The Impact of Trade Disruption with China on the Japanese Economy*

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Recent episodes of Russian invasion of Ukraine and the US-China decoupling have shown that key trade policies nowadays are shaped by geopolitical risks and economic security motives. In Japan, too, economic security in increasingly complex global supply chains is being discussed as an important policy theme, yet quantitative evidence is still scarce. This paper aims to quantify the impact of trade disruption with China on the Japanese economy. To do so, I develop a general equilibrium model of production networks with international trade, which incorporates non-unitary elasticity of substitution across intermediate inputs. The model is calibrated using large-scale firm-level network data in Japan. The aggregate impact of trade disruption is substantial in the short run, but becomes milder in the long run. If both export and import with China decline by 90%, the real GDP will drop by 7% within a year. Also, import disruption causes more severe damage than export disruption. There is a large sectoral heterogeneity in the negative impact of trade disruption depending on the sectoral exposure to trade, share of intermediate inputs and location in production networks.

Keywords: supply chains, propagation, production networks, economic security, international trade

JEL classification: C67, F14, F17

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1 Introduction

Globalization is unwinding. Trade policies have taken on an increasingly protectionist flavor over the past decade. Two recent episodes, Russian invasion of Ukraine and the US-China decoupling, underscore that key trade policies nowadays are shaped by geopolitical risks and economic security motives. Those protectionist trade policies come at a cost at least in the short run. In Europe, energy prices skyrocketed due to the wartime turmoil and economic sanctions. In the United States, electric vehicle (EV) prices are expected to surge due to the recently announced 100% tariff on Chinese-made EVs. It is critical to have an estimate of the economic impact of trade-related contingencies in an ever-changing global landscape.

In Japan, economic security is being discussed as an important policy theme mainly because of the uncertain outlook for Japan-China relationship. Japan is heavily dependent on China for both exports and imports, yet some policymakers and critics warn against the current situation due to geopolitical risks. Although anecdotal or qualitative evidence abound, quantitative analysis on the impact of trade disruption with China to the Japanese economy is scarce. This paper aims to fill the gap in order to promote fruitful policy discussions on economic security and global supply chains.

I build a general equilibrium model of production networks with international trade, which incorporates non-unitary elasticity of substitution across intermediate inputs. The flexible value of the elasticity of substitution is a key to generate rich and realistic implications of the policy experiments. Most models of production networks assume that the elasticity is either zero (Leontief) or one (Cobb-Douglas). When it is zero, the model exhibits complete complementarity, which leads to the overestimation of the impact of trade disruption. When it is one, the impact of sectoral trade disruption is completely determined by its Domer weight (sales share to GDP), which leads to the irrelevance of production network structure. As pointed out by Baqaee and Farhi (2019), this Cobb-Douglas case ignores several key factors in the economic environment: structural microeconomic elasticities of substitution, network linkages, microeconomic returns to scale, and the extent of factor reallocation. The model in this paper employs non-unitary elasticities of substitution both between labor and materials, and across intermediate inputs to overcome the shortcomings of the existing models. Also, we can interpret the economic impacts in different time horizons by changing the elasticity parameters.

The model is calibrated using large-scale firm-level network and trade data in Japan. The dataset contains firm-to-firm transaction relationships for hundreds of thousands of firms. A notable feature of the data is a highly skewed degree (the number of customers and suppliers) distribution. Most of the firms have only one or two partners whereas a handful of firms have thousands of partners. Since export or import activity is concentrated to those well-connected firms, this network pattern gives rise to a substantial share of indirect exporters and importers. Those indirect traders do not engage in trade activity by themselves but their customers or suppliers trade with foreign countries, and hence, they are also indirectly affected by foreign shocks. This propagation effect is quite large in the counterfactual simulations.

In sum, the aggregate impact of trade disruption is substantial in the short run, but becomes milder in the long run. Also, import disruption causes more severe damage than export disruption. There is a large sectoral heterogeneity in the negative impact of trade disruption depending on the sectoral exposure to trade, share of intermediate inputs and location in production networks.

