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How Resilient Was Trade to COVID-19?

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Abstract

This paper examines which product supply-side characteristics affect the resilience of traded products to the COVID-19 pandemic. Relying on monthly product-level exports by all countries to the United States, Japan, and 27 European Union countries from January 2018 to December 2020, the paper estimates a difference-in-differences specification for the impact of COVID-19 incidence (deaths per capita) mediated by product characteristics, accounting for when exports reach their destination by relying on product transportation lags. Higher reliance on foreign inputs, China as an input supplier, and unskilled labor and a lower degree of complexity negatively affected exports as a result of COVID-19.

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How Resilient Was Trade to COVID-19? *

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Introduction

The sudden onset of the COVID-19 shock in early 2020 resulted in substantial disruptions to economic activities as a large share of the global population was confined at home and a myriad of restrictions aimed at reducing the spread of the virus were put in place. Between January and June 2020, the volume of global trade retraced by 13 percent with a sharp rebound from then onwards (World Bank, 2020). The sudden drop in the supply of products from China led to debates on whether the increased exploitation of global comparative advantage, which in the decade prior to COVID-19 turned China into the world's manufacturing powerhouse, had produced a dangerous dependence. The unprecedented social distancing restrictions brought by the COVID-19 pandemic presented additional challenges to global production with reductions in in-person production.

An unexplored question we address in this paper is which are the supply-side characteristics of products that determined the vulnerability, or on the contrary, the resilience of their trade to the pandemic in 2020. We focus on how the following characteristics of exported products mediate the impacts of the COVID-19 crisis: unskilled labor-intensive production, production relying more on imported inputs, on inputs from dominant suppliers or for which China is a dominant supplier, and complex knowledge-intensive production.

Our identification strategy is based on a stringent difference-in-differences specification with bilateral monthly product exports (at Harmonized System (HS) 4-digit level) by all countries to 29 major markets - the 27 European Union (EU) countries, Japan, and the United States (US) – as the dependent variable. The main regressors are interaction terms between measures of COVID-19 incidence (death over population) and proxies for production vulnerability. We capture the effect of the COVID-19 shock by exploring how the response of exports for a given exporting country-importing country pair at the product level over time is mediated by production vulnerability measures. Our measures of COVID-19 incidence account for the distance and transport mode between countries through the use of specific lags at the HS 4-digit product - henceforth HS4 product - and country-pair levels. Our specification includes exporting country-importing country-product fixed effects and thereby exploits variation *within* exporting country-importing country-product triplets over time as the pandemic unfolded, relative to the period before the pandemic. Moreover, it includes exporting country-time (month-year) and importing country-time (month-year) fixed effects, which control for time-varying unobservable supply and demand shocks affecting exports during this period.

Our main findings are as follows. First, we find that the reliance on inputs for which China is a dominant supplier and unskilled intensity in production resulted in major negative effects of the COVID-19 shock on exports. Specifically, our estimates show that countries with higher COVID-19 deaths per capita decreased their exports of products that rely more on either inputs for which China is a dominant supplier or on unskilled workers. Our findings also suggest that exported products relying more on imported inputs suffered more from the COVID-19 shock. Finally, we find that exports of less complex and knowledge-intensive products were more vulnerable to the COVID-19 shock. Our estimates imply that countries with higher COVID-19 incidence by its median value experience larger declines in exports of more unskilled labor-intensive products by 1.5 percentage points, products with a higher reliance on inputs for which China is a dominant supplier by 1.69 percentage points, products with higher reliance on foreign inputs by 0.81 percentage points, and products with a lower degree of complexity by 1.09 percentage points, with higher vulnerability captured by the difference between the measures' 10th and 90th percentiles. The findings are robust to the use of alternative measures of production vulnerability and COVID-19 incidence (including the lag structure used), clustering of standard errors, and sample periods.

Second, we identify the following heterogeneous impacts. The negative effects of reliance on imported inputs and unskilled labor were more important in the last quarter of 2020, while the negative effects of reliance on inputs for which China is a dominant supplier were concentrated in the second quarter of 2020. Moreover, we find that our main results for the different product vulnerabilities are mainly driven by exports of intermediate products. Also, all product vulnerabilities affected negatively exports by richer countries while for poorer countries stronger negative effects on exports were experienced from unskilled and less complex and knowledge-intensive production and reliance on less diversified foreign input providers.

Our findings have important policy implications. Our evidence suggests that the diversification of input suppliers matters since a higher concentration of input providers and strong reliance on China hurt trade as the COVID-19 shock hit. Proposed approaches range from rethinking global production arrangements to revisiting the very strong reliance on a small set of foreign suppliers and the role of localized production (e.g., Javorcik, 2020). Simply reducing imports would result in considerable cost increases for global production (Baldwin et al., 2021; Grossman et al., 2021; OECD, 2021).

Our evidence also suggests that improving virtual collaborations and automation can increase resilience to future pandemics since exports of less complex products and that require unskilled labor inputs fared much worse in face of the COVID-19 shock. Adoption of digital technologies and learning can reduce production vulnerabilities by effectively substituting for in-person collaboration in production (Barrero et al., 2022). Automation of production can also reduce production vulnerabilities but at the risk of potential negative impacts on unskilled employment (that is more easily replaced by machines) that can only be addressed through investments in worker upskilling and alternative models for revenue sharing in the economy (Guellec and Paunov, 2019; Autor et al., 2020).

The main contribution of our study relative to the growing literature on the pandemic's effects on trade is the emphasis on the role of product resilience. We provide empirical evidence to inform two debates: whether reliance on inputs from abroad, and China in particular, caused more vulnerabilities and how social distancing measures affected global production and exports. Thereby, our paper adds to the studies of the impacts of COVID-19 on trade and GVCs (e.g., Bonadio et al. 2021; Cerdeiro and Komaromi, 2020; Crozet et al. 2021; Demir and Javorcik 2020; Espitia et al. 2022; Fujiy, et al., 2021; Lachitew and Socrates, 2020). Using cross-country-product-month level data, Berthou and Stumpner (2021) show that lockdown measures implemented by exporter and importer countries impacted trade. Bricongne et al. (2021), Pimenta et al. (2021), and Lucio et al. (2021) also show that lockdown stringency in destination markets reduced, respectively, French, Portuguese, and Spanish firms' exports at the onset of the COVID-19 crisis.

