Impacts of Russia-Ukraine conflict on Russian states and their recovery pathway

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Introduction

Since February 2022, the Russia-Ukraine war has exacerbated geopolitical tensions, and most western nations have announced severe sanctions against Russia, which involves in financial markets, service sectors, and trade[1]. Simultaneously, the outbreak of the Russia-Ukraine war brings out a series of negative effects. Apart from the direct impacts of losing life, cascading consequences induced by the war is hampering environment, economy, and society to push back the sustainable development goals (SDGs)[2]. Apparently, sanctions driven by the war is jeopardizing the implementation of the partnerships for the goals (SDG 17)[3]. Moreover, the war came at a bad time for global food markets because food prices were already high due to disruptions in the supply chain caused by the COVID-19 pandemic, strong global demand, drought, and poor harvests in South America the previous year[4]. The war further increased the complexity and vulnerability of the food security worldwide, especially in food availability, price, harvesting, and shipping[4-7]. Notably, Russia and Ukraine, as the global breadbasket, meet at least 30% of over 30 countries' wheat import demands and over 50% of at least 20 countries' wheat import demands[8]. And almost 40% of total African wheat imports come from Russia and Ukraine[8]. Furthermore, war is also a primary intervention to result in health problems, psychosocial wellbeing risks, and even burdens[9, 10]. Therefore, the onset of Russia-Ukraine war is seriously threatening realization of the SDG 1 (No poverty), SDG 2 (Zero hunger), and SDG 3 (Good health and well-being).

Existing studies have discussed the economic effects of the Russia-Ukraine conflict. Specifically, Europe is the most affected region, while Russia also suffers significant economic losses[11]. As the major producer of crude and natural gas[12], Russia plays an important role in global energy market and sanctions from western nations on Russia has triggered profound economic repercussions worldwide by global supply chains[11, 13, 14]. Besides, Russian and Ukrainian exports of wheat, corn and other coarse grains also account a significant percentage in global agriculture sector[15], which further adds to already strong inflationary pressures in the global economy. And the food costs would increase by 60-100% in 2023 from 2021 levels[16]. Some European and Central Asia's emerging economies is forecast to be decreased by 4.1% compared with the pre-war forecast of 3% growth, which compounds the ongoing impacts of the COVID-19 pandemic[17]. Because of the sanctions from other countries, reducing bilateral trade with Russia more broadly by 40% on all goods and services is estimated to have a larger negative effect on Russia than an oil embargo, which results in that household real income losses in Russia is roughly double the loss under the oil embargo[18]. From the global scale, the war would add about 1% to global inflation in 2023[19]. Nonetheless, no study quantifies the economic losses for Russia itself, especially on a regional scale. The trade embargo imposed by western countries, Russia's mobilization, and Russian emigration significantly altered the economic and labor structure of the Russian economy. Due to Russia's vast territory and significant regional heterogeneity in industry structure, wealth, and the role of supply chains, the war's effects on Russia's regions varied. It is unknown how the regional Russian economy performed prior to the current war and what would occur if the war continues.

In this context, we develop the first multi-regional input-output (MRIO) table for 85 Russian states across 65 economic sectors to quantify regional supply chains for each state. Then, we link Russian MRIO with the latest global MRIO from GTAP database to trace the global supply chain and quantify the heterogeneity of economic repercussions caused by foreign sanctions as well as army mobilization across Russian regions. Here, we apply the disaster impact model, an extension of the adaptive regional input-output (ARIO) model[20], to simulate the propagation of trade embargo and labor loss on the Russian regional economy during the one-year conflict to illustrate the paths of economic loss for 85 Russian states. In addition, we simulate future economic losses and the path to recovery under various scenarios if the war continues. We want to simulate questions such as: How long will it take for each region to recover to its pre-war level if the war ended immediately, and how much longer will it take if the war continues for another 6 months or 1 year? We believe the study aids in mitigating geopolitical frictions and promoting trade cooperation to prevent supply-chain-induced economic losses in globalization.

Results

Economic impacts in the first-year war

We quantified the value-added losses that have been already resulted in by the Russia-Ukraine war. Different Russian regions shows the heterogeneities of value-added losses. From the Figure 1, CHUKOTKA autonomous area has the largest value-added losses around 66%, followed by OMSK region, REPUBLIC OF KARELIA, IVANOVO region, and IRKUTSK region. Due to the difference of industrial structure, every region also presents various sectoral value-added losses. For example, energy products play an important role in OMSK region so that related sectors have undertaken large value-added losses during the war. Especially, both oil products and gas products had serious value-added losses about 73%.

