Global Propagation of the U.S.-China Trade War*

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Abstract

This paper examines global propagations of the U.S.-China tariff war in 2018-2019 through the lens of exports from 32 countries to China. Building an industry-country specific measure of input-output linkages with China, we obtain new empirical evidence that the U.S. tariffs on Chinese imports had a significant adverse effect on third countries by dampening Chinese demand for foreign inputs. One standard deviation rise in this upstream shock leads to a decline in the growth rate of exports to China by 2.6 percentage points. A quantification exercise shows that the upstream propagation of U.S. tariffs have incurred an average GDP loss of 0.06% for these countries between April 2018 and September 2019. Taiwan and Korea, key suppliers to China, were most severely hurt by this vertical effect. Firm-level analysis using a panel of Korean manufacturers lends further support to the importance of this vertical linkage channel.

JEL classification: D57, F13, F14

Key words: U.S.-China trade war, trade policy, input-output linkages, upstream effect

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1 Introduction

Since the United States implemented waves of unprecedented tariff increases against China in 2018 followed by China's retaliations, the U.S.-China trade war has been at the heart of debates for its economic consequence and broad implications on the world trading system (Crowley (2019)). Several studies thus far focus on the impact of these tariffs on the U.S. economy which is directly involved in the war.[1] However, an important aspect of modern international trade is the rapid expansion of globally interconnected supply chains and the rise trades in intermediates. The vertical linkages across countries and sectors could potentially work as a channel through which a local trade shock could create substantial repercussions on third countries and global trade as a whole (Caliendo and Parro (2014)).

This paper attempts an empirical assessment of the spillover impact of the U.S.-China tariff war on third countries through vertical linkages. Our analysis examines industry-level exports from 32 countries to China during 2017:Q1-2019:Q3 to study the U.S.-China tariffs that have been put into place since 2018. These countries represented approximately 51% of China's imports and 45% of global GDP in 2017 (IMF).[2] We focus on the upstream propagation of U.S. tariffs on Chinese imports into China's demand for foreign intermediates. This channel, which we refer to as the "U.S. vertical shock", is particularly relevant in light of China's rise in global supply chains and the importance of the U.S. market for Chinese exporters.[3] A key feature of this analysis lies in building an industry-specific measure of input-output linkages with China for each country that exports to China. This measure is constructed by combining the Chinese detailed input-output (IO) table and the World IO matrices with the U.S. tariffs on Chinese imports. Using this measure, we find strong and robust evidence that the massive U.S. tariff hikes since 2018 led to a significant contraction of third countries' exports to China through input-output linkages. The economic magnitude is large. A one standard deviation rise in this vertical shock measure is associated with a decline in the growth rate of these countries' exports to China by 2.6 percentage points. A quantification exercise shows that this upstream propagation of the U.S. tariffs has incurred an average GDP loss of 0.06% for these countries between April 2018 and September 2019. Taiwan and Korea, key suppliers to China, were most severely hurt by this upstream effect

[1] To name a few, see Amiti, Redding and Weinstein (2019), Amiti, Redding and Weinstein (2020) and Fajgelbaum, Goldberg, Kennedy and Khandelwal (2019) for U.S. consumers and welfare and Amiti, Kong and Weinstein (2020) and Handley, Kamal and Monarch (2020) for investment and exports of U.S. firms.

[2] These countries were selected based on the availability of monthly product-level export data in the U.N. Comtrade database and the cross-country input-output matrices in the World Input-Output Database (WIOD). We add a few more countries from alternative sources as well. See section 3 for a detail.

[3] In 2016, the U.S. was the single largest export market for China, accounting for 18.4% of its total exports.

of the U.S. tariffs with an estimated loss of 0.53 percent and 0.26 percent of GDP, respectively. We further examine the firm-level response to the industry-level U.S. vertical shock using balance-sheets for Korean firms. Korea is an appropriate test ground for this, as the single largest exporter to China. Korean firms in industries that were more exposed to the vertical shock of the U.S. tariffs on China experienced a larger fall in the growth rate of sales and stock returns. The overall results are quite comparable to the cross-country analysis, confirming the significance of this vertical channel. The cross-border upstream propagation of local trade policy changes, as found in this paper, illustrates how tightly productions are interconnected across countries and sectors, with the rising importance of China in this global supply chain.