This paper is related to two strands of literature: input-output models with non-unitary elasticity of substitution and foreign shock propagation via supply chains. Atalay (2017), Baqaee (2017), and Baqaee and Farhi (2019) consider sectoral input-output models with non-unitary elasticity of substitution. Atalay (2017) finds that the elasticity of substitution across intermediate inputs is less than one at a business cycle frequency. This indicates that industry-specific shocks are substantially more important than previously thought in the Cobb-Douglas model, accounting for at least half of aggregate volatility. Baqaee and Farhi (2019) also support Atalay's claim. They show that nonlinearities due to non-unitary elasticity magnify negative shocks and attenuate positive shocks, resulting in an aggregate output distribution that is asymmetric. In the long run, nonlinearities, which underpin Baumol's cost disease, account for a 20 percentage point reduction in aggregate TFP growth over the period 1948-2014 in the US. Although these papers unveil novel implications of sectoral shocks and propagation patterns compared to conventional wisdom, they do not consider the impact of foreign shocks through exports and imports.

In the literature of foreign shock propagations, the current paper is most closely related to the following two papers: Inoue and Todo (2022) and Tintelnot et al. (2021). Inoue and Todo (2022) use the same firm-level data in Japan to answer the same question as the current paper does. However, their production model is mechanical and there is no concept of price. It is characterized by perfect complementarity (Leontief), which results in a very large impact of trade disruption because there is no room for firms to substitute disrupted inputs. For instance, 80% import plunge from China lasting for two months leads to 15% aggregate production loss, which is much larger than the simulation result of the current paper. Although they derive similar qualitative results as the current paper, I aim to quantify the impact of trade disruption with more plausible framework and parameters. By solving the general equilibrium, I also provide welfare implications of the counterfactual experiments. Tintelnot et al. (2021) analyze the interplay between international trade and domestic production networks using Belgium value-added tax (VAT) data. They also uncover a substantial fraction of indirect exporters and importers, that are affected by foreign shocks via supply chains. Since the VAT records contain not only customers and suppliers of each firm (extensive margin) but also transaction amount (intensive margin), their micro data is richer than the Japanese data used in this paper. Yet, Belgium is a small open economy whose trade to GDP ratio is more than 150% whereas Japan is a large, but relatively closed economy whose trade to GDP ratio is less than 20%. Thus, the impact of trade disruption may differ substantially between the two countries. The current paper contributes to the literature by carefully quantifying the impact of trade disruption for a large and relatively closed economy.

This paper is organized as follows. Section 2 develops a theoretical framework which incorporates firm-level trade and firm-to-firm production networks. Section 3 describes the data and mapping procedure to the model. Section 4 presents simulation results on the impact of trade disruption with China, and Section 5 concludes.

2 Theoretical Framework

2.1 Model

Consider a small open economy in which N firms are producing a distinct product. Market structure is characterized by perfect competition. The household utility and firm production are modeled by constant elasticity of substitution (CES) functions. Production requires labor and intermediate inputs produced by other firms in the domestic market or imported materials. The representative consumer provides labor L inelastically, and wage rate is denoted by w.

Preferences

The representative consumer has the following CES preferences

$$U = \left[\sum_{i=1}^{N} \xi_i^{\frac{1}{\sigma}} c_i^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}}, \tag{1}$$

where c_i is the final consumption of product i and ξ_i is its preference weight. Since there are no firm profits, the total expenditure E is given by

$$E = wL. \tag{2}$$

Given a price p_i, utility maximization results in the following household demand function for product i

$$c_i = \Delta_H \xi_i p_i^{-\sigma}, \tag{3}$$

where $\Delta_H = EP^{\sigma-1}$ is the household demand shifter and the domestic price index P is defined by

$$P = \left[\sum_{i=1}^{N} \xi_i p_i^{1-\sigma} \right]^{\frac{1}{1-\sigma}}. \tag{4}$$

Production

Firms are indexed by i and j. To produce output, each firm combines labor and intermediate inputs produced by other firms. The usage of other firms' products as intermediate inputs gives rise to a firm-to-firm production network. Firms can also use imported materials as intermediate inputs. There are F number of foreign countries indexed by f. The output of firm i is given by the following nested constant-elasticity-of-substitution (CES) production function

$$y_i = \left[(1-\mu_i)^{\frac{1}{\epsilon}} l_i^{\frac{\epsilon-1}{\epsilon}} + \mu_i^{\frac{1}{\epsilon}} m_i^{\frac{\epsilon-1}{\epsilon}} \right]^{\frac{\epsilon}{\epsilon-1}}, \tag{5}$$

where l_i is the amount of labor hired by firm i, μ_i is the firm-specific intermediate input share, and ϵ is the elasticity of substitution between labor and intermediate inputs.[1] The intermediate input bundle, m_i, is given by

$$m_i = \left[\sum_{j=1}^{N} a_{ij}^{\frac{1}{\sigma}} x_{ij}^{\frac{\sigma-1}{\sigma}} + \sum_{f=1}^{F} a_{if}^{\frac{1}{\sigma}} x_{if}^{\frac{\sigma-1}{\sigma}} \right]^{\frac{\sigma}{\sigma-1}}, \tag{6}$$

where x_{ij} is the amount of good j used in the production of good i, x_{if} is the amount of materials imported from country f, and σ is the elasticity of substitution between different intermediate inputs. The weights of good j in the domestic market and imports from country f are parametrized by a_{ij} and a_{if} respectively. A larger value of a_{ij} means that firm i is more dependent on good j. If firm i does not use good j in its production, $a_{ij} = 0$.