Closer to our work, Liu et al. (2021) show better performance in the early phases of the pandemic of Chinese exports of medical products, products with a high share of work from home, high contract intensity, and capital goods, while Lafrogne-Joussier et al. (2021) look into one production vulnerability, the reliance on inputs from China, showing that French firms with higher such reliance suffered more input shortages that translated into a decline in their exports through input-output linkages. These two papers differ from ours in that they focus on single countries' exports (China and France) and single or few specific dimensions of how production was affected by COVID-19, while our analysis covers exports by all countries to the 29 largest markets and an encompassing set of product vulnerability dimensions. Differently from these studies, our paper shows where vulnerabilities in global product supply arose in the short-term and identifies the costs and benefits of building more resilience.

Our study also relates to the literature that studies the responses of trade to other crises and shocks. An important branch focuses on the 2008-2009 global financial crisis and the causes of the ensuing dramatic decline in trade (Ahn et al., 2011; Amiti and Weinstein, 2011; Behrens et al., 2012; Bricongne et al., 2012; Chor and Manova, 2012; Crozet et al., 2020; Levchenko et al., 2010; Eaton et al., 2016a). Another branch studies the effect of natural disasters or other unexpected shocks on trade and GVCs (Gassebner et al., 2010; Barrot and Sauvagnat, 2016; Boehm et al., 2019; Carvalho et al., 2021; Borin et al., 2022), while another explores the international transmission of foreign shocks (e.g., Johnson, 2014; Eaton et al., 2016a, 2016b). In addition to examining the unprecedented COVID-19 crisis, our paper differs from these studies by focusing on the drivers of trade resilience, helping in this way to pinpoint factors that need to be considered by policies aimed at building resilience.

The paper is organized as follows. Section 1 presents a conceptual discussion for the hypotheses we test. Section 2 describes the data while Section 3 discusses the empirical approach. Our results are presented in Section 4. Section 5 concludes.

1. Conceptual discussion and testable hypotheses

To guide our empirical analysis, we identify potential vulnerabilities or resilience of exports to the COVID-19 shock within a standard production function framework. Consider exports of Y produced using four inputs: unskilled labor (U), skilled labor (S), intermediate inputs (I), and capital (K): $Y = f(A, U, S, I, K)$, where A is total factor productivity, capturing everything in the production process related to the effective combination of a set of inputs to produce an output. The COVID-19 shock affected export production through all the production factors.

First, the COVID-19 shock reduced overall in-person labor supply due to social distancing to avoid infection and lockdowns imposed by governments to address the shock. This labor supply shock is relevant for all economic activities that are not possible to execute from home. Given the differential nature of their tasks, this shock affected mostly unskilled labor since highly skilled labor was better able to continue to work from home. As highly skilled workers shifted to remote work substituting in-person for virtual exchanges, the COVID-19 shock may have benefited production intensive in such workers. This hypothesis is supported by evidence in Barrero et al. (2021) that workers in higher earnings categories experienced productivity gains from remote work during the COVID-19 period. Our first hypothesis to test in the empirical work is as follows:

H1: A larger unskilled labor intensity of production was a source of vulnerabilities in the COVID-19 pandemic.

Second, the COVID-19 shock resulted in global disruptions in production and trade of intermediate inputs and capital. Thus, products that rely on foreign-produced inputs and capital are likely to be more negatively affected by the pandemic. Moreover, supply chains relying on a poorly diversified portfolio of input suppliers may be at higher risk of disruption and less able to absorb an adverse shock affecting production or trade from specific origin countries. In the early COVID-19 phase, the disruption of production in China may have greatly hindered the production processes of manufacturing GVCs highly dependent on Chinese imports. Our second hypothesis to test in the empirical work is as follows:

H2: Exports of intermediate inputs and capital goods relying more heavily on imported intermediates were more vulnerable to the pandemic. Further, downstream production and exports relying strongly on intermediates and capital goods for which either exports are *highly concentrated in a few producer countries or the main world supplier is China were more vulnerable to the pandemic.*

The COVID-19 shock may have adversely affected productivity due to reduced mobility and the disruption in in-person production activities but less so for more complex and knowledge-intensive products. This is because, for such products, productivity relies more on knowledge collaborations that were effectively shifted to virtual exchanges. The exponential growth of virtual online interactions for research and innovation collaborations - critical for productivity - and the wider use of virtual platforms have proven to be highly effective as is illustrated by the surprisingly quick responses to the pandemic, namely the rapid development of vaccines (Paunov and Planes-Satorra, 2021). Our third hypothesis to test in the empirical work is as follows:

H3: The productivity of complex and knowledge-intensive production processes may increase relative to that of less complex and knowledge-intensive processes since the former benefited more from remote work interactions. Hence less complex and knowledge-intensive products were more vulnerable to the pandemic.

2. Data

High-frequency bilateral product level trade data

Our analysis relies on several sources of data. For trade outcomes, we use monthly data on import flows at the product level by the major markets of the 27 EU countries, Japan, and the US fromJanuary 2018 to December 2020. The specific sources of data are, respectively, Eurostat monthlytrade flows for EU countries, the Ministry of Finance for Japan, and the United States InternationalTrade Commission for the US. These data are exploited to examine the evolution of export flows by all countries to these major markets – that represented half of global GDP and 28% of global imports pre-COVID-19 – as the pandemic unfolded.

All the data sets include the country's import flows from all partner countries for each product at the HS 6-digit or 8-digit level providing information on import value (in US dollars) and quantity or weight. We aggregate the data to the importing country-HS4 product-partner country-month-yearlevel concording product codes to the HS 2007 revision for comparability across countries, computational feasibility and to mirror the product resilience categories we rely on.

Using mirror import data to capture export flows has two advantages. First, import flows are better recorded than export flows, especially by high-income low-corruption countries such as our major markets (e.g., Javorcik and Narciso, 2017). Second, import flows are reported and made public quickly by those high-income countries while high-frequency export flows from all countries are reported with long delays to UN COMTRADE.