This paper is, to the best of our knowledge, the first empirical attempt to assess the vertical linkage effects of the U.S.-China trade war on third countries. Using the episode of unprecedented tariff escalations between the two largest economies, we contribute to two distinct strands of research: one is vast trade literature on the economic consequence of trade policy changes, and another is IO literature on the role of vertical specializations in international trade perspectives. Several papers investigate impacts of the global trade tensions led by the U.S. administration. Early work includes Amiti, Redding and Weinstein (2019), Amiti, Redding and Weinstein (2020), Fajgelbaum, Goldberg, Kennedy and Khandelwal (2019), Amiti, Kong and Weinstein (2020) and Huang, Lin, Liu and Tang (2019) that quantify the impact on firms and consumers in the U.S. or China. Our focus in this paper is to investigate the spillover impact of the trade war to other countries, which has been less explored thus far. In this respect, Our study broadly relates to the literature on trade policy externalities which includes Bown and Crowley (2006) and Bown and Crowley (2007).[4] While these papers focus on horizontal competition between exporting countries as an underlying mechanism, our analysis looks at a different channel of trade policy spillover linking it to the literature on vertical specializations across countries and industries. As another strand of research, there is growing interest in the role of production networks in the propagation of local economic shocks.[5] Some recent papers studying the trade war also underscore input-output linkages across countries. Handley, Kamal and Monarch (2020) leverage confidential U.S. firm-trade transactions data to build product-level supply chain exposures to import tariffs. They document that the rising input costs due to U.S. tariffs during 2018-19 lowered U.S. export growth for affected products. Since detailed firm-level data on produc-

[4] Using the episode of U.S. import restrictions in the 1990's, these papers show two channels through which a trade policy distorts the targeted country's trade with third countries - “trade diversion” and “trade depression”.

[5] For a review of recent empirical work on production networks, see Carvalho and Tahbaz-Salehi (2019).

tion networks are not readily available, some researchers employ industry-level IO tables to study economy-wide production linkages.[6] Using industry-level data for U.S. manufacturing sectors and the U.S. IO tables, Flaaen and Pierce (2019) find that the 2018 U.S. import tariffs are associated with declines in employment and increases in producer prices through rising input costs. Based on information about U.S. anti-dumping duties against China since the 1980s and the U.S. IO tables, Bown, Coconi, Erbahar and Trimarchi (2021) show that the U.S. import tariffs targeting Chinese upstream industries had a large negative impact on U.S. downstream industries through rising input prices. While these papers highlight the input-output linkages in the U.S.-China trade war through the lens of U.S. firms or industries, we focus on its propagation to other 32 major countries trading with China. Unlike the above-mentioned papers that focus on the downstream effects of the U.S. import tariffs, our study sees the U.S. tariffs as a negative demand shock against Chinese producers and attempts to capture the upstream effect of this shock on third countries. Finally, this paper is broadly related to growing literature on global value chains (GVC) exploiting cross-country input-output tables, such as Bems, Johnson and Yi (2011), Costinot and Rodríguez-Clare (2014), Antràs and Chor (2013) and Antràs and de Gortari (2020), among others.

The remainder of the paper proceeds as follows. Section 2 provides an overview of the U.S.-China trade war and describes potential mechanisms connecting the trade war to third countries' exports. Section 3 and 4 list the data sources and detail the empirical strategy including the construction of a measure of the U.S. vertical shock. Section 5 presents the results of cross-country analysis. Section 6 provides further evidence using balance-sheets for Korean manufacturing firms. Section 7 concludes.

