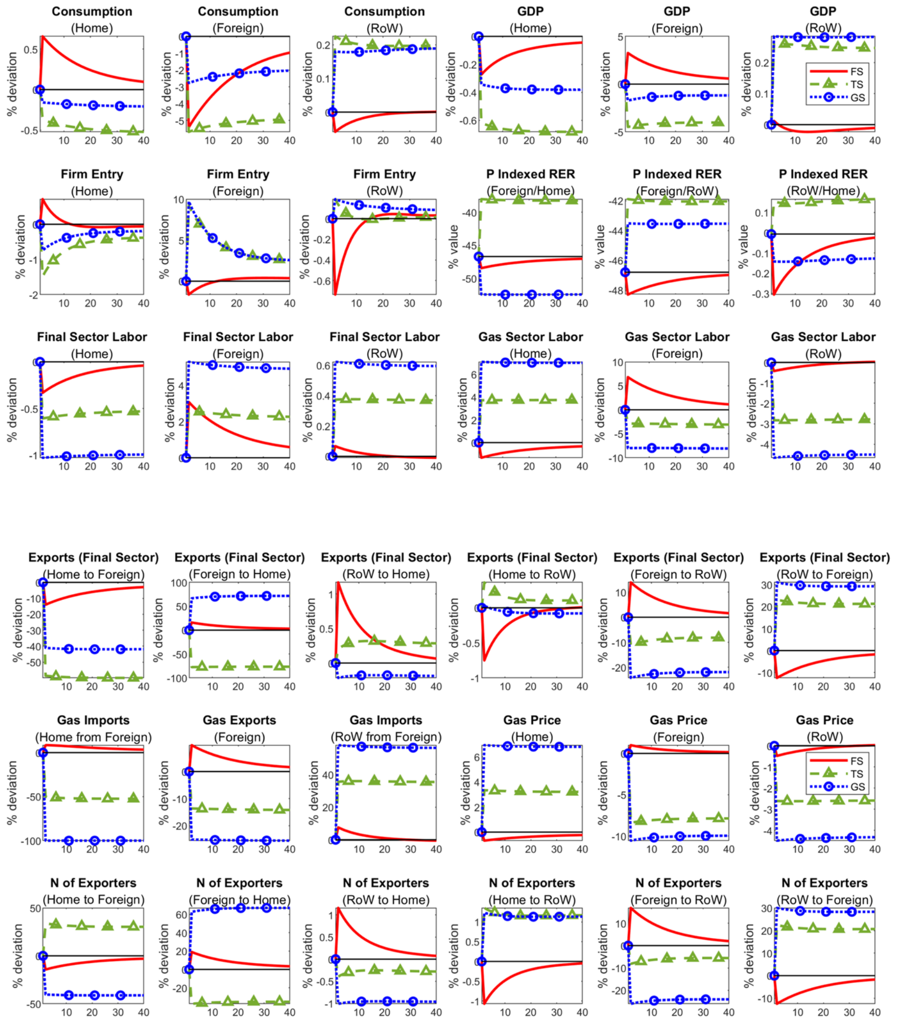


Fig. 5 Transitional dynamics under each sanction. *Notes*: Red solid lines, green dashed lines with triangles, and blue dashed lines with circles plot the transitional dynamics under financial (FS), consumption good sector trade (TS), and gas sanctions (GS), respectively. Sanctions are imposed at $t = 1$. All deviations except for the figures titled P indexed RER are in units of percent deviation from the initial steady state without sanctions ($t = 0$). The figures of ratio, titled P indexed RER, are in units of percent deviation from one, i.e., $100 \times (x - 1)$. See Appendix Fig. 11 for the other variables' responses. (Color figure online)

domestic gas to replace the lost imported gas. A high gas price reduces the profitability of a firm, which discourages new entrants into the market and reduces the total number of producers in Home. As a result, Home households increase labor supply to gas production and decrease labor supply to consumption good production.

Financial sanctions Red solid lines in Fig. 5 represent the transitional dynamics under financial sanctions (FS), specifically when 90% of Foreign households are excluded from participating in international transactions involving Home-issued bonds. In the initial equilibrium without sanctions, all Foreign households have a positive net foreign asset position. In the sanctioned equilibrium, while 90% of Foreign households have a zero net foreign asset position, a positive position is retained by the remaining 10% of households.

Our initial observation indicates that, in response to financial sanctions, Foreign consumption experiences a sharp short-term decline, which is more substantial than its long-term reduction. This behavior is primarily driven by wealth effects. When sanctions take effect, Foreign loses its holdings of Home bonds, leading to a negative transitory income shock with limited opportunities for savings through Home bonds. Consequently, Foreign's consumption demand decreases, including its demand for imports from both Home and RoW. The reduction in Foreign imports paves the way for a smaller number of Home and RoW exporters to access the Foreign market, raising their export thresholds, thereby lowering the average export price and resulting in a depreciation of the Foreign real exchange rate.

In response to the loss of Home bonds and limited saving options in Foreign, households increase their labor supply in both the consumption goods and gas sectors to compensate for the loss of income from Home assets. This increase in labor supply leads to lower wages, contributing to a depreciation of the Foreign real exchange rate.

Finally, in the long run, we observe that financial sanctions have a milder impact compared to other types of sanctions. This is because only a fraction of the Foreign population is subject to financial sanctions, allowing the sanctioned fraction to mitigate the effects by engaging in transactions with those in Foreign who still have access to international financial markets.

4.2 Combined Sanctions With(out) International Coordination

To account for the total impact of sanctions imposed on Russia, we study the impact of combined sanctions. We particularly focus on the changes to the impact, when sanctions are uncoordinated (only Home imposing sanctions) or coordinated (Home and RoW imposing sanctions together). Although the EU, the UK, and the US placed a wide range of sanctions against Russia, China, India, and Turkey did not follow.

We conduct simulations where Home imposes all the sanctions mentioned in the previous subsection on Foreign, but both RoW and Home impose sanctions on Foreign together. We label this scenario as "coordinated sanctions." Then, we compare this outcome with the case in which RoW does not join in imposing sanctions, which we label as "uncoordinated sanctions."