[1] The production function does not feature any productivity shocks because the focus of this paper is on the impact of foreign shocks.

Analogously, if firm i does not import from country f, we have $a_{if} = 0$. I normalize these weights to have $\sum_{j=1}^{N} a_{ij} + \sum_{f=1}^{F} a_{if} = 1$ for all i. Note that the CES production function encompasses several widely-used functions as special cases: Cobb-Douglas ($\sigma \to 1$), perfect substitute ($\sigma \to \infty$), and Leontief ($\sigma \to 0$). Although these special cases are easy to work with, they shut down many important margins of shock response and fail to generate realistic propagation patterns. As pointed out by Baqaee and Farhi (2019), the Cobb-Douglas specification is the only knife-edge case in which the Hulten's theorem (Hulten (1978)) applies. As we deviate from $\sigma = 1$, the errors of the first-order approximation increasingly become large.

Marginal costs and prices

The marginal cost of the intermediate input bundle m_i is given by

$$z_i = \left[\sum_{j=1}^{N} a_{ij} p_j^{1-\sigma} + \sum_{f=1}^{F} a_{if} p_f^{1-\sigma} \right]^{\frac{1}{1-\sigma}}, \tag{7}$$

where p_j is the price of good j and p_f is the import price of goods from country f. The import price p_f incorporates iceberg trade costs, and is common to all firms. It is exogenous and does not respond to any general equilibrium adjustments in the domestic economy. When I conduct the simulation analyses of the foreign shocks, I change p_f to reflect potential geopolitical risks.

Due to perfect competition, the price of good i equals to its marginal cost. The price of good i is thus given by

$$p_i = \left[(1 - \mu_i) \, w^{1-\epsilon} + \mu_i z_i^{1-\epsilon} \right]^{\frac{1}{1-\epsilon}}, \tag{8}$$

where w is the wage rate. Because the above expression of p_i includes z_i, which contains $\sum_{j=1}^{N} a_{ij} p_j^{1-\sigma}$ as in (7), we can see the interdependence of product prices. If firm i is connected to many low-cost suppliers ($a_{ij} > 0$ for lower p_j), its price p_i becomes lower as well. This "supplier cost advantage" is further magnified by μ_i. Also, the negative impact from the foreign shocks (a hike in p_f) becomes more severe if firm i is heavily dependent on the imported inputs (a large a_{if}).

Demand for labor and materials by firm i is given by

$$l_i = (1 - \mu_i) \left(\frac{w}{p_i} \right)^{-\epsilon} y_i \tag{9}$$

$$m_i = \mu_i \left(\frac{z_i}{p_i} \right)^{-\epsilon} y_i \tag{10}$$

Demand for domestic and imported intermediate inputs by firm i is given by

$$x_{ij} = a_{ij} \left(\frac{p_j}{z_i} \right)^{-\sigma} m_i$$

$$x_{if} = a_{if} \left(\frac{p_f}{z_i} \right)^{-\sigma} m_i$$

Exports

Firms can sell their products to other firms in the domestic market, the final consumer in the domestic market, and other countries as exports. Firm-specific demand shifter for product i in country f is denoted by Δ_{fi}. Foreign countries have the same demand elasticity σ as the domestic household. If firm i does not export to country f, I set $\Delta_{fi} = 0$. Export demand for firm i is characterized by

$$c_{fi} = \Delta_{fi} p_i^{-\sigma}, \tag{11}$$

where c_{fi} is the exported amount of good i to country f.

Market clearing and trade balance

For product i, goods market clearing condition implies

$$y_i = c_i + \sum_{f=1}^{F} c_{fi} + \sum_{j=1}^{N} x_{ji}, \tag{12}$$

where the three terms represent domestic final demand, foreign demand, and sales to other firms as intermediate inputs, respectively.