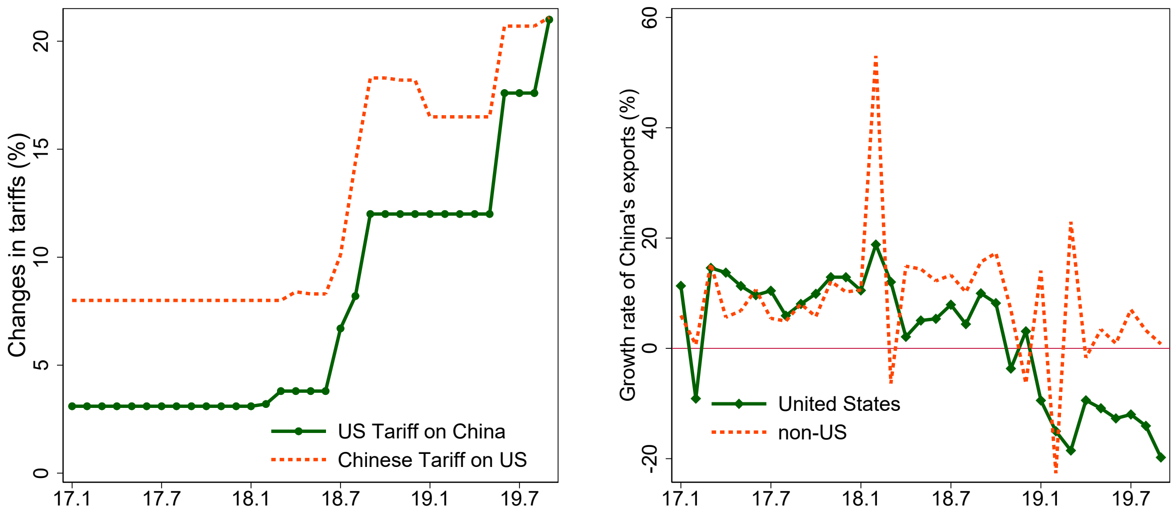
2 Overview: U.S.-China Trade War

This paper focuses on a series of large-scale tariff events between the U.S. and China during 2018-2019. In April 2018, the U.S. government announced an initial plan to impose tariffs on Chinese imports ("China Section 301") following its investigation into China's unfair trade practices. There were several waves of U.S. tariff action against China through to September 2019 and, in each round, China retaliated by raising its own tariffs on U.S. imports.[7]

[6] Early work using the IO tables to study production networks includes Bems, Johnson and Yi (2011) and Acemoglu, Akcigit and Kerr (2016). Bems, Johnson and Yi (2011) highlight the importance of vertical linkages in the trade collapse during the Great Recession of 2008-2009 based on a global IO framework. Using the detailed U.S. IO tables, Acemoglu, Akcigit and Kerr (2016) empirically test the theoretical upstream and downstream network effects of demand and productivity shocks on the U.S. economy.

[7] Even before April 2018, both countries raised their tariffs on one another for specific products, such as solar panels, washing machines and aluminium. However, the breadth and trade volumes associated with these tariffs were relatively small. For a detailed timeline of U.S.-China trade disputes, see Fajgelbaum,

Figure 1: U.S.-China tariffs & China's exports



Note: The left panel plots the bilateral tariffs (%) between the U.S. and China. The right panel shows the year-on-year growth rate (%) of U.S. monthly imports from China and the rest of the world. Sources: Amiti, Redding and Weinstein (2019), Amiti, Redding and Weinstein (2020), Bown, Jung and Zhang (2019) and Chinese Customs.

The left panel of Figure 1 shows the evolution of bilateral tariffs between the U.S. and China since 2017. The right panel shows the year-on-year growth rates of U.S. imports from China and the rest of the world during the same period. We observe a series of sizable increases in import tariffs since mid-2018, which were accompanied by double-digit reductions in the growth rate of U.S. imports from China on the right panel.[8] The dashed line on the right panel depicts the growth rate of China's exports to non-U.S. destinations during the same period. Despite some fluctuations, there appears to be no significant increase in China's exports to other destinations to offset the declining exports to the U.S. These imply that the rising U.S. tariffs on Chinese imports may have been associated with a decline in China's

Goldberg, Kennedy and Khandelwal (2019) and Amiti, Redding and Weinstein (2019).

[8] More formally, I run a regression for 12-month log difference in U.S. imports from China ($\Delta\log imv_{i,t}^{US}$) against U.S. tariff changes ($\Delta\tau_{i,t}^{US\to CN}$) between January 2017 and September 2019, both of which are aggregated at the 87 Chinese SIC industry level (the level of aggregation in this paper):

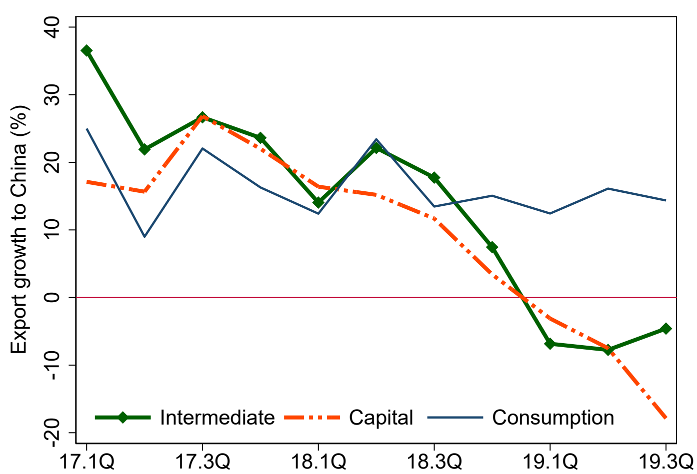
$$\Delta\log imv_{i,t}^{US} = \underset{(0.345)}{-1.179^{***}}\Delta\tau_{i,t}^{US\to CN} + \alpha_i + \eta_t + \epsilon_{i,t}$$

where α_i and η_t are industry and time fixed effects, and the standard error in parenthesis is clustered at the industry level. The growth rate of U.S. imports from China drops by 1.179 percentage points in response to a one percentage point rise in U.S. tariffs on China. The size of the coefficient is in line with prior literature (e.g. -1.52 to -1.42 at the HS 10-digit level in Amiti, Redding and Weinstein (2019) and Fajgelbaum, Goldberg, Kennedy and Khandelwal (2019)).

total export.