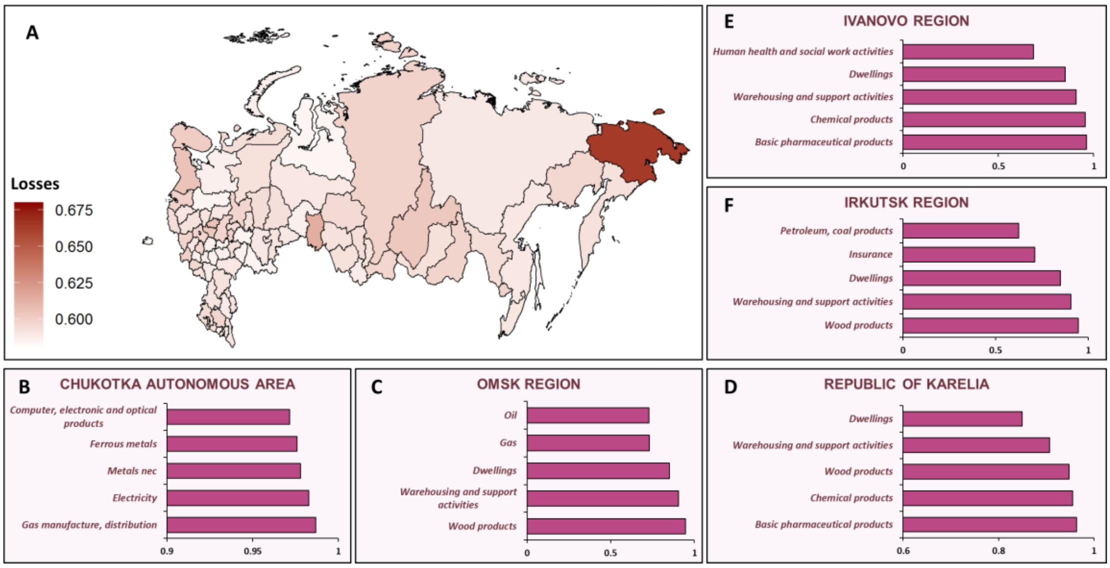

Figure 1 Economic impacts (value-added loss) of Russia-Ukraine war. **A**, Map of Russian economic impacts on regional scale; **B-F**, Top 5 Russian regions with the top 5 sectors with the largest economic impacts.

Economic impacts in the first-year war

Every Russian region presents different value-added losses path facing with the onset of the war (Figure 2 A). The economy has certain period to recovery even the end of the war. Specifically, the scenario that the war lasts one year, there are three weeks lags for the economy to start recovering.

Moreover, the longer the war goes on, the longer it takes for the economy to recover (Figure 2 A). For example, if the war last more 6 months, the economic recovery period would extend 26 weeks for most of Russian regions. Besides, the cost of war would be less under the earlier end of the war (Figure 2 B).