COVID-19 incidence data

For COVID-19 incidence, we use the total number of reported COVID-19 deaths per capita per month in each country from the World Health Organization (WHO) Global Health Observatory Repository from December 2019 onward.[1] In robustness tests, we consider alternative measures of COVID-19 incidence. The number of COVID-19 cases per capita, also from the WHO, and a measure of stay-at-home requirements imposed by each country each month from the Oxford COVID-19 Government Response Tracker are used in other research on COVID-19 impacts (e.g., Bonadio et al., 2021; Chen et al., 2020).[2]

[1] See https://github.com/owid/COVID-19-data/tree/master/public/data.
[2] See https://www.bsg.ox.ac.uk/research/research-projects/coronavirus-government-response-tracker#data.

Defining the lag structure of impacts

Exporting involves lags between the product departure from the exporting country and arrival to the destination country. Since we rely on import data by major destination countries to studythe impacts of COVID-19 incidence in the exporting country, it is crucial to carefully define the lag structure for the impacts. For example, identification critically relies on understanding if India's exports recorded by the US (as imports) in October 2020 were expedited from India in June, July, August, or September 2020. Previous studies argue that shipment times average 2-3 months (Brincogne et al., 2012). But these times depend on the transportation mode which varieswith the type of product. Continuing with the example, we may mistakenly attribute India's September 2020 COVID-19 incidence to products already expedited in July 2020. This issupported by evidence from Flaaen et al. (2021) who use daily data from bill of lading informationfor US imports and Indian exports to show that India's national lockdown announced on March 24, 2020, led to a decline in India's exports to the US recorded in US import data only 5-10 weekslater due to shipping lags.

Consequently, we apply a product-specific origin-destination country lag structure for the COVID-19 incidence variable's impact on trade combining US Census data on HS4 imports by transportation mode in 2015 with searates.com data on shipping days between capital cities as of early 2020 as follows:

(i) For HS4 products whose share of imports by air transport is above 75 percent, a one-month lag is used;

(ii) For the remaining HS4 products, the lag length depends on the number of shipping days between the country pair: one-month for fewer than 7 shipping days, two-month for 7 to 29 shipping days, three-month for 30 to 59 shipping days, and four-month for more than 60 shipping days.

(iii) For landlocked exporter and/or importer countries, we add the number of days needed to transport goods by road from (or to) the closest port to (or from) the capital using the shortest road distance from Google Maps as in Akbar et al. (2018) and Zarate (2021).

Product vulnerability measures

We rely on several data sources to construct proxies for production resilience which we map to our HS4 product categories. First, we use data from US NBER-CES Manufacturing Industry Database on the unskilled labor intensity of production: the ratio of unskilled (blue-collar) employment to capital for each 6-digit 1997 NAICS industry in 2011 (the most recent year available).

Second, we rely on OECD's harmonized input-output tables for 2011 to compute sectoral imported input contents following Hummels et al. (2001).[3] We compute the reliance of production on imported inputs as the ratio of imports over the sum of output plus imports minus exports by ISIC 2-digit industry and exporting country. Using a measure with country variation (from the input-output table) accounts for different countries' sources of different inputs.

Third, we use export data from UN COMTRADE at the exporting country-HS4-year level combined with the aforementioned OECD harmonized input-output tables to construct measures of (i) the reliance on China as a supplier of inputs for production of each sector and (ii) the

[3] OECD input-output tables are available for 63 countries (all 36 OECD countries and a variety of other countries including several developing countries). Since our monthly trade data cover exports for an additional 158 countries with no OECD input-output tables, we assign to each of those countries the input-output table from the country that is most similar in terms of three dimensions: level of development captured by GDP per capita, size captured by population and economic structure captured by share of manufacturing value added, all from World Development Indicators. We assign to countries with no input-output table the table of the country with the lowest aggregate difference across the three dimensions, which we aggregate using inverse-variance weighting.

concentration (across producer countries) in the exports of intermediates used by a sector. To obtain (i), we calculate for each HS4 product the share of China in the product's world exports in 2015. We average this share by ISIC revision 3 broad sector (the classification used in the input-output tables), after mapping HS4 products to broad sectors. Then, we use each country's input-output table to construct for each given broad sector X the reliance on China as supplier of its inputs as the weighted average across all the broad sectors' average China share, where weights are given by the shares of inputs from each broad sector used for production of broad sector X's output. To obtain (ii), we calculate for each HS4 product the share of its largest exporter in the world in 2015. Then, we use each country's input-output table to construct for each given broad sector X the export concentration of its inputs as the weighted average across all the broad sectors' average share of the largest exporter, where weights are given by the shares of inputs from each broad sector used for production of broad sector X's output. We then map these two measures at the broad sector level into the HS4 level. The resulting measures vary at the exporting country and HS4 product level. Allowing for these two dimensions of variability is important since different countries are likely to source very different inputs.

Fourth, as a proxy for technology, we use product complexity defined as the weighted average of the GDP per capita of the countries that export the HS4 product, where weights are given by countries' revealed comparative advantage (RCA) index in that product following Hausmann and Hidalgo (2009, 2011). We compute this RCA (Balassa) index, the ratio between the share of an HS4 product in a country's export portfolio and the share of the same product in world exports, using data from UN COMTRADE and GDP per capita data from the World Development Indicators for 2012.

Finally, as a control variable we use an indicator for COVID-19 medical products from the World Trade Organisation at the HS4 product level.[4] Summary statistics are provided in Appendix Table 1.