Figure 4 shows quarterly exports from 32 countries to China by U.N. Broad Economic category (BEC). We observe the growth rate of exports falling rapidly in both intermediates and capital goods in the escalation of the trade war in 2018.[9] Exports of consumption goods, by contrast, remained relatively stable throughout the whole period. Note that the total exports from these countries to China move in parallel with exports of intermediates due to their large shares.[10] As a potential channel driving the decline in exports of intermediates, this paper sheds light on the upstream propagation of U.S. tariffs on Chinese imports. Specifically, the U.S. tariffs depress U.S. demand for Chinese imports which in turn dampens China's demand for foreign inputs from around the world. The two stylized facts mentioned in introduction - (1) China's status as a 'world factory' consuming a wide range of foreign intermediates for production and (2) the importance of U.S. markets for Chinese exporters - validate the relevance of this channel.

Figure 2: 32 Countries' Exports to China by End-Use Category



Note: The figure plots the four-quarter log differences in exports from 32 countries to China by the U.N. Broad Economic Categories (BEC). Sources: U.N. Comtrade, Eurostat and Taiwan customs.

[9]Related to the fall in exports of capital goods, the trade war may have affected investment for Chinese firms through various channels. Higher tariffs on Chinese imports and a subsequent fall in U.S. demand may have directly lowered expected returns to capital. Moreover, trade policy uncertainty could also stifle investments of Chinese firms (Handley and Limão (2015)). As a related research, Amiti, Kong and Weinstein (2020) show that U.S.-China tariff actions through 2018 and 2019 significantly lowered the investment growth rate of listed U.S. firms.

[10]The share of each category in the 2017 total exports to China is 67.3% for intermediates, 14.8% for capital goods, 6.6% for consumption goods and 11.3% for others that are classified into multiple categories or unclassified.

3 Data

This paper exploits four types of datasets from multiple sources: (1) 32 countries' monthly product-level exports from U.N. Comtrade, Eurostat and Taiwan customs, (2) the U.S. and Chinese tariffs from Amiti, Redding and Weinstein (2019), Amiti, Redding and Weinstein (2020), Bown, Jung and Zhang (2019) and the World Bank WITS (World Integrated Trade Solution), (3) the 2012 Chinese IO table from China's National Bureau of Statistics and the World IO tables from the 2012 World Input-Output Database (WIOD), and (4) quarterly balance-sheet data for 964 Korean manufacturing firms from the KISVALUE database.

Export Data: For the cross-country analysis, we use monthly exports from 32 countries to China at the 6-digit Harmonized System (HS) product level. The countries here include 24 European countries, five Asia-Pacific countries and three countries from the Americas.[11] The choice of these countries is initially based on the availability of monthly export data at the HS 6-digit level up to September 2019 in the U.N. Comtrade database and the cross-country input-output matrices in the WIOD. Among these countries, we choose those with shares of China's total imports are not smaller than 0.05 percent in both 2016 and 2017. Using other sources, we further include five countries - France, the Netherlands, Austria, Czechia and Taiwan considering their large shares in China's total imports. Specifically, exports from the four European countries are collected from Eurostat, while we obtain exports for Taiwan from its customs office website.

Tariff Data: We obtain monthly U.S. tariffs on Chinese imports at the HS 10-digit level from Amiti, Redding and Weinstein (2020). For monthly Chinese tariffs on U.S. imports and MFN tariffs, We use the HS 6-digit data from Amiti, Redding and Weinstein (2019) during 2016-2018 and extend them to September 2019 using Bown, Jung and Zhang (2019) which provides the HS 10-digit tariff changes in January and June in 2019 based on statements by the Chinese government. To merge the above-mentioned export datasets, the U.S. tariffs are aggregated at the HS 6-digit level as simple averages of the original 10-digit level tariffs.

Input-Output Tables: To identify vertical linkages between China and other countries, we exploit the detailed 2012 Chinese IO table. It consists of 139 industries at the 5-digit Chinese Standard Industry Classification (CSIC) and, among these, we use 93 tradable industries that include agriculture, mining and manufacturing industries.[12] We obtain

[11] See the Appendix Table A2 for the full list of the countries with the values of their exports to China for 2016.