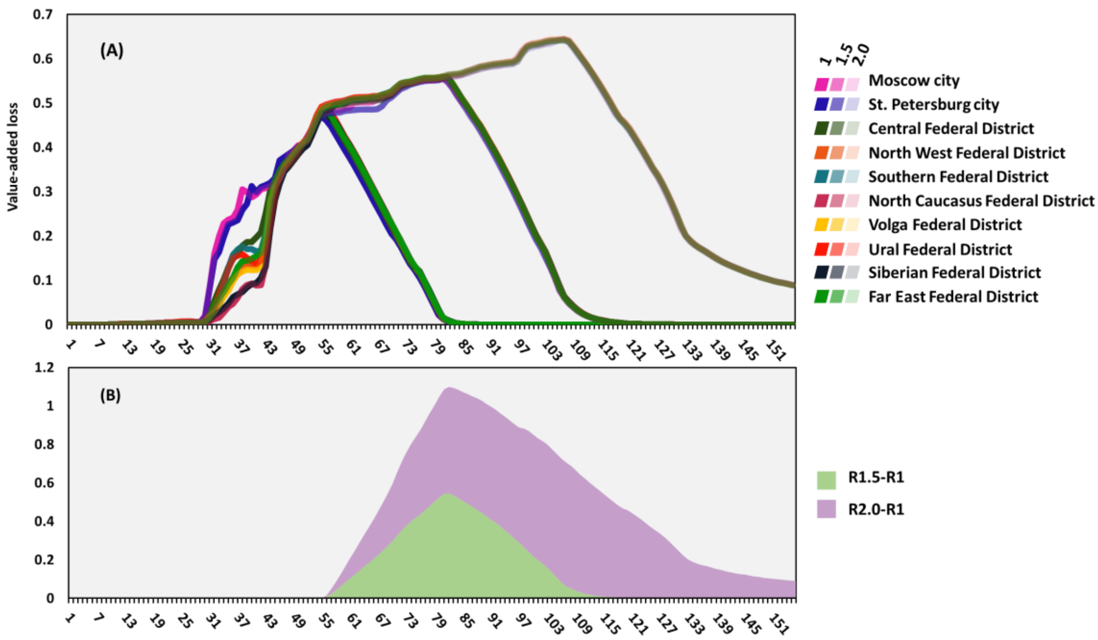

Figure 2 Trend of Russian regional value-added losses under different period of the Russia-Ukraine war. A, The regional value-added losses under different periods of the war. In the legend, 1 means the first year of the war. 1.5 means the war would last more 6 months after the first year. 2 means the war would last more 1 year after the first year. B, The R1.5-R1 means value-added losses increment between the scenario that war lasts more 6 months and the reality (one-year war). And R2.0-R1 means value-added losses increment between the scenario that war lasts more 1 year and the reality.

Method

Scenario sets design. After the Russia's assault on Ukraine in February 2022, the US, Europe, and a number of other countries imposed economic sanctions on the country. The impact brought by the war on economy can mainly be divided into direct effects and indirect effects[13, 21]. One the one hand, the shortage of labor capacity induced by army mobilization can result in adverse impacts on production directly to affect economy. On the other hand, the sanctions against Russia imposed by other countries have a direct effect on bilateral trade to influence economy. Due to the interdependency of trading, propagated impacts on a supply chain can also trigger negative shocks on global economy, especially Russia and Ukraine are important suppliers of energy and agriculture commodities[11]. In this context, we set four scenarios mainly according to labor constraints and trade constraints to explore the economic impacts induced by Russia-Ukraine war on Russia from regional and sectoral perspectives. The first scenario describes the value-added losses caused by one-year conflict period. The other three scenarios simulate the economic impacts of the war lasting for 1.5 years, 2 years, and maintaining the current state all the time on economy, respectively. Then, we can investigate the characteristics of economic recovery under different durations of the war to explore paths of the war's economic recovery.

The recursive dynamic economic impact assessment model. Input-output (IO) analysis is a popular method to estimate disaster impact from the view of economic sectoral interdependencies. Although IO-based models are suitable to capture the impact of sudden shocks on the economy, it probably overestimates the impacts of a disaster due to a lack of the adaptive behavior of economic agents in a disaster aftermath. In such context, the adaptive regional input-output (ARIO) model is developed to simulate the disaster-induced propagation throughout the economy by considering both production capacity constraints and possibilities of overproduction[22-24].

Here, we built an extension of the ARIO model to simulate the propagation of negative shocks in multiple regions[25-29]. Similar to previous research[30, 31], our model includes two types of agents, that is, producers (intermediate demand) and households (final demand). Specifically, each economic sector is regarded as a both producer which mainly includes labor as well as capital, and consumers which require intermediate products from other sectors.

Because Russia-Ukraine war occurs without any predication and economic agents cannot adjust in the short term, Leontief production function from IO basic theory that inputs cannot be substituted is used for this study.

$$x_{i,r} = \min\,(\text{for all } p, \frac{z_{i,r}^{p}}{a_{i,r}^{p}}; \frac{v_{i,r}}{b_{i,r}}) \tag{1}$$

Where $x_{i,r}$ represents the output from sector i in region r; p is the type of intermediate products; $z_{i,r}^{p}$ represents the intermediate product p used in sector i; $v_{i,r}$ refers to the value-added (including labor and capital) for the sector i;Values $a_{i,r}^{p}$ and $b_{i,r}$ are the input coefficients of intermediate products p and primary inputs of sector i, which can be calculated as

$$a_{i,r}^{p} = \frac{\bar{z}_{i,r}^{p}}{\bar{x}_{i,r}},\ \ b_{i,r} = \frac{\bar{v}_{i,r}}{\bar{x}_{i,r}} \tag{2}$$