Figure 6 presents the transition dynamics between the no-sanction and the sanction steady states. Green dashed lines with triangles indicate dynamics when only Home sanctions Foreign (called uncoordinated sanctions), whereas red solid lines indicate dynamics when both Home and RoW sanction Foreign (called coordinated sanctions).

Under uncoordinated combined sanctions, Home and Foreign consumption fall while RoW consumption increases. RoW GDP increases in response to uncoordinated sanctions because of the substitution effects. RoW reallocates its economy towards consumption good production to match the additional demand coming from Foreign. Moreover, RoW expands exports to Foreign while increasing its gas imports from Foreign. It is important to note that Foreign still suffers from Home's sanctions even though RoW does not join sanctioning. The sanctioned imports from Home are partially substituted with RoW imports, but exporters in RoW have to pay fixed trade costs to be able to enter the export market. It is easier for Foreign to move factors of production to its relatively disadvantageous consumption good production sector. Inefficient resource allocation (in comparison with the initial steady state) in Foreign still makes sanctions bite.

According to the model, Foreign's final consumption good imports from RoW increase by 23% (Home currency value) after the Home imposes combined sanctions without RoW coordination. Following the imposition of sanctions, the Foreign economy's access to Home produced goods has been constrained, leading to an increase in imports from RoW and an increase in final consumption goods production to replace Home products. Increased foreign demand for its domestically produced goods causes Foreign firms to sell domestically rather than export to RoW. Furthermore, Foreign raises labor employment in firm entry and production to extensively and intensively boost final consumption good production. Wages, prices, and currency grow as a result, causing them to lose competitiveness in the RoW consumption goods market. Therefore, Foreign firms considerably reduce exports to RoW. Because of Foreign (and also RoW) currency appreciation, the value of exports from Foreign to RoW in terms of Home currency drops by just 4 percentage points, contradicting the data's modest increase of Russia's exports to China, India, and Turkey. Wages, prices, and currency grow as a result, causing them to lose competitiveness in the RoW consumption goods market. Therefore, Foreign experiences trade deficit with RoW.[28] As shown in the subfigure (a) of Fig. 2, Russia's imports from Turkey, China, and India are rising more than its exports to those countries.

Coordination of sanctions helps Home to share the burden of sanctions with RoW while amplifying the impact of sanctions against Foreign. The loss in Foreign consumption and GDP, in both short and long term, are almost doubled. However, RoW consumption and GDP suffers from the sanctions as in Home. Under coordinated sanctions, RoW rebalances its economy towards gas production. An important question is whether the additional cost on RoW is greater than the additional impact of coordinated sanctions against Foreign. To provide an answer to this question, we focus on welfare in the next section.

5 Welfare Analysis

We calculate welfare as the lifetime utility from consumption and disutility from labor. We incorporate the impact of sanctions after they are imposed in the first period, i.e., $t = 1$, include transition dynamics until $t = 201$, and the terminal impact. Simulating our model for 200 periods is enough for the economy to reach its new steady state. In particular, we compute the lifetime utility to measure the welfare with sanctions as follows.

[28] Foreign currency appreciation dampens this channel.

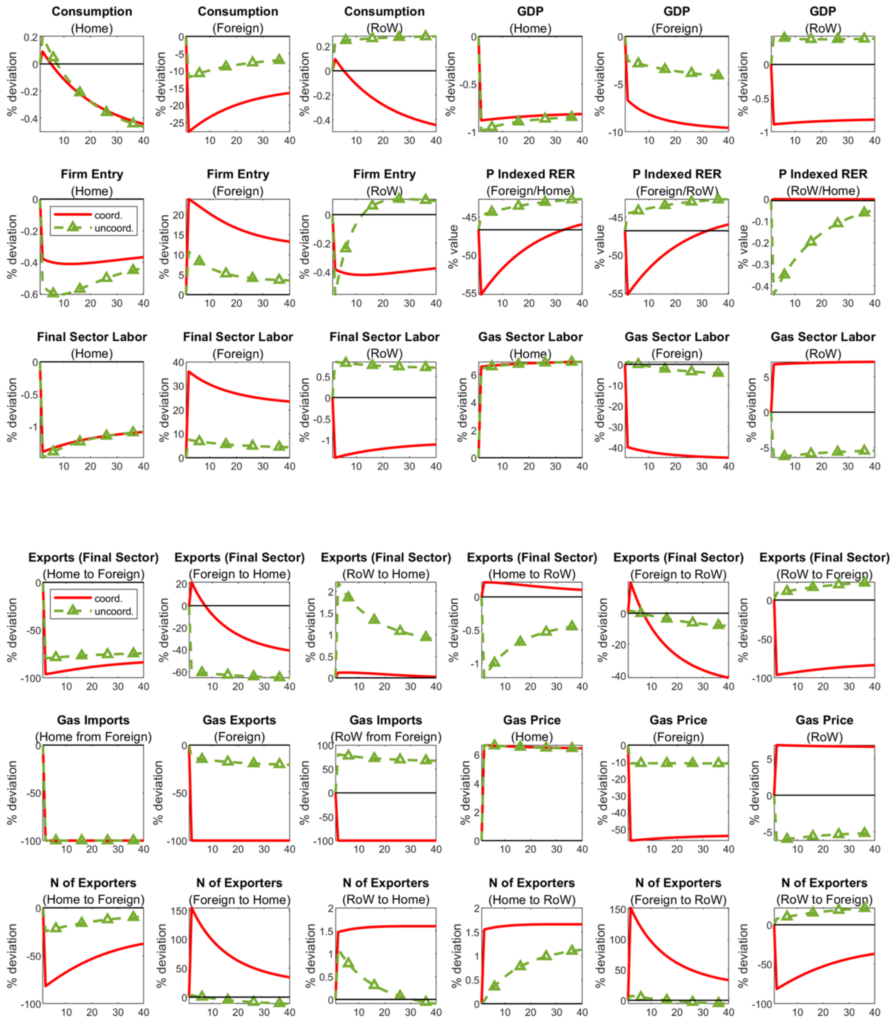


Fig. 6 Transition dynamics after the (un-)coordinated Sanctions. *Notes*: The red solid lines (labeled coord.) plot the model transition dynamics when all sanctions are imposed by Home and RoW at $t = 1$. The green dashed lines (labeled uncoord.) with triangles plot the model transition dynamics when all sanctions are imposed by Home at $t = 1$, while the RoW does not participate in sanctions. All deviations except for the figures titled P indexed RER are in units of percent deviation from the initial steady state without sanctions ($t = 0$). The figures of ratio, titled P indexed RER, are in units of percent deviation from one, i.e., $100 \times (x - 1)$. See Appendix Fig. 12 for the other variables' responses. (Color figure online)