Labor market clearing implies that

$$L = \sum_{i=1}^{N} l_i. \tag{13}$$

Aggregate (not country-specific) trade balance is given by

$$\underbrace{\sum_{i=1}^{N}\sum_{f=1}^{F} p_f x_{if}}_{\text{imports}} - \underbrace{\sum_{i=1}^{N}\sum_{f=1}^{F} p_i c_{fi}}_{\text{exports}} = D, \tag{14}$$

where D is a trade deficit.

2.2 Equilibrium

The equilibrium of this economy is defined in a usual way.

Definition 1. Given a set of parameters $\sigma, \epsilon, L, \{\xi_i\}, \{\mu_i\}, \{a_{ij}\}, \{a_{if}\}, \{\Delta_{fi}\}, \{p_f\}$, the equilibrium of this economy consists of a price vector $\{p_i\}$ and a set of quantities that satisfy equations (1) - (14).

As in Lim (2018), we can define the following *network productivity and demand* respectively

$$\Phi_i = p_i^{1-\sigma}$$
$$\Delta_i = m_i z_i^{\sigma}.$$

These terms concisely summarize the importance of firm i as a supplier and a customer in the economy. Also, define the demand shifter of firm i, D_i, as

$$D_i = \Delta_H \xi_i + \sum_{f=1}^{F} \Delta_{fi} + \sum_{j=1}^{N} \Delta_j a_{ji}.$$

Then, sales by a supplier j to a customer i can be expressed as

$$p_j x_{ij} = a_{ij} \Delta_i \Phi_j$$

and the total sales of firm i can be expressed as

$$p_i y_i = D_i \Phi_i.$$

To solve for Φ_i and Δ_i, we can use equations (5) - (8). Since $0 < \mu_i < 1$ and $a_{ij} \leq 1$ for all i and j, the contraction mapping theorem holds. It is guaranteed that iteration on Φ_i and Δ_i converges to the unique solution.[2]

[2] I use MATLAB's sparse matrix functions for this iteration. The network matrix $A = [a_{ij}]$ cannot be

For counterfactual simulations, I change p_f to describe import shocks and Δ_{fi} to describe export demand shocks.

3 Data

Data come from two sources: Tokyo Shoko Research (TSR) Company Database and the Basic Survey of Japanese Business Structure and Activities (the Basic Survey, henceforth) collected by the Ministry of Economy, Trade and Industry (METI).

TSR is a credit reporting company which collects the business information of more than a million firms in Japan. Firm-level data in year 2021 is used in this research. The dataset reports the basic firm demographics such as sales, the number of employees, address of the headquarters, and JSIC (Japan Standard Industry Classification). I drop firms whose fiscal duration is not 12 months or JSIC corresponds to public sectors (local municipalities, social security service, and so forth)[3]. To accelerate computation, I also drop firms whose sales is less than 300 million yen (approx. two million USD). This results in the sample of 249491 firms. Due to the fat-tailed distribution of sales, the resulting sample covers more than 95% of total sales in the original sample. TSR data also report whether a firm is an exporter, importer or both. Although this is an indicator variable (the value of trade is not recorded), I use this information to impute the trade values using the sectoral trade share data from the input-output table. A unique feature of the TSR data is its firm-to-firm transaction network. TSR reports suppliers and customers of each firm up to 24 partners. Though this upper limit of 24 partners seems restrictive, we can grasp the good picture of the entire network by merging self-reported and other-reported data. For instance, a large automaker reports its suppliers up to 24, but many other firms may report this automaker as their customer. In this way, the truncation threshold of 24 does not matter much. As discussed in Bernard et al. (2019) and Carvalho et al. (2020), the degree distribution of the TSR network is very skewed and well approximated by a Pareto distribution. In my sample of about a quarter million firms, the median number of customers and suppliers are both three whereas the top firms have more than 3,000 suppliers or customers.

The Basic Survey is government statistics and reports the firm demographics such as sales, profits, purchase of intermediate inputs, industry classifications, and balance

programmed in a standard way because the number of firms is around a quarter million. Also, we should avoid computing the Leontief inverse matrix because the inverse of a sparse matrix is dense, and a standard memory cannot store the results.

[3] In the four-digit JSIC, they are 4852, 6211, 6222, 6491, 6513, 6732, 7299, 8311, 8429, 8511,8711, 8721, 9300 or above.

sheets for the universe of firms who have more than 50 employees and capital amount of 30 million yen (approx. 200,000 USD). In 2021, around 34,000 firms are surveyed in this dataset. The Basic Survey also reports firm-level import and export values by six regions (China, Asia excluding China, Middle East, Europe, North America, and Other). There are about 8,000 exporters and importers in the dataset.