We assume that total output can meet the intermediate demands and final demands of consumers before the outbreak of the Russia-Ukraine war. While due to the war, lots of Russian and Ukrainian labor were mobilized to join the army, which would decrease the production capacity and outputs to break the economic balances. Thus, labor constraint is a key factor to be considered in disaster impact analysis and the proportion of surviving productive capacity from the constrained labor productive capacity (x_i^L) after a shock is expressed as:

$$x_i^L(t) = (1 - n_i^L(t)) \times \bar{x}_i \tag{3}$$

Where $n_i^L(t)$ refers to the proportion of labor that is unavailable at each time step t during containment. The factor $(1 - n_i^L(t))$ contains the available proportion of employment at time t.

$$n_i^L(t) = (\bar{L}_i - L_i(t))/\bar{L}_i \tag{4}$$

The proportion of the available productive capacity of labor is thus a function of the losses from the sectoral labor forces and its pre-disaster employment level. According to the assumption of fixed input–output relationships, the productive capacity of labor in each region after a disaster (x_i^l) will represent a linear proportion of the available labor capacity at each time step.

The shortage of intermediate products will result in the less production capacity of downstream sectors and reduce their outputs because of the forward effect. The potential production level that the inventory of the p^{th} intermediate product can support is

$$x_i^p(t) = \frac{S_i^p(t-1)}{a_i^p} \tag{5}$$

Where $S_i^p(t-1)$ refers to the amount of p^{th} intermediate products held by firm i at the end of time step $t-1$. By considering the limitations of primary and intermediate inputs, the maximum production capacity of sector i in time t ($x_{i,r}^{max}(t)$) can be expressed as equation (6).

$$x_{i,r}^{max}(t) = \min\left(x_i^L(t); x_{i,r}^K(t); \text{for all } i, r, x_{i,r}^p(t)\right) \tag{6}$$

Where $x_{i,r}^L(t)$, $x_{i,r}^K(t)$, $x_{i,r}^p(t)$ are the maximum outputs when considering the labor constraints, capital limitation and intermediate input scarcity, respectively.

The actual production of firm i, $x_i^a(t)$, depends on both its maximum supply capacity and the total orders the firm received from its clients,

$$x_i^a(t) = min(x_i^{max}(t), TD_i(t-1)) \tag{7}$$

The inventory held by firm i will be consumed during the production process,

$$S_i^{p,used}(t) = a_i^p * x_i^a(t) \tag{8}$$

When some firms in the economic system suffer a negative shock, their production will be constrained by a shortage to primary inputs such as a shortage of labor supply in the outbreak of war. In this case, a firm's output will not be able to fill all orders of its clients. To describes how suppliers allocate products to their clients, A *rationing scheme* that reflects a mechanism based on which a firm allocates an insufficient amount of products to its clients is needed[25, 32]. In this study, we applied a *proportional rationing scheme* according to which a firm allocates its output in proportion to its orders. Under the proportional rationing scheme, the amounts of products of firm i allocated to firm j and household h is as follows:

$$FRC_j^i(t) = \frac{FOD_i^j(t-1)}{\left(\sum_j FOD_i^j(t-1) + \sum_h HOD_i^h(t-1)\right)} * x_i^a(t) \tag{9}$$

$$HRC_h^i(t) = \frac{HOD_i^h(t-1)}{\left(\sum_j FOD_i^j(t-1) + \sum_h HOD_i^h(t-1)\right)} * x_i^a(t) \tag{10}$$

Firm j received intermediates to restore its inventories,

$$S_j^{p,restored}(t) = \sum_{i \to p} FRC_j^i(t) \tag{11}$$

Therefore, the amount of intermediate p held by firm i at the end of period t is

$$S_j^p(t) = S_j^p(t-1) - S_j^{p,used}(t) + S_j^{p,restored} \tag{12}$$

In the perspective of demand, restrictions on trade (exports and imports) of Russia and substituted consuming activities impact on the output of producers by changing demand of consumers. Therefore, the total order demand for the sector i in time t $TOD_{i,r}(t)$ can be calculate as equation (13).

$$TOD_{i,r}(t) = \sum_{j,s} FOD_{i,r}^{j,s}(t) + \sum_s HOD_{i,r}^s(t) \tag{13}$$

Where $FOD_{i,r}^{j,s}(t)$ represents the intermediate demand that sector j in in region s required from supplier i in region r and $HOD_{i,r}^s(t)$ refers to the household demand that household in region s required from supplier i in region r.