$$
\begin{aligned}
\mathcal{W}_i^{\text{Sanction}} = & \sum_{t=0}^{200} \beta^t \left\{ \ln C_{i,t} - \frac{\kappa}{2} \left[(L_t^i)^{\frac{1+\varrho}{\varrho}} + (L_{G,t}^i)^{\frac{1+\varrho}{\varrho}} \right]^{2\frac{\varrho}{1+\varrho}} \right\} \\
& + \frac{\beta^{201}}{1-\beta} \left\{ \ln C_{i,201} - \frac{\kappa}{2} \left[(L_{201}^i)^{\frac{1+\varrho}{\varrho}} + (L_{G,201}^i)^{\frac{1+\varrho}{\varrho}} \right]^{2\frac{\varrho}{1+\varrho}} \right\}.
\end{aligned}
\tag{30}
$$

Table 4 Change in welfare and GDP after sanctions

Type of sanctions	International coordination	% Welfare Loss (Δ) Home	Foreign	RoW	% Change of GDP per capita Home	Foreign	RoW
Panel A. Individual sanctions							
Financial	Yes	0.69	4.32	0.69	– 0.03	0.55	– 0.02
	No	0.69	2.25	0.89	– 0.03	0.27	0.00
Gas	Yes	1.18	5.95	1.18	– 0.42	– 3.05	– 0.43
	No	1.14	2.05	0.68	– 0.38	– 1.21	0.28
C-good export	Yes	1.21	8.74	1.21	– 0.52	– 5.98	– 0.52
	No	1.35	4.60	0.68	– 0.67	– 3.15	0.26
C-good import	Yes	0.97	2.14	0.97	– 0.05	– 2.86	– 0.05
	No	0.99	1.16	0.87	– 0.08	– 1.35	0.03
C-good trade	Yes	1.25	9.89	1.26	– 0.52	– 7.63	– 0.54
	No	1.40	5.19	0.68	– 0.68	– 4.05	0.25
Panel B. Sanction combinations							
Gas + Financial	Yes	0.98	10.42	0.98	– 0.46	– 2.28	– 0.46
	No	0.94	4.32	0.68	– 0.41	– 0.81	0.28
C-good trade + Financial	Yes	1.05	13.32	1.06	– 0.53	– 7.41	– 0.55
	No	1.19	6.96	0.69	– 0.70	– 3.88	0.24
Gas + C-good trade + Financial	Yes	1.27	17.85	1.27	– 0.80	– 9.89	– 0.81
	No	1.27	7.87	0.59	– 0.82	– 4.52	0.39
Panel C. Sanction combinations under the model version with invariant export cutoff							
C-good trade + Financial	Yes	0.98	15.58	0.99	– 0.40	– 9.66	– 0.43
	No	1.18	7.59	0.65	– 0.67	– 4.53	0.31
Gas + C-good trade + Financial	Yes	1.29	17.42	1.30	– 0.80	– 9.80	– 0.80
	No	1.26	8.05	0.58	– 0.79	– 4.72	0.40

The first three columns present the welfare (lifetime utility) loss of sanctions in terms of per-capita consumption defined in Eq. (33). The last columns present the percent change of GDP per-capita from the initial period GDP per-capita ($t = 0$) to the terminal period GDP per-capita ($t = 201$). The Foreign welfare losses and GDP per-capita changes are calculated from the weighted sum of financially sanctioned and unsanctioned foreign households. The changes in welfare and GDP are calculated in Panel C by preventing less productive firms entering the export market in response to trade sanctions

When there is no sanction, the welfare is

$$\mathcal{W}_i^{\text{NoSanction}} = \frac{1}{1-\beta}\left\{\ln C_{i,0} - \frac{\kappa}{2}\left[(L_0^i)^{\frac{1+\varrho}{\varrho}} + (L_{G,0}^i)^{\frac{1+\varrho}{\varrho}}\right]^{2\frac{\varrho}{1+\varrho}}\right\}, \tag{31}$$

where $C_{i,0}$, L_0^i, and $L_{G,0}^i$ represent the consumption, consumption good labor supply, and gas sector labor supply for country i without sanctions. Now, we calculate the welfare loss in terms of consumption equivalents.

$$\mathcal{W}_i^{\text{Sanction}} = \frac{1}{1-\beta}\left\{\ln[(1-\Delta_i)C_{i,0}] - \frac{\kappa}{2}\left[(L_0^i)^{\frac{1+\varrho}{\varrho}} + (L_{G,0}^i)^{\frac{1+\varrho}{\varrho}}\right]^{2\frac{\varrho}{1+\varrho}}\right\}, \tag{32}$$

where Δ_i can measure country i's lifetime welfare losses in consumption per capita equivalent terms. After some algebra, it can be expressed by

$$\Delta_i = 1 - \exp\left((1-\beta)[\mathcal{W}_i^{\text{Sanction}} - \mathcal{W}_i^{NoSanction}]\right). \tag{33}$$

Foreign consists of two different types of households. To measure their aggregate welfare losses, we calculate Δ_i of Eq. (33) by using the weighted average of welfare of sanctioned and non-sanctioned households indexed by S and NS, for example, $\mathcal{W}_F^{\text{Sanction}} = \lambda \mathcal{W}_{F,S}^{\text{Sanction}} + (1-\lambda)\mathcal{W}_{F,NS}^{\text{Sanction}}$ and $\mathcal{W}_F^{NoSanction} = \lambda \mathcal{W}_{F,S}^{NoSanction} + (1-\lambda)\mathcal{W}_{F,NS}^{NoSanction}$.