[12] The remaining 46 industries in non-tradable sectors include energy production, construction and a

cross-country IO linkages from the 2012 World Input-Output Database (WIOD).[13] One limitation of the World IO is that it is constructed at the more aggregated 2-digit sector level of the International Standard Industry Classification (ISIC) system, which consists of only 22 tradable sectors. To construct a measure of the vertical U.S. shock at the more detailed CSIC industry level for each origin country, we adopt a proportionality assumption and disaggregate the elements of the World IO table using the industry-level Chinese IO. The detailed procedure is described in the next section.

Firm Data: For the firm-level analysis, we use balance-sheets for firms in Korean manufacturing sectors from the proprietary KISVALUE database run by NICE, Korea's largest credit information agency. Of the total of approximately 12,000 Korean manufacturing firms in the database, we initially obtain 1,247 firms that are listed in Korean stock markets as these firms report their financial statements on a quarterly basis. The items used in the analysis include total sales, total assets, capital intensity measured by fixed tangible assets per employee, credit score, stock price, market capitalization, firm age (year of birth) and the firms' industry affiliations at the 5-digit Korean Standard Industry Classification (KSIC) level.

3.1 Combining Datasets

Using these data, we construct two distinct datasets for the analysis. First, we build a trade dataset for the cross-country analysis by aggregating the monthly exports for 32 countries and the U.S. and Chinese tariffs at the CSIC industry level based on 2016 trade weights.[14] These data are aggregated at a quarterly frequency, since monthly trade flows are noisy. We then plug the Chinese industry-level IO table into the aggregated trade dataset. Finally, we merge the sector-level World IO tables into the trade dataset.[15] The final sample covers the period between 2017:Q1 and 2019:Q3.

Second, we build a firm-level dataset by combining the balance-sheets for Korean manufacturing firms with the industry-level tariff variables. Of the initial 1,247 stock-listed manufacturing firms from the KISVALUE database, we truncate the sample in the following

wide range of private and public services industries that are not subject to tariffs. According to the 2012 imported input matrix for China available in the WIOD, 82.0% of imported intermediates into China are used by tradable industries while the other 18.0% is used by non-tradable industries.

[13] The World IO table is constructed using both product-level trade flows across countries and national IO tables. For more details on WIOD, refer to Timmer et al. (2015).

[14] For matching between the CSIC 5-digit industries and the HS 6-digit products, we exploit the lookup table between the Korean SIC (KSIC) 5-digit industries and the HS 6-digit products provided by Statistics Korea as a bridge since the KSIC 5-digit industries and the CSIC 5-digit industries are very well aligned.

[15] The 2-digit ISIC sectors in World IO tables correspond to the first two digits of the CSIC-industries.

steps; First, we drop zeros or negative values of assets and sales. We further drop firms with annual growth rate of sales of more than 200% or less than -66% in any year between 2016 and 2018 to prevent the tariff effects from being overstated by these firms with highly volatile sales.[16] Finally, we exclude firms whose records are missing at least once throughout 2016:Q1-2019:Q3.[17] The final sample contains 964 firms for the period between 2017:Q1 and 2019:Q3.

3.2 Aggregation by End-use Category

In our cross-country analysis, we run separate regressions by end-use classification of exports, intermediates in particular. While the end-use categories (U.N. BEC) are initially defined at the HS 6-digit product level (denoted by p), our analysis uses observations at the CSIC industry by country level (i, c). Since most of the CSIC industries consist of multiple end-use categories at the product level, we take the following procedure for aggregation.[18] First, each HS 6-digit-by-country export (p, c) and HS 6-digit tariff (p) are assigned into separate bins by each end-use category. Then, for each bin, we aggregate export values and tariffs using 2016 trade weights at the industry-by-country pair (i, c). By doing so, we build samples of industry-by-country level observations for each end-use category. Note that the U.S. vertical shock measure is initially constructed using the CSIC-industry level IO tables and thus it is identical across all the end-use categories.

4 Empirical Strategy

4.1 Measure of U.S. Vertical Shock

The primary goal of this paper is to investigate upstream propagations of the U.S.-China tariff shocks into third countries' exports to China. Since detailed information on production networks across countries is not available, we exploit the IO tables to build an industry-specific measure of vertical linkage exposures to U.S. tariffs for each origin country. Specifically, we define U.S. Vertical Shock, denoted by $VS_{i,c,t}^{US \to CN}$, as follows:

[16] These firms make up around 8% in total number of entities and account for only about 3% in aggregate sales, which implies that they are quite small firms. Adding these outlier firms yields qualitatively same results, with somewhat larger and equally significant estimates overall.