Our model assume that every sector holds some inventory of intermediate goods to make a more realistic simulation to the real production process. Thus, sectoral inventories can provide alternative intermediate products for production. Then sectors can also purchase intermediate products from their supplying sectors to restore their inventories. The amount of intermediate product p held by sector j in region s in time t is denoted as $S_{j,s}^p(t)$ and we assume the inventory of intermediate product p required by sector j in region s is $S_{j,s}^{p^*}(t)$, which could meet its consumer demand for $n_{j,s}^p$ days. Hence, the order issued by sector j to its supplying sector i is expressed by equations 14 and 15.

$$FOD_{i,r}^{j,s}(t) =$$

$$\begin{cases} \left(S_{j,s}^{p^*}(t) - S_{j,s}^{p}(t)\right) \times \frac{\overline{FOD}_{i,r}^{j,s} \times x_{i,r}^{max}(t)}{\sum_{j\to p}\left(\overline{FOD}_{i,r}^{j,s} * x_{i,r}^{max}(t)\right)} & \text{if } S_{j,s}^{p^*}(t) > S_{j,s}^{p}(t); \\ 0 & \text{if } S_{j,s}^{p^*}(t) \le S_{j,s}^{p}(t) \end{cases} \quad (14)$$

$$S_{j,s}^{p^*}(t) = n_{j,s}^{p} \times a_{j,s}^{p} \times x_{j,s}^{max}(t) \quad (15)$$

Households issue orders to their suppliers based on their demand and the supply capacity of their suppliers. In this study, the demand of household s to final products q, $HD_s^q(t)$, is given exogenously at each time step. Then, the order issued by household s to its supplier i is

$$HOD_{i,r}^{s}(t) = HD_s^q(t) * \frac{\overline{HOD}_{i,r}^{s} \times x_{i,r}^{max}(t)}{\sum_{i\to q}\left(\overline{HOD}_{i,r}^{s} \times x_{i,r}^{max}(t)\right)} \quad (16)$$

Economic footprint. We define the value-added decrease of all firms in a network caused by an exogenous negative shock as the disaster footprint of the shock. For the firm directly affected by exogenous negative shocks, its loss includes two parts: a) the value-added decrease caused by exogenous constraints, and b) the value-added decrease caused by propagation. The former is the direct loss, while the latter is the indirect loss. A negative shock's total economic footprint ($TEF_{i,r}$), direct economic footprint ($DEF_{i,r}$), and propagated economic footprint ($PEF_{i,r}$) for firm i in region r are:

$$TEF_{i,r} = \overline{va}_{i,r} \times T - \sum_{t=1}^{T} va_{i,r}^{a}(t) \quad (17)$$

And,

$$DEF_{i,r} = \overline{va}_{i,r} \times T - \sum_{t=1}^{T} va_{i,r}^{max}(t) \quad (18)$$

And,

$$PEF_{i,r} = TEF_{i,r} - DEF_{i,r} \quad (19)$$

Russian-global supply-chain network. We build a Russian-global supply chain network based on Russian multiregional input-output (MRIO) table and version 10 of the Global Trade Analysis Project (GTAP) database. On top of that, we employ a partial survey approach to construct the Russian MRIO table firstly according to the available data for the year of 2016[33, 34]. This Russian MRIO table includes Russian 85 regions and each region contains 65 production sectors. GTAP 10 provides a MRIO table for the year of 2014. This MRIO table divides the world into 141 economies, each of which contains 65 production sectors.

If we treat each sector as a firm (producer), and assume that each region has a representative household, we can obtain the following information in the MRIO table: a) suppliers and clients of each firm; b) suppliers for each household, and c) the flow of each supplier-client connection under the equilibrium state. This provides a benchmark for our model. When applying such a realistic and aggregated network in the disaster footprint model, we need to consider the substitutability of intermediate products supplied by suppliers from the same sector in different regions. The substitution between some intermediate products is fairly straightforward while other suppliers in some regions are non-substitutable. If we assume that all goods are non-substitutable as in the traditional IO model, then we will overestimate the loss of producers such as fragrance extraction firm. If we assume that products from suppliers in the same sector can be completely substitutable, then we will significantly underestimate the losses of producers. Thus, we set the possibility of substitution for each firm based on the region and sector of supplier supply to alleviate the shortcomings of the evaluation deviation under some assumptions.

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