Table 4 presents welfare losses and changes of GDP per capita in Home, Foreign, and RoW under sanctions. Panels A and B provide the numbers under individual and combined sanctions, respectively. As expected, sanctions generate welfare losses in the sanctioning and the sanctioned economies. Because of Home's larger size, welfare loss and the fall in GDP per capita are smaller than in Foreign under all scenarios.

The difference between coordinated and uncoordinated scenarios highlights the importance of international coordination in sanctions in Table 4. Coordinated sanctions result in significantly greater welfare losses in Foreign in comparison to unilateral sanctions. In most cases, coordination dampens the Home's negative effect of sanctions. The required rebalancing of Home economy in response to sanctions is smaller when RoW joins sanctions (see the section above). This translates into smaller welfare and GDP losses in Home under sanctions when RoW joins. On the other hand, uncoordinated sanctions result in little welfare loss for RoW while simultaneously increasing its GDP per capita. Joining sanctions always come at a cost for RoW, both in terms of welfare and GDP.

The effects of coordinated versus uncoordinated sanctions differ more in Foreign than in Home. In particular, under gas sanctions, the impact of coordinated sanctions against Foreign is more than double the impact of uncoordinated sanctions. This is due to the fact that the foreign economy is gas-intensive and dependent on gas exports because of the small size of the Foreign country and its comparative advantage in the gas sector.

6 Robustness

6.1 Alternative Financial Sanctions

As in the case of benchmark financial sanctions, the parameter $\lambda > 0$ represents the fraction of Foreign households excluded from international bond markets. In contrast to capturing the financial assets of the sanctioned economy (as in the benchmark scenario), we introduce the alternative scenario for bond-trade sanctions, by imposing an obligation on the sanctioned economy to redeem their Home bonds.

Moreover, under this alternative scenario, the excluded households are not able to trade Home bonds while transitioning to the new sanction equilibrium, resulting in their terminal steady-state holdings being reduced to zero, as expressed by $B_H^{F,t+1} = B_H^F = 0$. If the RoW also joins the sanctions, the terminal steady-state holdings of RoW bonds also decline to zero, i.e., $B_{R,t+1}^{F*} = B_R^F = 0$. In contrast, the non-sanctioned households can continue to trade Home bonds during the transitional period, but even for them, their terminal steady-state holdings eventually reach zero, i.e., $B_H^F = 0$ ($B_R^F = 0$ if the RoW joins the sanctions as well). This differs from the benchmark financial sanctions where the initial and terminal steady-state holdings of non-sanctioned Foreign households remain the same.

In Fig. 7, transitional dynamics under the alternative financial sanctions are represented by green dashed lines with triangles, while red solid lines depict the dynamics under the benchmark financial sanctions. The no-sanction equilibrium is the same under both scenarios. Foreign maintains a positive net foreign asset position, however; under the sanction equilibrium, the alternative sanctions enforce a zero net foreign asset position for Foreign with respect to Home. The benchmark sanctions do not achieve this outcome; they only lead to a zero net foreign asset position for a fraction λ of Foreign households.

In response to the alternative financial sanctions, Foreign's consumption initially rises in the short run but reverts to its previous levels in the long run. This contrasting impact compared to the benchmark scenario is primarily driven by wealth effects in the alternative scenario. When the alternative sanctions kick in, Foreign starts to liquidate their bond holdings, leading to a positive transitory income shock. However, this comes with limited opportunities for saving. Consequently, Foreign's consumption demand increases, including its demand for exports from Home. The surge in Foreign imports stimulates new exporters in Home, influencing the average export prices and causing a real exchange rate appreciation for Foreign.

6.2 Alternative Consumption Good Trade Sanctions

We explore an alternative approach to sanctions in the realm of consumption goods trade, focusing on the restriction of certain firms' export opportunities. When Home imposes export sanctions on Foreign, at the start of each period, Home firms face exclusion from the Foreign market with a probability denoted as Λ. Importantly, this probability is uniform across all Home firms, regardless of their level of productivity. Consequently, a fraction of Λ of these firms do not export, even if their productivity exceeds the cutoff threshold $\underline{z}_{F,t}^H$, resulting in $(1 - \Lambda)\Phi(\underline{z}_{j,t}^i)N_{D,t}^H$ exporters. Similarly, Home's import sanctions against Foreign exclude Foreign firms from Home's consumption goods market with the same probability, Λ. For simplicity and computational efficiency, we assume that the shocks causing exclusion from export/import markets are uniform across firms and independent of an individual firm's prior history of exclusion and export activity.

In our model of alternative consumption goods trade sanctions, we set $\Lambda = 0.65$. Given the identical exclusion shock assumption, our calibrated model demonstrates around 65% reduction in aggregate exports/imports between Home and Foreign in the initial steady state. This parameterization mirrors the outcome of our benchmark scenario for consumption goods trade sanctions, which also results in a 64% decrease in exports in the terminal steady state. This alternative scenario with $\Lambda = 0.65$ implies that when Home unilaterally imposes all sanctions against Foreign without coordination with RoW, Home experiences a 64% reduction in imports from