3. Empirical approach

Our empirical specification to test the hypotheses discussed in Section 2 consists in a difference-in-differences specification that estimates the within effect of the COVID-19 shock on bilateral exports to each major market mediated by proxies for production vulnerability or resilience as in:

$$Y_{eipt} = \sum^{v} \beta_v \; covid\_incid_{et-n} * vulnerability_{v,p} + \sum^{v} \varphi_v \, covid\_incid_{et-n} * vulnerability_{v,ep} + \sum \alpha \; covid\_incid_{et-n} * X_p + k_{eip} + \theta_{et} + \pi_{it} + \varepsilon_{eipt} \qquad (1)$$

where Y is the logarithm of the value of exports by country e of HS4 product p to destination market i in month-year t and ε is an independent and identically distributed error term. The coefficients of interest (β_v, φ_v) are those on the interactions between each of the measures of $vulnerability_{v,p}$ at the product level (unskilled labor intensity and complexity) or $vulnerability_{v,ep}$ at the product-exporting country level (reliance on imported inputs, export concentration of inputs, and China export share in inputs) and lagged COVID-19 incidence $covid_{incid_{et-n}}$ is the number of reported COVID-19 deaths per capita per month in each exporting country using the lags defined in Section 2.

By including exporting country-importing country-HS4 product fixed effects k_{eip}, Equation (1) identifies the coefficients based on the within (time-series) variation in bilateral export flows at the product level as the COVID-19 shock unfolds. Exporting country-month-year fixed effects θ_{et} account for changes in economic conditions in the exporting country related or unrelated to

[4] http://www.wcoomd.org/-/media/wco/public/global/pdf/topics/nomenclature/covid_19/hs-classification-reference_2_1-24_4_20_en.pdf?la=en.

the COVID-19 shock that may affect their exports (e.g., exchange rate shocks or any other supply shifters). Importing country-month-year fixed effects $\pi_{"\$}$ account for the COVID-19 incidence in the destination markets and any changes in economic conditions that may affect their imports (e.g., exchange rate shocks or any other demand shifters).[5]

To address the possibility that our coefficients of interest pick up the impact of other product characteristics correlated with product resilience, the vector $X_{\#}$ includes the indicator for COVID-19 medical products whose demand increased due to the COVID-19 shock. We estimate Equation (1) by OLS. Inference is based on robust standard errors clustered by exporting country and the most aggregate product characteristic (unskilled-intensive products) referred to as broad sector. Our findings are robust to clustering by exporting country and HS4 product.

4. Results

Baseline results

The results from estimating the effects of COVID-19 incidence on trade flows depending on product vulnerability are presented in Table 1. We first explore the effect of the shock on trade flows by simplifying Equation (1) to include only the number of reported COVID-19 deaths per capita per month in each exporting country. The estimates in columns (1) and (2) suggest that countries with more COVID-19 deaths reduce more their exports on average across all products over time in line with previous work (Berthou and Stumpner, 2021; Liu et al.,2021).

Next, we test the hypotheses discussed in Section 2. Starting with our first hypothesis, our estimates show that countries with a higher incidence of COVID-19 deaths reduce relatively more their exports of unskilled labor-intensive products (column 3). Our findings also confirm our

[5] Exporting country-month-year fixed effects also account for COVID-19 incidence in levels included in theinteraction model while production vulnerabilities in levels are embedded in the panel fixed effects (exporting country-importing country-product).

second hypothesis on the effect of COVID-19 on trade via global supply chain vulnerability, as exports of products that rely more on inputs for which China is a dominant supplier declined more in countries with a higher incidence of the COVID-19 shock (column 4). Moreover, exports of products more involved in GVCs were more adversely affected by the COVID-19 shock (column 5). However, we do not find an additional effect of the concentration of the exports of intermediates inputs used measured by the sector's share of the largest exporter in the product's world exports in 2015 (column 6). Then, we investigate our third hypothesis and find that more complex products were more resilient to the COVID-19 shock.

All in all, our main results suggest that the key product vulnerabilities adversely affecting exports during the pandemic were related to the nature of the inputs used, unskilled labor as well as intermediate inputs imported, while more complex products were more resilient to the COVID-19 shock. Our estimates in column (7) of Table 1 imply that countries with higher COVID-19 incidence by its median value (0.66) experience a 1.5 percentage-point larger decline in exports of products at the 90th relative to the 10th percentile of the unskilled labor intensity, corresponding to a decrease by 1,074 million USD in median exports.[6] A similar increase in COVID-19 incidence decreases exports of products with a higher reliance on inputs for which China is a dominant supplier by 1.69 percentage points and exports of products with higher reliance on foreign inputs by 0.81 percentage point which correspond to decreases in median exports of 1,199 million USD and 574 million USD, respectively. Finally, a similar increase in COVID-19 incidence leads to a decrease in exports of products with lower complexity by 1.09 percentage points, which corresponds to a 777 million USD decrease in median exports.

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[6] Designating the 10th and 90th percentiles of the unskilled labor intensity measure as *vulnerability_p10* and *vulnerability_p90* and the median of the COVID-19 incidence as *covid_incid_med*, this economic magnitude is computed as (β_1 * *vulnerability_p90* - β_1 * *vulnerability_p10*) * *covid_incid_med*. Appendix Table 1 provides the means, standard deviations, 10th and 90th percentiles for all variables.

Heterogeneity of COVID-19 impacts: Products, countries, and time

In this section, we investigate further the role played by the type of products and of exporting country for the impacts of the COVID-19 shock on exports. First, we split our sample into exported final, intermediate, and capital goods. The estimates in columns (1), (2) and (3) of Table 2 show that our baseline effects of the COVID-19 shock depending on the resilience of products are mostly arising from the effects on intermediate products. We interpret this finding as further evidence on the importance of GVCs as conduits for the propagation of the COVID-19 shock.

Next, we interact our main interaction terms between measures of product vulnerability and COVID incidence separately with an indicator variable for rich countries (high-income countries in the World Bank classification) and an indicator variable for poorer countries (non- high-income). Column (4) of Table 2 shows a statistically stronger impact of COVID-19 incidenceon exports of poorer countries for products that are less complex and that rely intensively on a less diversified portfolio of input suppliers. However, we also identify negative effects of COVID-19 incidence on rich countries' exports for products that rely more heavily on inputs that are imported or for which China is a dominant supplier.

In the last columns of Table 2, we add controls for the effect of product reliance on inputs for which countries other than China are the main global suppliers. Column (5) shows that exports of products that rely on intermediate inputs from one of the other leading four input suppliers – Germany, Japan, the Republic of Korea and the US – were not negatively affected but instead were positively affected by the COVID-19 shock. This may be due to the greater stability of supplies from their combined production during the pandemic. The negative impact of reliance on intermediate inputsfrom China remains significant.