[17] Using a balanced panel of firms would alleviate any selection bias associated with entry or exit. A large number of firms are dropped due to the use of the balanced panel.

[18] For instance, the CSIC-industry "Glass and glass products (30055)" includes intermediates (HS 6-digit of 700100, "Cullet and other waste and scrap of glass; glass in the mass"), consumption goods (701322, "Stemware drinking glasses, other than of glassceramics: Of lead crystal") and capital goods (701322, "Signalling glassware and optical elements of glass").

$$\textbf{(Measure 1)} \quad VS_{i,c,t}^{US\to CN} = \underbrace{\textstyle\sum_j \theta_{j,i,c}^{F}}_{\text{Upstream propagation}} \underbrace{\left(\psi_j^{US}\Delta\tau_{j,t}^{US\to CN}\right)}_{\text{US tariff shock}}$$

where $\Delta\tau_{j,t}^{US\to CN}$ denotes the year-on-year changes in tariffs imposed by the U.S. on Chinese imports of CSIC industry j in tradable sectors at time t.[19] ψ_j^{US} is the U.S. share in China's total exports of industry j in 2016. $\theta_{j,i,c}^{F} = \frac{Impint_{j,i,c}}{\sum_j Impint_{j,i,c}}$ is the origin country-industry specific import coefficient for China where $Impint_{j,i,c}$ denotes intermediate imports of input industry i into Chinese output industry j from origin country c in 2012. These import coefficients captures the input-output linkages between country c and China for each industry-pair.[20]

The way in which this measure captures the vertical propagation of U.S. tariffs against China is quite intuitive: First, the U.S. tariff hikes reduce U.S. demand for Chinese affected industry j ($\Delta\tau_{j,t}^{US}$). Falling U.S. demand will dampen the production of Chinese industry j up to the importance of the U.S. market for Chinese producers (ψ_j^{US}). That in turn leads to a fall in Chinese industry j's demand for imported inputs of industry i from origin country c through the global IO structure ($\theta_{j,i,c}^{F}$). Finally, for a foreign supplier i in country c, the total change in China's demand for its input is the sum across the Chinese output industries (j) that are targeted by the U.S. tariffs. One may argue that it should be the U.S. share of China' total output rather than the U.S. share of China's total exports (ψ_j^{US}) in measuring the U.S. tariff shocks to Chinese producers. There are two rationales for using the latter. First is a well-documented fact that the production for exports tends to be more intensive in the use of imported intermediate than for domestic sales.[21] Thus, foreign input demand is likely to be more sensitive to demand changes in export markets. Second is the importance of processing exports in China.[22] As imported inputs are used exclusively for re-exports of

[19] There are 93 CSIC industries in the tradable sectors: agriculture, mining and manufacturing. Among these, three industries do not export: "Support service to farming, forestry etc." (05005), "Mining support activity etc." (11011), "Slaughtering and processing of meat" (13016), and "Other electronic equipment (39090)".

[20] This U.S. vertical shock measure is conceptually linked to the "upstreamness measure" by Antràs and Chor (2018), and the "vertical specialization measure" by Hummels, Ishii and Yi (2001) as these all capture the forward linkages in productions across countries. The main difference is that our vertical shock measure attempts to identify a relatively short-run upstream effect of U.S. tariffs that is specific to input suppliers to China, whereas Antràs and Chor (2018) capture the cross-country upstreamness in a general equilibrium setting.

[21] For empirical evidence, see Bernard, Jesen and Schott (2008) and Amiti, Itskhoki and Konings (2014).

[22] Processing trade was introduced by the Chinese government in the 1980s in an effort to boost their competitiveness in global markets (Yu (2014)). Chinese firms import all or part of the raw materials and intermediate inputs, and then re-export the finished products after local processing or assembly. Despite their diminishing share, processing exports still accounted for 37.8% of China's total exports in 2014 (Kang

finished goods under this trading regime, it should further increase the sensitivity of China's imported input demand to export market conditions. Using the U.S. share of China's total output, instead, is likely to understate the magnitude of the foreign demand shock on China's foreign input demand, as it assumes that imported inputs are used equally by domestic and exporting producers.[23]