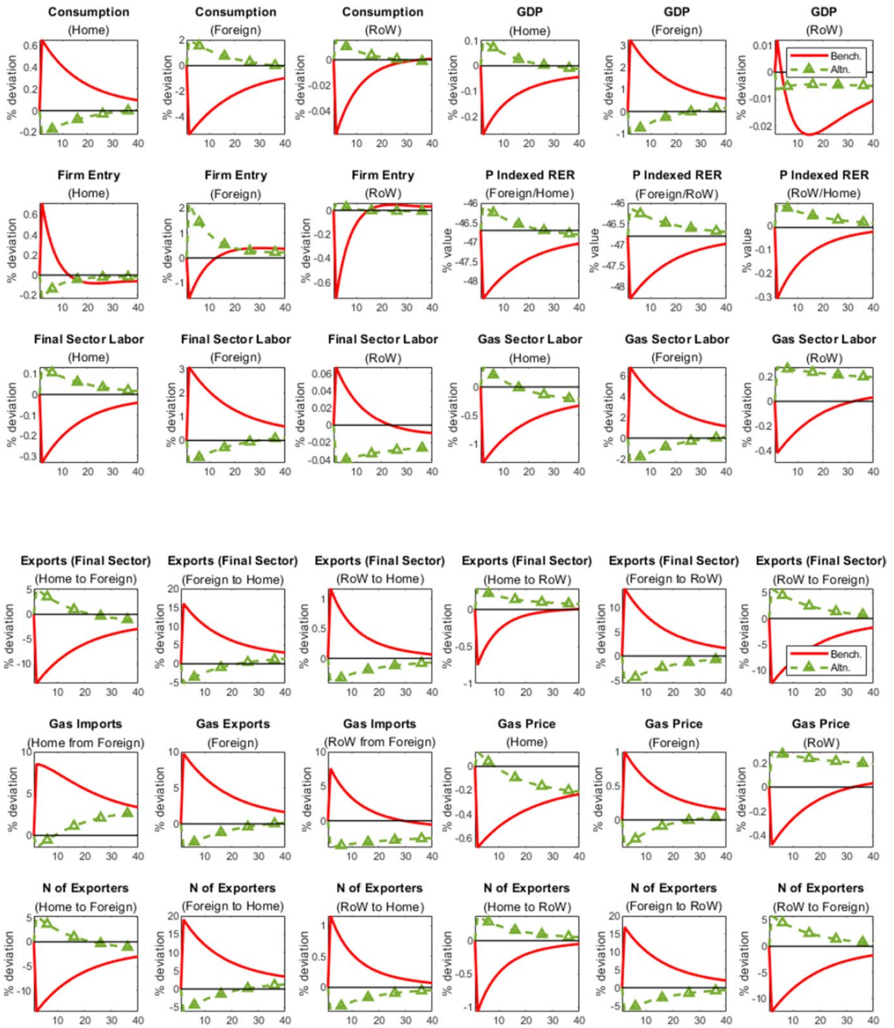


Fig. 7 Transitional dynamics under trade Sanctions with the benchmark and alternative financial Sanctions. *Notes*: The red solid lines plot transitional dynamics in the model under the benchmark financial sanctions. The green dashed lines with triangles plot transitional dynamics in the model with the alternative financial sanctions. Sanctions are imposed at $t = 1$. All deviations except for the figures titled P indexed RER are in units of percent deviation from the initial steady state without sanctions ($t = 0$). The figures of ratio, titled P indexed RER, are in units of percent deviation from one, i.e., $100 \times (x - 1)$. See Appendix Fig. 13 for the other variables' responses. (Color figure online)

Foreign and a 60% reduction in exports to Foreign, measured in terms of unit values for consumption goods.

In Fig. 8, the transitional dynamics under the alternative trade sanctions are represented by green dashed lines with triangles, while the red solid lines depict the dynamics under the benchmark trade sanctions. The alternative sanctions result in a dampening effect on key trade and macroeconomic variables, such as consumption, GDP,

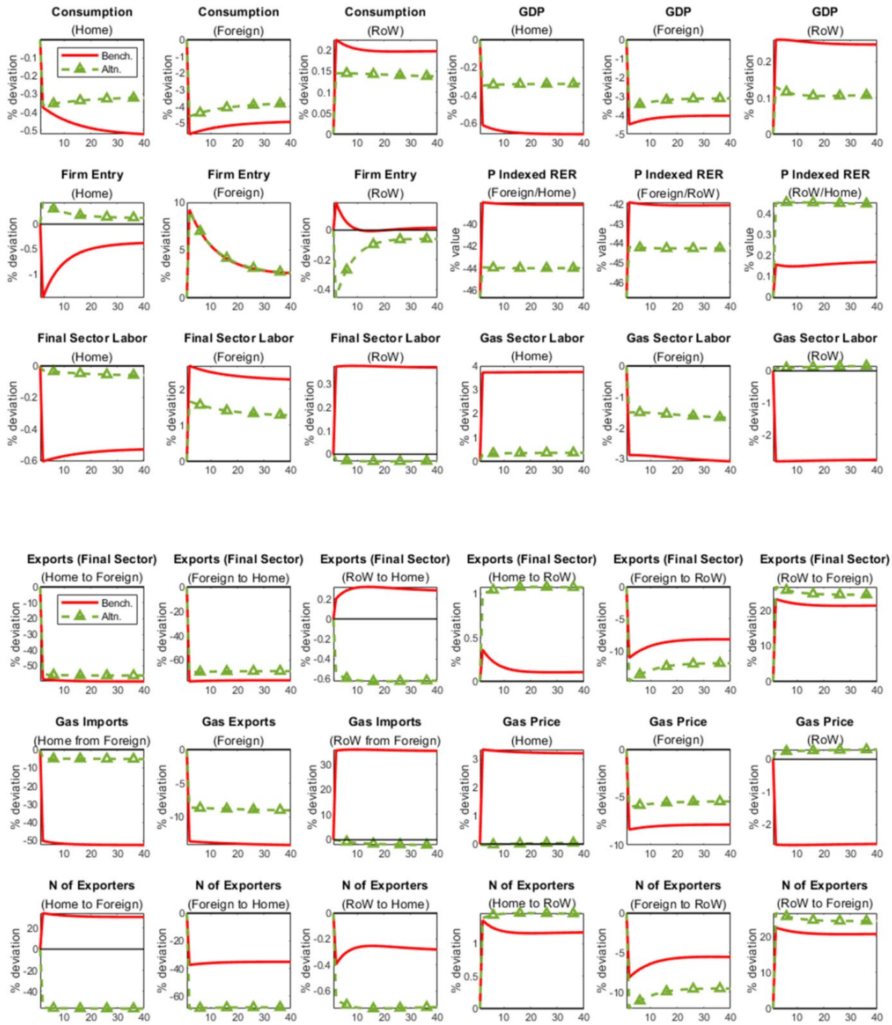


Fig. 8 Transitional dynamics under trade Sanctions with the benchmark and alternative consumption good trade Sanctions. *Notes*: The red solid lines plot transitional dynamics in the model under the benchmark trade (export and import) sanctions. The green dashed lines with triangles plot transitional dynamics in the model with the alternative trade (export and import) sanctions. Sanctions are imposed at $t = 1$. All deviations except for the figures titled P indexed RER are in units of percent deviation from the initial steady state without sanctions ($t = 0$). The figures of ratio, titled P indexed RER, are in units of percent deviation from one, i.e., $100 \times (x - 1)$. See Appendix Fig. 14 for the other variables' responses. (Color figure online)

labor in the consumption goods sector, exports, imports, and the exchange rate, when compared to the benchmark sanctions. Under the benchmark scenario, excluding the most productive firms from the consumption goods trade leads to exacerbated inefficiencies in reallocations, thereby intensifying productivity losses and price increases.