Finally, we investigate the dynamic effects of the COVID-19 shock depending on product vulnerability as the pandemic unfolded throughout 2020. We extend our baseline specification to include interactions between the last three quarters of 2020 and our measures of product vulnerability interacted with COVID-19 incidence and plot the corresponding estimated coefficients in Figure 1. The negative effects of the COVID-19 shock on exported products that rely more on imported inputs, on inputs whose export supply is concentrated, and that are unskilled-intensive are more important in the last quarter of 2020, while the negative effects on exports of products that rely more on inputs for which China is a dominant supplier were concentrated in the second quarter of 2020 when the COVID-19 shock started. This is intuitive and reflects the timing of the initial COVID-19 shock that hit China first and then affected other countries and consequently their inputs.

Robustness tests

We conduct a series of robustness tests to our baseline results using alternative measures of product vulnerabilities and of COVID-19 incidence (total cases per capita and stay-at-home requirementsand a different lag structure), sample periods, clustering of standard errors and the exclusion fromour sample of China or the US as exporting country and of medical products. Our findings are robust and stable in all cases and results are presented and discussed in the Online Appendix. In particular, we find the effect of COVID-19 incidence on exports of differentiated (Rauch, 1999), high-contractability (Nunn. 2007) and R&D-intensive products, three alternative measures of complexity, is also positive and significant.

Additionally, we estimate specifications where we account for the China-US tariff war and for thepossibility of COVID-19 being a positive demand shock (for home office products and outdoor activity products) and the results are robust. Moreover, our main results are maintained for export quantities but COVID-19 incidence reduces export prices only for products relying on a less diversified portfolio of input suppliers and increases export prices for products whose inputs have China as a dominant supplier, illustrating the role of supply disruptions due to the impact of COVID-19 in China itself.

5. Conclusion

In this study we show that the nature of the inputs used - a higher reliance on unskilled labor, on imported inputs and on inputs for which China is a dominant supplier and less complex and knowledge-intensive products - are the main production vulnerabilities which negatively impacted global exports to the EU, Japan, and the US due to the COVID-19 shock in 2020. These product vulnerabilities hit both developing and developed economies.

Our evidence can inform debates on building more resilience to future shocks of similar or different nature than COVID-19. The first finding on the effects of concentration and reliance on Chinese imports is about diversification of production inputs showing that low diversification has strong immediate adverse effects. The second, less debated to date in light of resilience, is the vulnerabilities caused by the challenge of organizing in-person production (affecting less skilled production). These point to the benefits of wider automation and a more extensive exploration of remote collaborations for resilience to future shocks, in addition to their benefits for productivity (Barrero et al., 2021).

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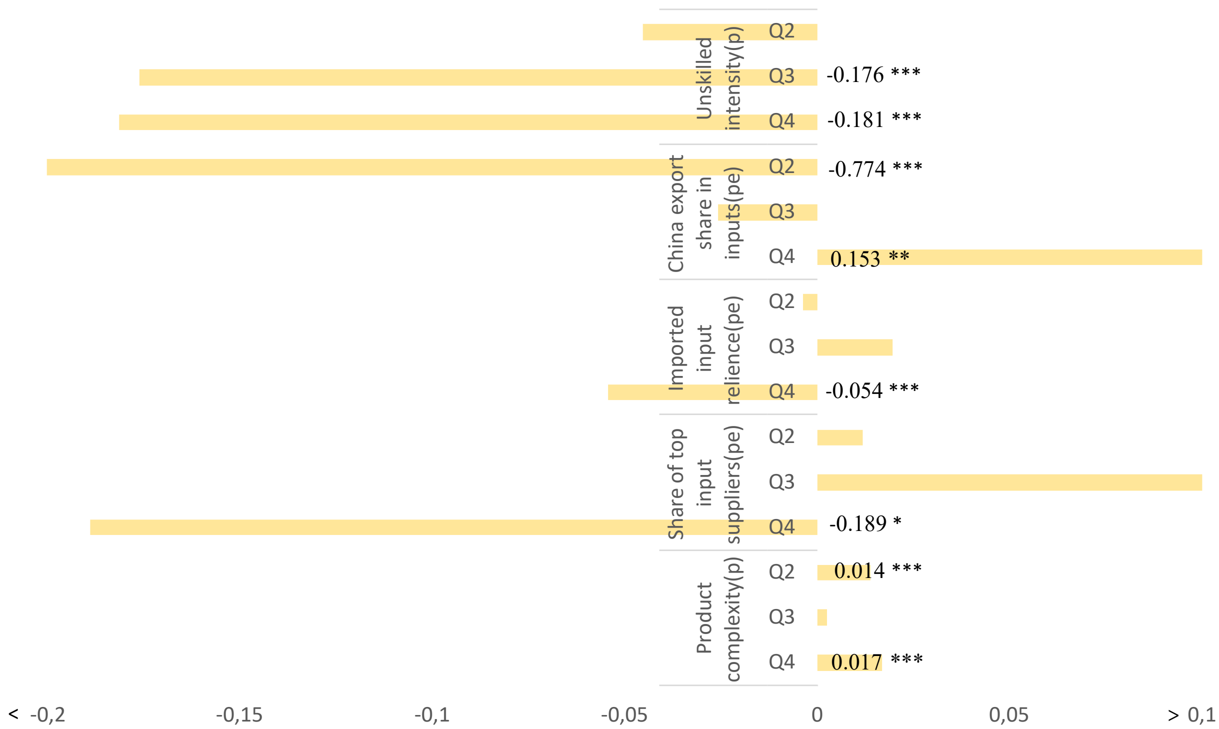
Figure 1: Dynamic effects of COVID-19 incidence on exports depending on product resilience



Notes: The figure plots the estimates of the following equation $Y_{!"\#\$} = \sum^{\%}_{(} \gamma_{\%}\, covid\_incid_{!\$\&'} * X_{\#} * Q_{'} + k_{!"\#} + \theta_{!\$} + \pi_{"\$} + \varepsilon_{!"\#\$}$. Robust standard errors clustered by exporting country and broad sector used.∗∗∗, ∗∗, and ∗ indicate significance at the 1, 5, and 10 percent levels respectively.