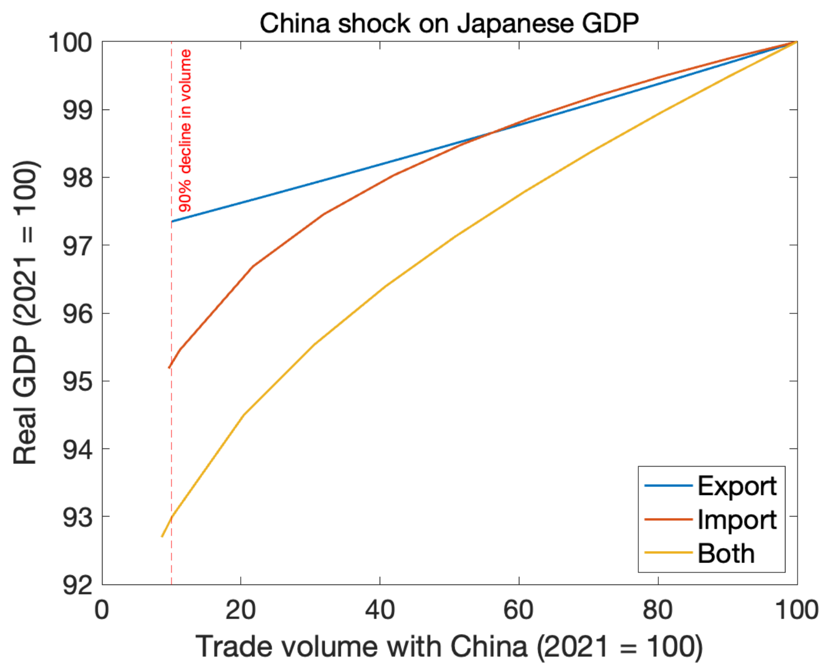
The TSR data and the Basic Survey are merged using corporate numbers (*"hojin bango"* in Japanese). Among the quarter million firms in the TSR data, around 30,000 firms are also collected in the Basic Survey. If a firm appears in both datasets, I use sales values in the Basic Survey although these two are almost identical. For the firms in the Basic Survey, I also use their purchase of intermediate inputs to calibrate μ_i (intermediate input share) in the model. For other firms (TSR firms), I impute this parameter based on sectoral intermediate input shares from the Japan Industrial Productivity (JIP) input-output table. There are firms who are identified as exporters or importers in the TSR data, but do not appear in the Basic Survey. For those firms, I first impute their firm-level export or import values using the trade shares data from the JIP database. Then, the total export or import values are allocated to six regions based on the sector-region shares in the Basic Survey data. Since the TSR network data do not report the transaction values (intensive margin), I impute a_{ij} using the suppliers' sales as weights. In the benchmark calibration, I set $D_T = 0$. With the calibrated parameters, the trade to GDP ratio becomes 19.7%, which roughly matches the aggregate trade data in 2021-2022.

4 Simulation Results

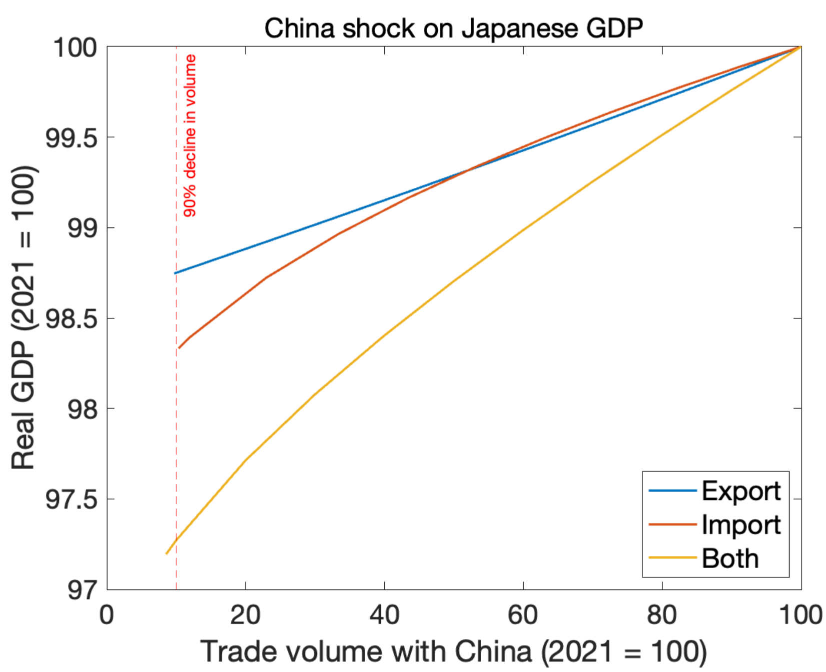
This section presents the counterfactual simulation results on the impact of trade disruption with China. I consider three different scenarios of trade disruption: 1) export only, 2)import only, and 3) both. In case of export disruption, I lower the export demand shifter of China $\Delta_{China,i}$ to all firms uniformly. In case of import disruption, I raise the price of imported goods from China p_{China}. In case of both disruption, I lower Δ_{China} and raise p_{China} simultaneously.