Under the alternative trade sanctions, the number of Home exporters to Foreign experiences a sharp decrease, mainly driven by the exclusion of existing exporters, resulting in a decline in consumption goods sector exports. Consequently, there is milder drop in the average size of exporters. In contrast, the benchmark trade sanctions lead to an increase in the number of Home exporters to the Foreign market, despite a decline in export values. These newly entering exporters are less productive and replace the most productive firms in export markets. This replacement contributes to the decline in the average export size within the consumption goods sector.

6.3 Welfare Results

This subsection explores how alternative designs of financial and trade sanctions influence our welfare analysis (Sect. 5). Since the alternative sanctions yield different transitional dynamics compared to our benchmark sanctions, they systematically affect our welfare results. Importantly, it's worth noting that the difference in welfare analysis between the benchmark and alternative scenarios is not qualitative and also quantitatively small.

The first panel of Table 5 reports the welfare loss and GDP changes resulting from the imposition of the alternative financial sanctions. The negative impacts on sanctioned Foreign households are less severe because they are required to fire-sell their Home bonds when the alternative sanctions are imposed, rather than losing the Home bonds they initially held under the benchmark sanctions. In other words, at the onset of financial sanctions, benchmark-sanctioned and alternative-sanctioned Foreign households temporarily experience a decrease and increase in their budgets, respectively, at period $t = 1$.

According to the second panel of Table 5, the welfare losses and GDP changes are smaller than the benchmark results in Table 4. Under the alternative consumption good export/import/trade sanctions, firms' exclusion is independent of firm productivity. Trade sanctions lower welfare because households lose variety and need to shift their consumption from imported goods to domestically produced goods, resulting in expenditure switching to products of less productive firms (at higher prices). Under the benchmark trade sanctions, these effects are amplified because we exclude the most productive firms. Therefore, the benchmark trade sanctions cause more significant welfare impacts than the alternative sanctions.

7 Conclusions

Geopolitical tensions have become a major challenge for the world economy. In this paper, we contribute to the understanding of how economic sanctions affect international relative prices, macroeconomic aggregates, and welfare. We calibrate a three-country, two-sector model of the world economy in which a sanctioning bloc (the European Union, the United Kingdom, and the United States) targets Russia with trade and financial sanctions, and a third bloc (China, India, and Turkey) does not impose sanctions. In our calibrated model, sectoral reallocation and real exchange rate fluctuations are central to the transmission of sanctions, as are

Table 5 Change in welfare and GDP after alternative sanctions

Type of Sanctions	International coordination	% Welfare Loss (Δ) Home	Foreign	RoW	% Change of GDP per capita Home	Foreign	RoW
Panel A. Alternative financial sanctions							
Financial	Yes	0.89	0.29	0.89	− 0.02	0.61	− 0.04
	No	0.89	0.26	0.89	− 0.02	0.31	− 0.01
Gas + C-good trade + Financial	Yes	1.46	14.05	1.46	− 0.80	− 9.85	− 0.81
	No	1.48	5.97	0.58	− 0.82	− 4.49	0.39
Panel B. Alternative consumption good trade sanctions							
C-good export	Yes	1.02	7.89	1.02	− 0.21	− 5.41	− 0.20
	No	1.17	3.93	0.72	− 0.38	− 2.68	0.21
C-good import	Yes	0.98	1.60	0.98	− 0.05	− 1.89	− 0.07
	No	1.00	0.90	0.87	− 0.09	− 0.89	0.03
C-good trade	Yes	1.08	8.52	1.08	− 0.25	− 6.40	− 0.24
	No	1.20	4.08	0.75	− 0.32	− 3.13	0.11
Gas + C-good trade + Financial	Yes	1.20	16.18	1.20	− 0.66	− 8.00	− 0.67
	No	1.14	6.97	0.61	− 0.63	− 3.63	0.38

The first three columns present the welfare (lifetime utility) loss of sanctions in terms of per-capita consumption defined in Eq. (33). The last columns present the percent change of GDP per-capita from the initial period GDP per-capita ($t = 0$) to the terminal period GDP per-capita ($t = 201$). The Foreign welfare losses and GDP per-capita changes are calculated from the weighted sum of financially sanctioned and unsanctioned foreign households. The changes in welfare and GDP are calculated in Panel C by preventing less productive firms entering the export market in response to trade sanctions

changes in producer entry into domestic and export markets. However, exchange rate movements are not a good criterion to assess the success or failure of sanctions. The direction of movement of the exchange rate is tied to how economies rebalance themselves by shifting resources between sectors in response to sanctions.

The welfare analysis of the calibrated model shows that, when sanctions are imposed, coordination with the third bloc nearly doubles the welfare losses in Russia. Additionally, coordinated imposition of sanctions reduces their negative effects on Western countries. However, because of the lost gains from substitution when sanctions are imposed only by the West, coordination is costly for the third bloc. This highlights the importance and difficulty of coordinating sanctions across countries.

There are several directions in which we plan to extend our analysis in future work. Especially important among them will be to study sanctions of uncertain, state-dependent duration, as well as the endogenous determination of the optimal menu of sanctions and policy responses in an explicitly game theoretic setting.

Appendix

See Figs. 9, 10, 11, 12, 13 and 14.