Table 1: The effect of COVID-19 incidence on exports depending on product resilience

Dependent variable:	Export value by country e of product p to destination market i in time t						
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Death rate(e,t-n)	-0.025***	-0.009**					
	(0.004)	(0.004)					
Death rate(e,t-n) x Unskilled intensity(p)			-0.040***				-0.131***
			(0.007)				(0.030)
Death rate(e,t-n) x China export share in inputs(pe)				-0.098***			-0.185**
				(0.031)			(0.072)
Death rate(e,t-n) x Imported input reliance(pe)					-0.020***		-0.022*
					(0.007)		(0.013)
Death rate(e,t-n) x Share of top input suppliers(pe)						-0.047***	-0,093
						(0.011)	(0.088)
Death rate(e,t-n) x Product complexity(p)							0.014***
							(0.004)
Death rate(e,t-n) x Medical supplies goods(p)			0.103***	0.106***	0.104***	0.105***	0.096***
			(0.011)	(0.011)	(0.011)	(0.011)	(0.011)
Product-exporting country-importing country fixed effects	yes	yes	yes	yes	yes	yes	yes
Exporting-country-time (month-year) fixed effects			yes	yes	yes	yes	yes
Importing-country-time (month-year) fixed effects		yes	yes	yes	yes	yes	yes
Observations	8,624,108	8,624,108	8,624,108	8,624,108	8,624,108	8,624,108	8,624,109
R-squared	0.863	0.866	0.866	0.866	0.866	0.866	0.867

Notes: Robust standard errors clustered by exporting country and broad sector in parentheses. ∗∗∗, ∗∗, and ∗ indicate significance at the 1, 5, and 10 percent levels respectively.

Table 2: The heterogeneous effect of COVID-19 incidence on exports depending on product resilience by product type and country

Dependent variable:	Export value by country e of product p to destination market i in time t				
	Final goods	Intermediates	Capital goods	Rich and poor	
	(1)	(2)	(3)	(4)	(5)
Death rate(e,t-n) x Unskilled intensity(p)	0,042	-0.149***	-0.113**		-0.127***
	(0.062)	(0.028)	(0.045)		(0.029)
Death rate(e,t-n) x China export share in inputs(pe)	-0,100	-0.261***	0,435		-0.174**
	(0.102)	(0.073)	(0.427)		(0.070)
Death rate(e,t-n) x Imported input reliance(pe)	0,019	-0.031*	0,016		-0.044***
	(0.030)	(0.016)	(0.027)		(0.015)
Death rate(e,t-n) x Share of top input suppliers(pe)	-0.583***	-0,047	-0,384		0,047
	(0.174)	(0.091)	(0.407)		(0.089)
Death rate(e,t-n) x Product complexity(p)	0.020***	0.015***	0,009		0,003
	(0.005)	(0.003)	(0.010)		(0.004)
Death rate(e,t-n) x Unskilled intensity(p) x Rich(e)				-0.130***	
				(0.030)	
Death rate(e,t-n) x Unskilled intensity(p) x Poor(e)				-0.169**	
				(0.073)	
Death rate(e,t-n) x China export share in inputs(pe) x Rich(e)				-0.209**	
				(0.082)	
Death rate(e,t-n) x China export share in inputs(pe) x Poor(e)				0,023	
				(0.144)	
Death rate(e,t-n) x Imported input reliance(pe) x Rich(e)				-0.026**	
				(0.013)	
Death rate(e,t-n) x Imported input reliance(pe) x Poor(e)				-0,062	
				(0.078)	
Death rate(e,t-n) x Share of top input suppliers(pe) x Rich(e)				-0,008	
				(0.097)	
Death rate(e,t-n) x Share of top input suppliers(pe) x Poor(e)				-0.677***	
				(0.223)	
Death rate(e,t-n) x Product complexity(p) x Rich(e)				0.012***	
				(0.004)	
Death rate(e,t-n) x Product complexity(p) x Poor(e)				0.034***	
				(0.007)	
Death rate(e,t-n) x Top supplier countries'* export share in inputs(pe)					0.926***
					(0.330)
Control variables	yes	yes	yes	yes	yes
Product-exporting country-importing country fixed effects	yes	yes	yes	yes	yes
Exporting-country-time (month-year) fixed effects	yes	yes	yes	yes	yes
Importing-country-time (month-year) fixed effects	yes	yes	yes	yes	yes
Observations	2,546,142	4,473,547	1,402,921	8,622,105	8 624 108
R-squared	0,88	0,87	0,85	0.866	0,87

Notes: Robust standard errors clustered by exporting country and broad sector in parentheses. ∗∗∗, ∗∗, and ∗ indicate significance at the 1, 5 and 10 percent levels respectively.

Appendix

Appendix Table 1. Summary statistics

Characteristics of monthly exports					
Number of exporting countries	181				
Number of HS 4-digit products	1,046				
Key variables	Average	Median	Std. dev.	Perc. 10	Perc. 90
Log exports by exporter-importer-country-product	11.21	11.17	2.41	8.00	14.39
Deaths over population (/100)	0.66	0.12	1.09	0.00	2.30
Product vulnerabilities or resilience in exports					
Unskilled intensity(p)	0.57	0.62	0.10	0.50	0.67
Product complexity(p)	9.79	9.90	0.48	9.12	10.30
China export share in products (pe)	0.18	0.18	0.05	0.10	0.24
Imported input reliance(pe)	0.41	0.34	0.35	0.14	0.69
Share of top input suppliers(pe)	0.36	0.36	0.03	0.33	0.41

Correlation matrix

	Unskilled intensity (p)	Product complexity (p)	China export share in products (pe)	Imported input reliance (pe)	Share of top input suppliers (pe)
Unskilled intensity(p)	1.00				
Product complexity(p)	-0.35	1.00			
China export share in products (pe)	-0.19	-0.14	1.00		
Imported input reliance(pe)	-0.19	0.11	0.15	1.00	
Share of top input suppliers(pe)	0.33	-0.41	0.24	-0.19	1.00

Note: Correlation matrix based on average at HS4-exporting country average of HS4 and export countries included in the estimating sample. The summary statistics for deaths over population are computed over the COVID-19 period only.