The impact of trade disruption on the macroeconomy critically depends on the values of σ (elasticity of substitution across intermediate inputs) and ϵ (elasticity of substitution between labor and materials). When σ is high, firms can easily substitute disrupted inputs with alternative inputs, and hence, the macro impact would be small. Carvalho et al. (2020) carefully estimates the values of σ and ϵ using the same TSR firm network data. They employed the Great East Japan Earthquake in 2011 as a natural experiment to supply chain disruption, and obtained estimated values of $\sigma = 1.183$ and $\epsilon = 0.593$. I use these values for my benchmark calibration. Since their estimation uses year-to-year variations, I interpret these numbers as the elasticities of substitution at one year horizon, and call it short run. For longer time horizons, I use higher values of σ. I interpret the difference in σ corresponds to the difference in time horizon. For instance, I interpret $\sigma = 2$ as the long-run elasticity, which corresponds to a five-year horizon.

Figure 1 displays the impact of trade disruption with China on the real GDP in Japan. The upper panel shows the effect in the short run ($\sigma = 1.183$) and the lower panel shows the effect in the long run ($\sigma = 2$). The horizontal axis is the trade volume and the vertical axis is the real GDP (both are indexed to be 100 in 2021). Three lines correspond to the export only, import only, and both disruption cases. We should read the graph from the right to left. As the trade volume plunges due to exogenous disruption, the real GDP (welfare) declines. The impact of export disruption (blue line) is linear whereas the impact of import disruption (orange line) is non-linear. The model exhibits constant returns to scale implying that the price system and demand system are determined independently leading to the liner impact of export disruption (demand decline). Hence the price of each firm depends non-linearly on other firms' and import prices, the effect of import disruption becomes non-linear. If the trade volume with China declines by 90%, the export, import, and both disruption cause 2.7%, 4.8%, and 7% drop in real GDP respectively within a year. The bottom panel of Figure 1 shows the same exercise with a higher σ. I interpret this value corresponds to long-run horizon of five years. In the long run, the impact of disruption becomes milder and both export and import disruption causes 2.7% decline in real GDP.



(a) short run ($\sigma = 1.183$)



(b) long run ($\sigma = 2$)

Figure 1: The impact of trade disruption with China on real GDP

The differential impacts of trade disruption at different time horizons are summarized in Figure 2. The figure illustrates the impact of both disruption with different values of σ. As σ becomes larger, the impact becomes smaller.