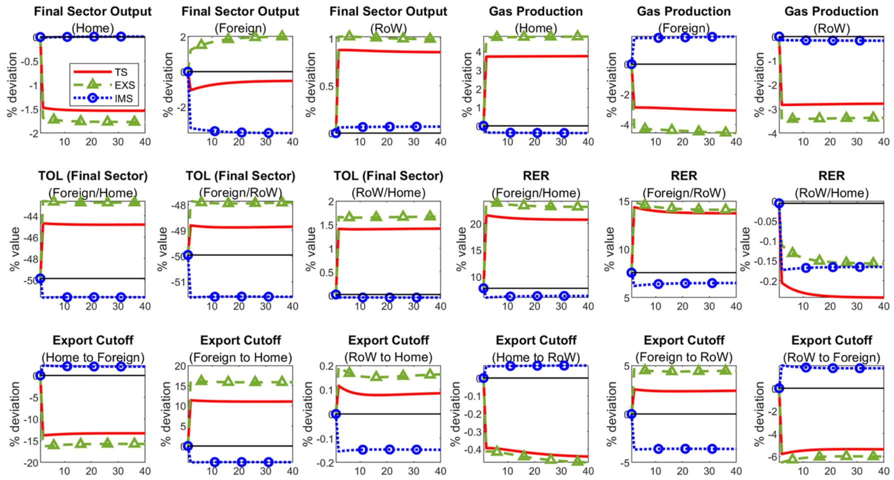


Fig. 9 Transitional dynamics under trade sanctions: other variables. *Notes*: The red solid lines plot the model transition dynamics when trade sanctions (TS, export and import sanctions) are imposed at $t = 1$. The green dashed lines with triangles plots the model transition dynamics when export sanctions (EXS) are imposed at $t = 1$. The blue dashed lines with circles plots the model transition dynamics when import sanctions (IMS) are imposed at $t = 1$. All deviations except for the figures titled and TOL (Final Sector) are in units of percent deviation from the initial steady state without sanctions ($t = 0$). The figures of ratios, titled RER and TOL (Final Sector), are in units of percent deviation from one, i.e., $100 \times (x - 1)$. See Fig. 3 for the main macro and trade variables' responses. (Color figure online)

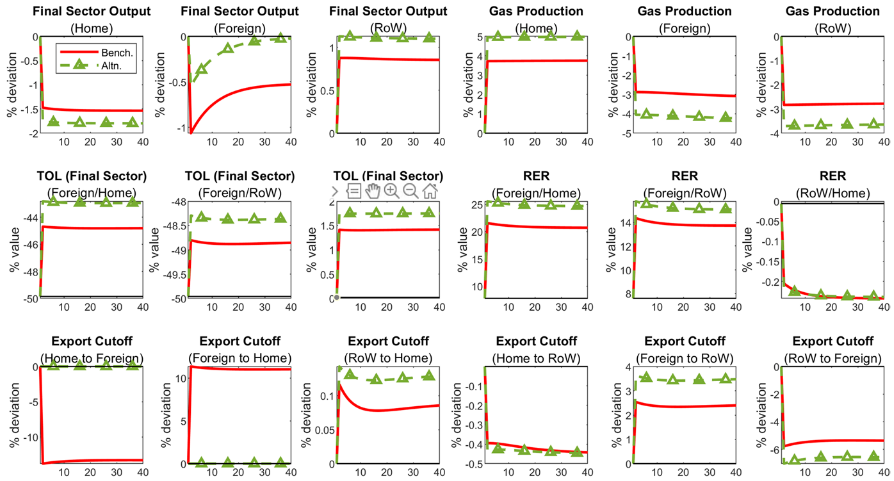


Fig. 10 Transitional dynamics under trade sanctions with invariant exporter productivity cutoffs: other variables. *Notes*: The red solid lines plot transitional dynamics in the benchmark model under combined trade sanctions. The green dashed lines with triangles plot transitional dynamics in the model with invariant exporter entry under combined trade sanctions. Sanctions are imposed at $t = 1$. All deviations except for the figures titled and TOL (Final Sector) are in units of percent deviation from the initial steady state without sanctions ($t = 0$). The figures of ratios, titled RER and TOL (Final Sector), are in units of percent deviation from one, i.e., $100 \times (x - 1)$. See Fig. 4 for the main macro and trade variables' responses. (Color figure online)

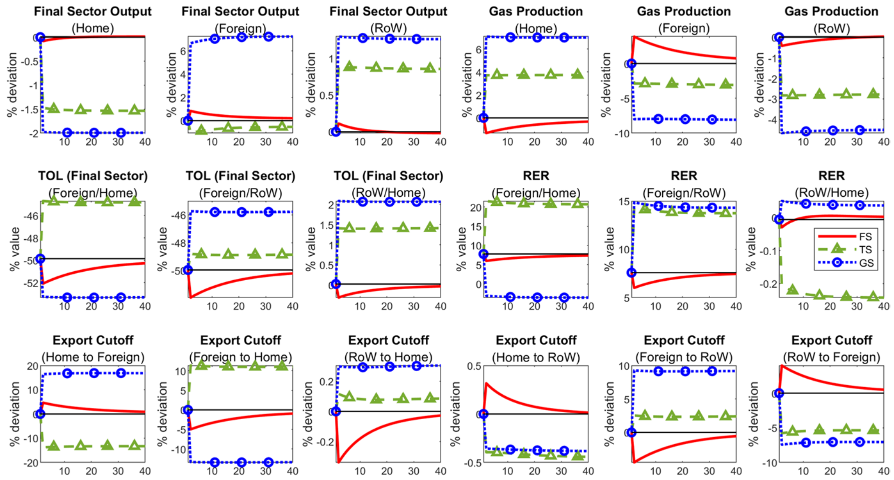


Fig. 11 Transitional dynamics under each sanction: other variables. *Notes*: Red solid lines, green dashed lines with triangles, and blue dashed lines with circles plot the transitional dynamics under financial (FS), consumption good sector trade (TS), and gas sanctions (GS), respectively. Sanctions are imposed at $t = 1$. All deviations except for the figures titled and TOL (Final Sector) are in units of percent deviation from the initial steady state without sanctions ($t = 0$). The figures of ratios, titled RER and TOL (Final Sector), are in units of percent deviation from one, i.e., $100 \times (x - 1)$. See Fig. 5 for the main macro and trade variables' responses. (Color figure online)