Online Appendix

"How resilient was trade to COVID-19?"

Maria Bas (University of Paris 1, CES)

Ana Fernandes (World Bank)

Caroline Paunov (OECD)

Robustness tests

This Online Appendix provides a series of sensitivity tests to our main specification presented in the article entitled "How resilient was trade to COVID-19?" using alternative measures of product vulnerabilities and of COVID-19 incidence, sample periods, clustering of standard errors and the exclusion from our sample of China or the US as exporting country and of medical products.

Alternative measures of product resilience

First, we explore three alternative measures of product vulnerabilities or resilience. Regarding product complexity, we consider the Rauch (1999) differentiated products and the Nunn (2007) input contractability intensity measures that either identify products that are not sold on an organized exchange nor reference-priced or measure the share of intermediate inputs used by a sector that require customized or relationship-specific investments both at the HS4 product level. Additionally, we consider R&D intensity of the sector constructed as the ratio of R&D spending (in million US dollars) from the US National Science Foundation to the size of the industry (total value of shipments) from the U.S. Census Bureau's Annual Survey of Manufactures both for 2015 and converted from NAICS 5-digit sectoral to our HS4 product level. Results are reported in columns (1) to (3) of Table A1. The effect of COVID-19 incidence on exports of differentiated products, high-contractability products and R&D-intensive products is always positive and significant in line with our previous results using product complexity. These findings suggest that exports of more complex and knowledge-intensive products were less vulnerable to the COVID-19 shock.

Second, we use an alternative measure of the reliance of production on inputs from China, the share of production inputs for which China is the dominant supplier. Column (4) of Table A1 shows the results are maintained using this measure.

Alternative explanation: the China-US tariff war

We also account for an important trade policy development occurring over our sample period: the China-US tariff war. While most tariffs were imposed by the US prior to the pandemic, there could be delayed responses and heterogeneous effects across countries as shown by Fajgelbaum et al. (2021). Hence, we add to our specification in column (5) of Table A1 an interaction between an indicator variable for the products subject to increased US tariffs taken from Bown (2021) and COVID-19 incidence. The coefficient on the interaction term is insignificant and all other results are maintained.

Alternative sample periods and COVID-19 measures

We carry out additional robustness tests related to the sample period and the COVID-19 measures used. Column (1) of Table A2 shows that our findings are robust to the use of a shorter sample period starting in January 2019. Columns (2) and (3) show that our estimates are robust to the classical way of lagging the COVID-19 incidence measure using one- or two-month lags instead of the specific lags defined in Section 2. The last two columns of Table A2 show robust results when using alternative measures of COVID-19 incidence relying on total cases per capita (column (4)) and stay-at-home requirements (column (5)).

Disentangling the effect on export quantities and prices

We investigate the effects of the pandemic on export quantities (measured by weight) and unit values (defined as values divided by weight). Columns (1) and (2) of Table A3 show that the effects of the COVID-19 shock on export quantities depending on product vulnerability are qualitatively similar to those on export values. However, the effects differ for unit values. The COVID-19 shock reduces significantly export prices only for products that rely on a less diversified portfolio of input suppliers but increases prices for products whose inputs have China as a dominant supplier. The latter finding hints at the role of supply disruptions due to the impact of COVID-19 in China itself.

Additional robustness tests

We investigate the robustness of our main findings when we exclude specific countries from the estimating sample. Columns (3) to (5) of Table A3 show that our findings are robust to the exclusion from our sample of China or the US as exporting country and medical products. Unreported estimates available upon request show the results are maintained dropping each destination market at a time.

Lastly, to account for COVID-19 as a demand shock we add to our specification interactions between COVID-19 incidence and two sets of products with divergent demand trends due to the pandemic: home office products whose demand likely increased due to work from home (column (6) of Table A3) and outdoor activity products such as ski boots whose demand likely decreased due to lockdowns (column (7) of Table A3).[1] The estimates confirm the demand conjectures and do not change our baseline results.

[1] Home office products are defined HS4 8471, 8443, 8525, 8528, 8517, 8518 and 9403 and outdoor products are taken from Lucio et al. (2021).

Table A1: Alternative product vulnerability measures

Dependent variable	Export value by country e of product p to destination market i in time t				
	(1)	(2)	(3)	(4)	(5)
Death rate(e,t-n) x Differentiated goods(p)	0.057***				
	(0.019)				
Death rate(e,t-n) x Product contractability (p)		0.038***			
		(0.012)			
Death rate(e,t-n) x R&D intensity(p)			0.053**		
			(0.021)		
Death rate(e,t-n) x Unskilled intensity(p)	-0.116***	-0.116***	-0.162***	-0.116***	-0.131***
	(0.029)	(0.029)	(0.032)	(0.030)	(0.030)
Death rate(e,t-n) x China export share in inputs(pe)	-0.500***	-0.289***	-0.352**		-0.184**
	(0.152)	(0.090)	(0.137)		(0.072)
Death rate(e,t-n) x Imported input reliance(pe)	0,001	-0,005	0,027	-0.028**	-0.024*
	(0.015)	(0.014)	(0.024)	(0.013)	(0.013)
Death rate(e,t-n) x Share of top input suppliers(pe)	0.313***	0.236***	0.290***	-0,125	-0,093
	(0.074)	(0.072)	(0.103)	(0.090)	(0.088)
Death rate(e,t-n) x Product complexity(p)				0.012***	0.014***
				(0.003)	(0.004)
Death rate(e,t-n) x China top 1 export share in inputs(pe)				-0.044**	
				(0.018)	
Death rate(e,t-n) x China-US trade war product(p)					-0,003
					(0.008)
Control variables	yes	yes	yes	yes	yes
Product-exporting country-importing country fixed effects	yes	yes	yes	yes	yes
Exporting-country-time (month-year) fixed effects	yes	yes	yes	yes	yes
Importing-country-time (month-year) fixed effects	yes	yes	yes	yes	yes
Observations	8 624 108	8 509 260	1 502 548	8 620 906	8,624,108
R-squared	0,87	0,87	0,86	0,87	0,87

Notes: Robust standard errors clustered by exporting country and broad sector in parentheses. ∗∗∗, ∗∗, and ∗ indicate significance at the 1, 5, and 10 percent levels respectively.