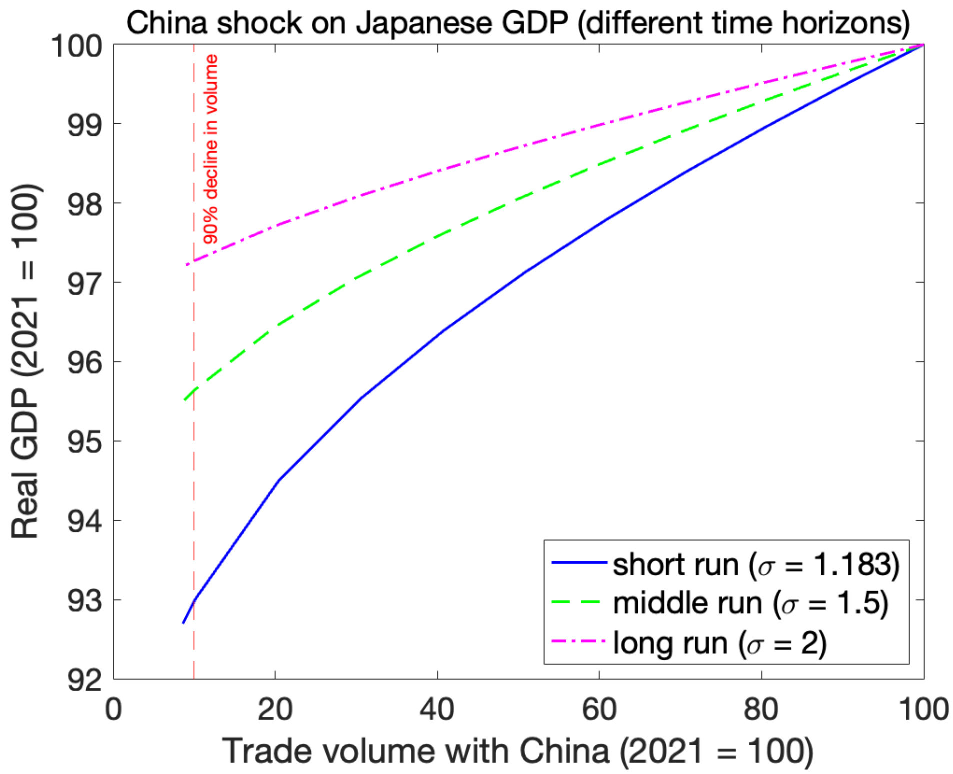
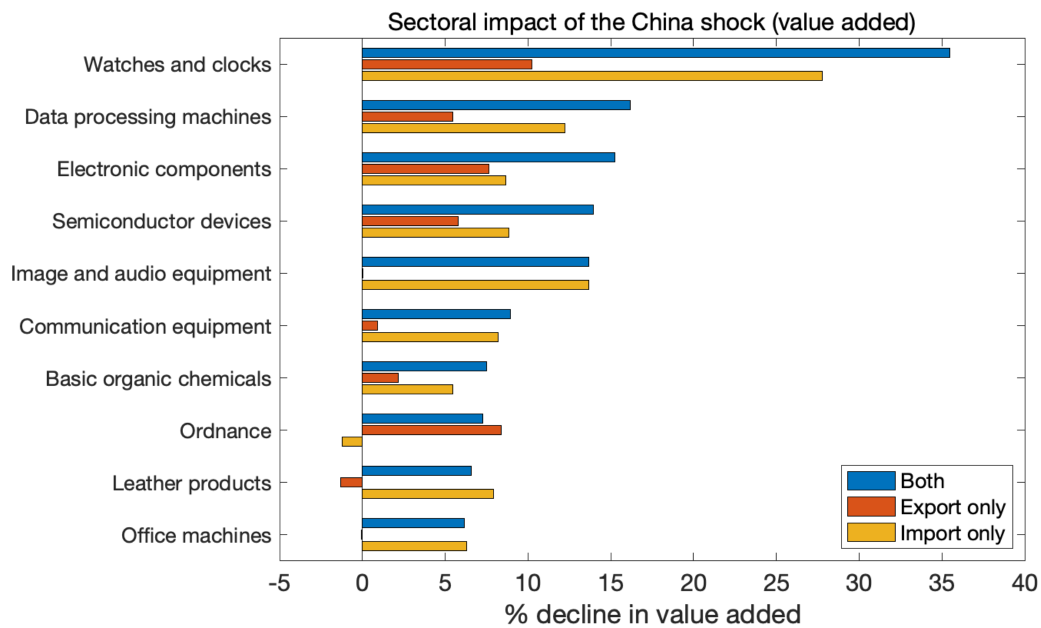
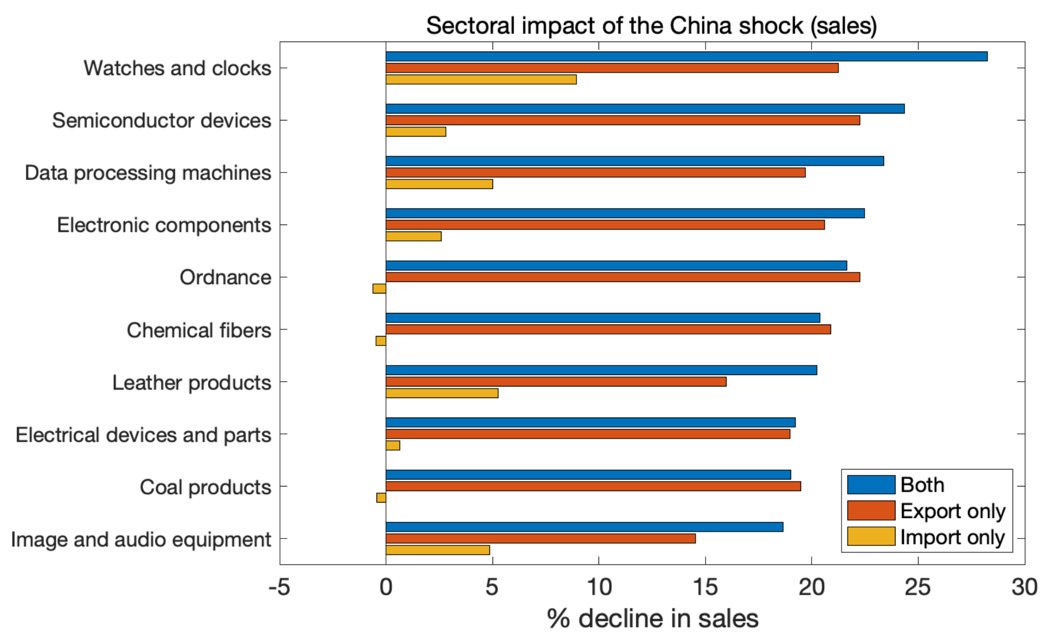