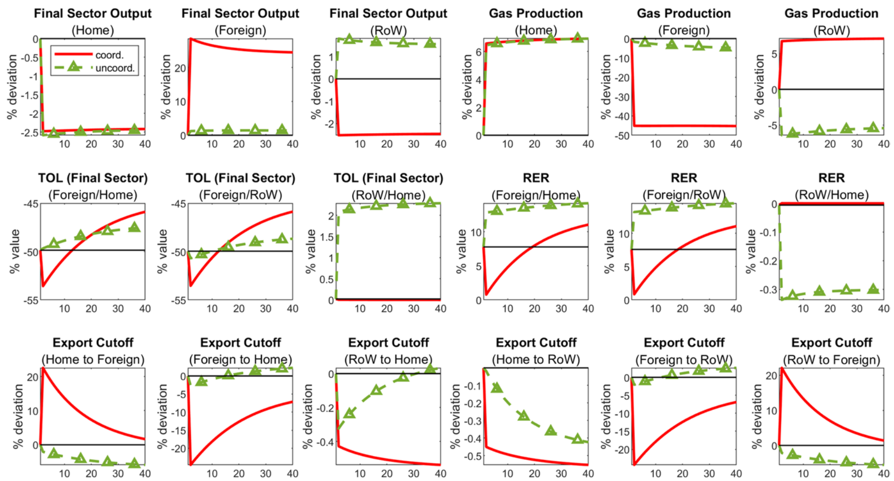


Fig. 12 Transition dynamics after the (un-)coordinated sanctions: other variables. Notes: The red solid lines (labeled coord.) plot the model transition dynamics when all sanctions are imposed by Home and RoW at $t = 1$. The green dashed lines (labeled uncoord.) with triangles plot the model transition dynamics when all sanctions are imposed by Home at $t = 1$, while the RoW does not participate in sanctions. All deviations except for the figures titled and TOL (Final Sector) are in units of percent deviation from the initial steady state without sanctions ($t = 0$). The figures of ratios, titled RER and TOL (Final Sector), are in units of percent deviation from one, i.e., $100 \times (x - 1)$. See Fig. 6 for the main macro and trade variables' responses. (Color figure online)

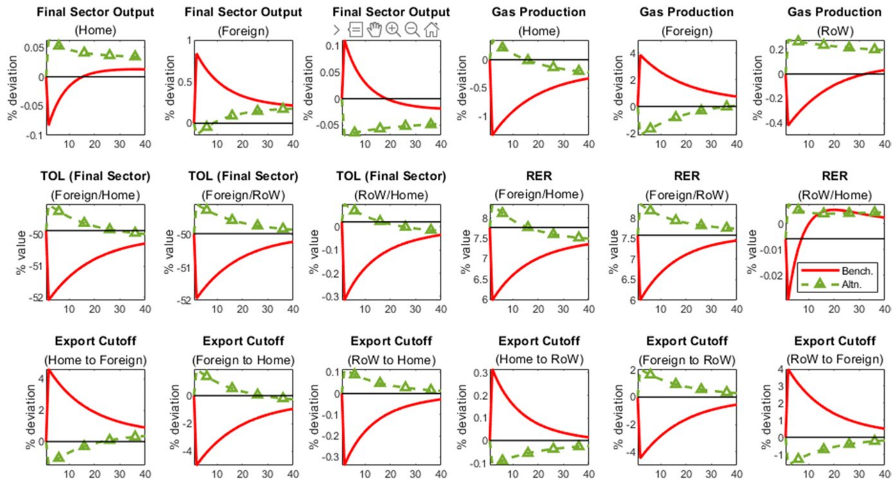


Fig. 13 Transitional dynamics under trade sanctions with the benchmark and alternative financial sanctions: other variables. *Notes*: The red solid lines plot transitional dynamics in the model under the benchmark financial sanctions. The green dashed lines with triangles plot transitional dynamics in the model with the alternative financial sanctions. Sanctions are imposed at $t = 1$. All deviations except for the figures titled P indexed RER are in units of percent deviation from the initial steady state without sanctions ($t = 0$). The figures of ratio, titled P indexed RER, are in units of percent deviation from one, i.e., $100 \times (x - 1)$. See Fig. 7 for the other variables' responses. (Color figure online)

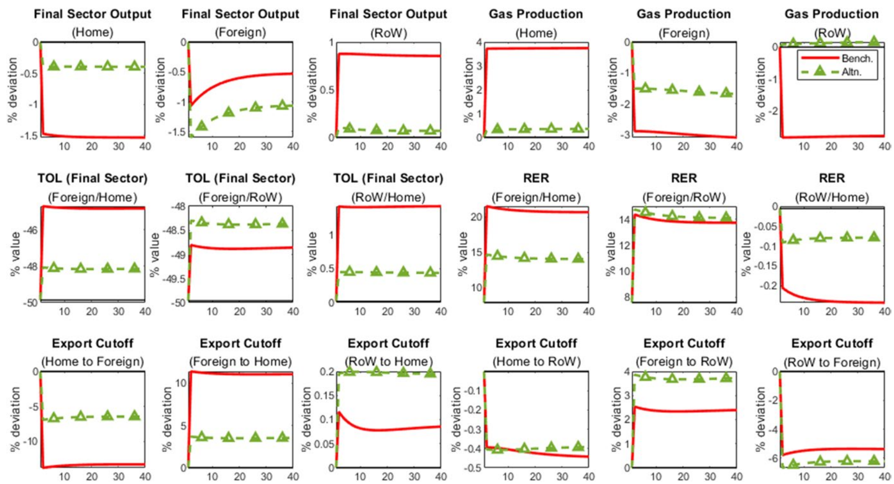


Fig. 14 Transitional dynamics under trade sanctions with the benchmark and alternative consumption good trade sanctions: other variables. *Notes*: The red solid lines plot transitional dynamics in the model under the benchmark trade (export and import) sanctions. The green dashed lines with triangles plot transitional dynamics in the model with the alternative trade (export and import) sanctions. Sanctions are imposed at $t = 1$. All deviations except for the figures titled P indexed RER are in units of percent deviation from the initial steady state without sanctions ($t = 0$). The figures of ratio, titled P indexed RER, are in units of percent deviation from one, i.e., $100 \times (x - 1)$. See Fig. 8 for the other variables' responses. (Color figure online)

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