One practical challenge to building this vertical shock measure is that there is no formal inter-country IO coefficients ($\theta^F_{i,j,c}$) at the CSIC industry level as the WIOT is constructed at the more aggregated sector level. To tackle this problem, we introduce a proportionality assumption and disaggregate the sector-pair values of intermediate use in the WIOT into industry-pairs proportionally to the corresponding elements in the detailed Chinese IO table. The underlying assumption is that the use of imported inputs from each origin country is proportional to the use of total inputs for each industry-pair within each sector-pair. To illustrate, suppose transport equipment - which consists of the auto and shipbuilding industries - as a hypothetical output sector, and electrical machinery - which consists of the motor and battery industries - as an input sector. Also suppose that, according to the Chinese industry-level IO table, \$5 (15) and \$10 (20) of motors (batteries) are used as total inputs (domestic and foreign) by the auto and shipbuilding industries, respectively. Further assume that, according to the sector-level WIOT, \$100 of imports of electrical machinery sector from Korea are supplied to the Chinese transport equipment sector. Then we apportion \$10 of these imports (=100*5/(5+15+10+20)) into the motor-auto industry pair and \$40 (=100*20/(5+15+10+20)) into the battery-shipbuilding industry pair, and so forth.[24] These disaggregated import values for each industry-pair are used as the numerators of import coefficients $\theta^F_{j,i,c}$ in which i is motor or battery industry, j is auto or shipbuilding industry and c is Korea in this example.

One concern would be that the above-mentioned import proportionality is too strong to hold for imports from every origin country-industry pair. For instance, the value of China's imports from Slovakia's electronics industry is quite trivial, and it would be unrealistic to assume that the industry's inputs are used proportionally across all Chinese output industries. Considering this, we also experiment with an alternative measure that simplifies the benchmark. We use the *total* imports of industry i into Chinese industry j in constructing the import coefficients for China. This is based on the conjecture that the proportionality assumption is more plausible for total imports rather than origin country-specific.

and Liao (2016)).

[23]By the same token, we admit that using the U.S. share of China's total exports as in this paper would possibly overstate the U.S. tariff effects on Chinese producers.

[24]Analogously, \$30 (=100*15/(5+15+10+20)) and \$20 (=100*10/(5+15+10+20)) of the imports are assigned to the motor-shipbuilding and battery-auto industry pairs, respectively.

$$\textbf{(Measure 2)} \quad VS_{i,t}^{US\to CN} = \sum_j \theta_{j,i}^F \psi_j^{US} \Delta\tau_{j,t}^{US\to CN}$$

where $\theta_{j,i}^F = \frac{Impint_{j,i}}{\sum_j Impint_{j,i}}$ and $Impint_{j,i}$ denotes the *total* intermediate imports of input industry i into Chinese output industry j from all origin countries in 2012. Note that, unlike the benchmark measure, this alternative does not have a cross-country variation.

4.2 Estimating Equation

To assess the vertical impact of the U.S.-China trade war, we run regressions for the growth rate of exports from 32 countries to China as follows:

$$g\_exv_{i,c,t}^{CN} = \beta VS_{i,c,t}^{US\to CN} + \gamma' Z_{i,t} + \alpha_{i,c} + \eta_{c,t} + v_s t + \epsilon_{i,c,t} \tag{1}$$

where subscripts i, c, and t denote 89 tradable CSIC industries,[25] 32 countries and 11 quarters between 2017:Q1 and 2019:Q3. The dependent variable $g\_exv_{i,c,t}^{CN}$ is the mid-point growth rate of quarterly country-industry (i,c) exports to China relative to the previous year:

$$g\_exv_{i,c,t}^{CN} = \frac{(exv_{i,c,t}^{CN} - exv_{i,c,t-4}^{CN})}{\frac{1}{2}(exv_{i,c,t}^{CN} + exv_{i,c,t-4}^{CN})} * 100 \tag{2}$$

where $exv_{i,c,t}^{CN}$ denotes country c's exports of industry i to China at quarter t. This approach has an advantage over logarithmic growth in accounting for adjustments in extensive margins (exit and entry) that are particularly rampant in high-frequency trade data. We use the year-on-year changes in exports to handle seasonality in trade flows. As the key variable of interest, $VS_{i,c,t}^{US\to CN}$ aims to capture the negative upstream effect of the U.S. tariffs on other countries ($\beta_1 < 0$). Additional tariff controls ($Z_{i,t}$) include $\Delta Tariff_{i,t}^{US\to CN}$ and $\Delta Tariff_{i,t}^{CN\to US}$ which are the year-on-year changes in the U.S. and Chinese tariffs on one another multiplied by the U.S. share of China's exports and imports in 2016, respectively. The inclusion of these tariffs is based on the literature emphasizing horizontal competition across countries in the spillover of trade policy (Bown and Crowley (2006)). First, there is a possibility that the U.S. tariffs on China ($\Delta Tariff_{i,t}^{US\to CN}$) reduce third countries' exports to China in the same industry as the unsold Chinese products in U.S. markets crowd out other foreign imports in Chinese home markets. This so called 'trade depression' should