Figure 2: China shock at different time horizons

The impact of trade disruption with China is heterogeneous across sectors. Figure 3 displays the 10 most affected sectors in terms of value added (top panel) and sales (bottom panel) in the benchmark case. Regarding value added, we can see that the trade disruption with China most severely affect watches and clocks sector. Most of the impact comes from import disruption. This is due to the fact that watches and clocks sector is heavily dependent on intermediate inputs imported from China. For most of the top 10 sectors, import disruption causes severe damage, not export disruption except for ordnance sector. The main buyer of the Japanese ordnance sector is China, and thus, the export disruption slushes the value added in ordnance sector. Regarding sales, the top 10 sectors are similar, but the main driver of the decline is export disruption.



(a) value added



(b) sales

Figure 3: Sectoral impact of the China shock

5 Conclusion

Two recent episodes, Russian invasion of Ukraine and the US-China decoupling, underscore that key trade policies nowadays are shaped by geopolitical risks and economic security motives. In Japan too, economic security is being discussed as an important policy theme mainly because of the uncertain outlook for Japan-China relationship. Japan is heavily dependent on China for both exports and imports, yet some policymakers and critics warn against the current situation due to geopolitical risks. This paper attempts to quantify the impact of trade disruption with China on the Japanese economy via supply chains.

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A Trade with Russia

Figure

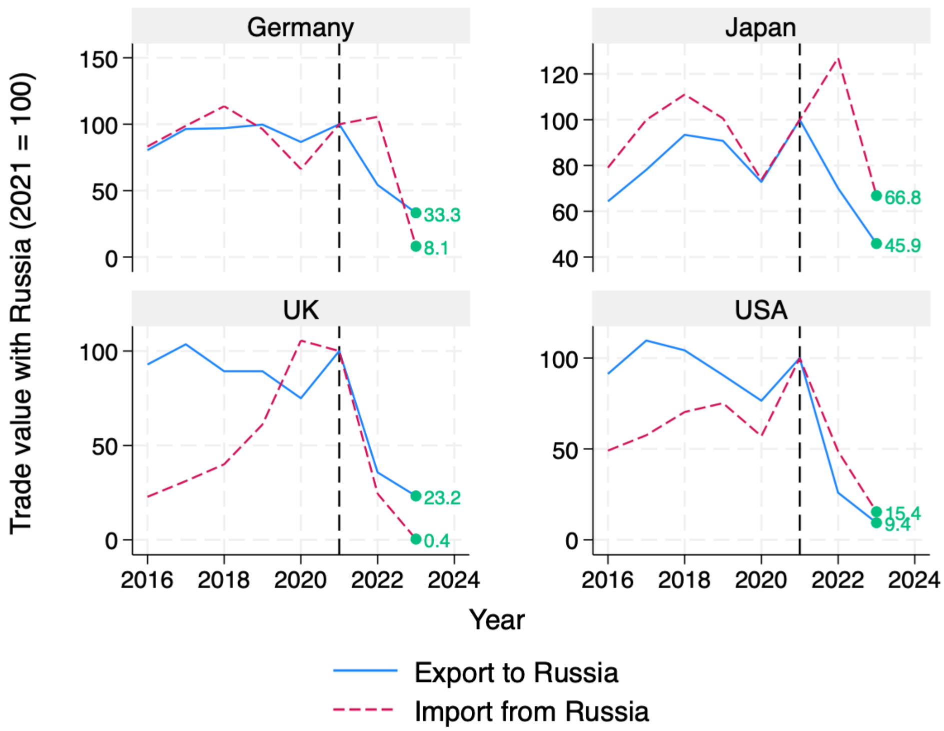

Figure 4: Trade with Russia