Table A2: Additional robustness tests I

Dependent variable:	Export value by country e of product p to destination market i in time t				
	From 2019	Alternative homogeneous lags		Alternative covid measures	
		t-1	t-2	Cases	Policy
	(1)	(2)	(3)	(4)	(5)
Death rate(e,t-n) x Unskilled intensity(p)	-0.110***				
	(0.027)				
Death rate(e,t-n) x Product complexity(p)	0.015***				
	(0.003)				
Death rate(e,t-n) x China export share in inputs(pe)	-0.160**				
	(0.064)				
Death rate(e,t-n) x Imported input reliance(pe)	-0.019				
	(0.012)				
Death rate(e,t-n) x Share of top input suppliers(pe)	-0.159**				
	(0.080)				
Death rate(e,t-1) x Unskilled intensity(p)		-0.181***			
		(0.030)			
Death rate(e,t-1) x Product complexity(p)		-0.006			
		(0.005)			
Death rate(e,t-1) x China export share in inputs(pe)		-0.244***			
		(0.074)			
Death rate(e,t-1) x Imported input reliance(pe)		-0.045**			
		(0.018)			
Death rate(e,t-1) x Share of top input suppliers(pe)		-0.364***			
		(0.106)			
Death rate(e,t-2) x Unskilled intensity(p)			-0.137***		
			(0.042)		
Death rate(e,t-2) x Product complexity(p)			-0,003		
			(0.005)		
Death rate(e,t-2) x China export share in inputs(pe)			-0.269***		
			(0.067)		
Death rate(e,t-2) x Imported input reliance(pe)			-0.045*		
			(0.026)		
Death rate(e,t-2) x Share of top input suppliers(pe)			-0.448***		
			(0.124)		
Cases(e,t-n) x Unskilled intensity(p)				-0.003***	
				(0.000)	
Cases(e,t-n) x Product complexity(p)				0.0003***	
				(0.000)	
Cases(e,t-n) x China export share in inputs(pe)				0,001	
				(0.001)	
Cases(e,t-n) x Imported input reliance(pe)				-0.001***	
				(0.000)	
Cases(e,t-n) x Share of top input suppliers(pe)				-0,002	
				(0.002)	
Stay at home requirements(e,t-n) x Unskilled intensity(p)					-0.120***
					(0.024)
Stay at home requirements(e,t-n) x Product complexity(p)					0.014***
					(0.002)
Stay at home requirements(e,t-n) x China export share in inputs(pe)					-0.260***
					(0.044)
Stay at home requirements(e,t-n) x Imported input reliance(pe)					-0,010
					(0.008)
Stay at home requirements(e,t-n) x Share of top input suppliers(pe)					-0,097
					(0.084)
Control variables	yes	yes	yes	yes	yes
Product-exporting country-importing country fixed effects	yes	yes	yes	yes	yes
Exporting-country-time (month-year) fixed effects	yes	yes	yes	yes	yes
Importing-country-time (month-year) fixed effects	yes	yes	yes	yes	yes
Observations	5 500 176	9 931 544	9,205,266	8,624,108	8 541 540
R-squared	0,87	0,87	0,87	0,87	0,87

Notes: Robust standard errors clustered by exporting country and broad sector in parentheses. ∗∗∗, ∗∗, and ∗ indicate significance at the 1, 5, and 10 percent levels respectively.

Table A3: Additional robustness tests II

Dependent variables:	Quantity	Unit value	Export value				
		by country e of product p to destination market i in time t					
			Excluding from the sample				
			Chinese exports	US exports	Medical products		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Death over population (e,t-n) x Unskilled intensity(p)	-0.165***	0,019	-0.131***	-0.131***	-0.140***	-0.110***	-0.120***
	(0.032)	(0.016)	(0.030)	(0.030)	(0.029)	(0.028)	(0.028)
Death over population (e,t-n) x Imported input reliance(pe)	-0,023	-0,004	-0.024*	-0.024*	-0.025**	-0,019	-0.021*
	(0.018)	(0.008)	(0.013)	(0.013)	(0.012)	(0.013)	(0.012)
Death over population (e,t-n) x Share of top input suppliers(pe)	0,124	-0.073*	-0,094	-0,093	-0,098	-0,041	-0,115
	(0.101)	(0.044)	(0.088)	(0.088)	(0.087)	(0.085)	(0.089)
Death over population (e,t-n) x Product complexity(p)	0.011**	0	0.014***	0.014***	0.016***	0.010***	0.017***
	(0.004)	(0.001)	(0.004)	(0.004)	(0.004)	(0.003)	(0.004)
Death over population (e,t-n) x China export share in inputs(pe)	-0.346***	0.135***	-0.182**	-0.185**	-0.215***	-0.142**	-0.237***
	(0.087)	(0.028)	(0.071)	(0.072)	(0.071)	(0.069)	(0.069)
Death rate(e,t-n) x Home office product(p)						0.057***	
						(0.015)	
Death rate(e,t-n) x Outdoor activity product(p)						-0.027***	
						(0.009)	
Death rate(e,t-n) x Product trade elasticity |ϵ|(p)							-0.002***
							(0.000)
Control variables	yes	yes	yes	yes	yes	yes	yes
Hs4-exporting country-importing country fixed effects	yes	yes	yes	yes	yes	yes	yes
Exporting-country-time (month-year) fixed effects	yes	yes	yes	yes	yes	yes	yes
Importing-country-time (month-year) fixed effects	yes	yes	yes	yes	yes	yes	yes
Observations	7,802,279	8,008,145	8,128,252	8,624,108	8,556,547	8 606 945	7,082,358
R-squared	0,89	0,86	0,86	0,87	0,87	0,87	0,87

Notes: Robust standard errors clustered by exporting country and broad sector in parentheses. ∗∗∗, ∗∗, and ∗ indicate significance at the 1, 5, and 10 percent levels respectively.