[25]There are four out of 93 tradable CSIC industries that do not export - "Support service to farming, forestry etc." (05005), "Mining support activity etc." (11011), "Slaughtering and processing of meat" (13016), and "Other electronic equipment (39090)".

be captured by the negative coefficient ($\beta_2 < 0$).[26] Second is 'trade diversion'; Chinese retaliatory tariffs against the U.S. ($\Delta Tariff_{i,t}^{CN \to US}$) could lead to substitutions of the U.S. imports with other foreign products in Chinese home markets. This channel predicts a positive impact on third countries ($\beta_3 > 0$). $Z_{i,t}$ further includes the changes in China's MFN tariffs ($\Delta Tariff_{i,t}^{MFN}$) which could directly affect third countries' exports to China.[27] Apart from these tariffs, we adopt a stringent set of fixed effects to separate out the upstream effect of the U.S. tariffs from other unobserved factors affecting third countries' exports. We control for industry-country fixed effects ($\alpha_{i,c}$) to allow for the industry-country specific characteristics as well as country-time fixed effects ($\eta_{c,t}$) that absorb macro shocks including exchange rate movements. In order to account for global business cycle components across sectors, we also add sector-specific liner trends ($v_s t$).[28] Standard errors are clustered at the country-sector pair.[29]

A major threat to our identification strategy is potential endogeneity of trade policy changes. Note that, in building the vertical shock measure, we exploit the cross-country IO linkages measured in 2012 - several years prior to the trade war. Thus, endogeneity issues may arise primarily in tariff changes between the U.S. and China. As noted by Amiti, Redding and Weinstein (2019), however, this is less problematic in the context of the U.S.-China trade war back in 2018. Since President Trump's election in 2016 was largely unexpected by many observers, so were the tariff changes implemented thereafter. The phenomenal work by Fajgelbaum, Goldberg, Kennedy and Khandelwal (2019) and Amiti, Redding and Weinstein (2020) devote significant efforts to show that the changes in U.S.-China tariffs were uncorrelated with other unobserved demand and supply shocks and claim the validity

[26] Both the vertical impact and trade depression due to U.S. tariffs predict a negative impact on third country exports to China. But while trade depression could take place in any type of the end-use categories, the vertical propagation should occur in intermediates only.

[27] Chinese government cut its MFN tariffs on other trading partners when imposing retaliatory tariffs against the U.S. in 2018 (Bown, Jung and Zhang (2019)).

[28] Since some ISIC 2-digit sectors include only one CSIC-industry, we group these sectors with other similar sectors together. Specifically, we combine "Crop and animal production, hunting and related service activities (A01)", "Forestry and logging (A02)" and "Fishing and aquaculture (A03)") as a single sector group. We further group "Manufacture of paper and paper products (C17)" and "Printing and reproduction of recorded media (C18)" as "C17-18", "Manufacture of chemicals and chemical products (C21)" and "Manufacture of basic pharmaceutical products and pharmaceutical preparations (C22)" as "C21-22", "Manufacture of basic metals (C24)" and "Manufacture of fabricated metal products, except machinery and equipment (C25)" as "C24-C25", and "Manufacture of motor vehicles, trailers and semi-trailers (C29)" and "Manufacture of other transport equipment (C30)" as "C29-C30". The results using the initial definition of sectors are largely similar, however. We also test the sector-specific second-degree time polynomials to account for potentially non-linear aspects of the global business cycle. The results are very similar, with almost none of the coefficients for sectoral trends being significant.

[29] This is to account for the possibility of correlated residuals within sectors as our vertical shock measure exploits the IO elements in the WIOD. Alternative clustering - at the country-industry pair - does not make much difference, though.

of using the tariffs as a source of identification. From the perspective of third countries, the tariff changes between the U.S. and China are even more likely exogenous as they are not the direct counterparts targeted by the tariffs. It is hard to imagine that the U.S. tariffs on Chinese imports were intended to distort trade flows between third countries and China all the way through the global supply chain. Despite these arguments, one may still concern that a positive productivity shock to foreign input suppliers, if any, could have boosted exports of Chinese downstream industries to the U.S., leading to higher U.S. tariffs. To address this concern, we test for pre-existing trends in the effect of the U.S. vertical shock in the following section.

5 Results

This section presents the results for the impacts of the U.S.-China tariff shocks on third countries' exports. Note that each shock is standardized to have zero mean and unit variance for all the coefficients to be directly comparable.

5.1 Baseline

Table 1 shows the baseline results. All specifications include industry-country and country-time fixed effects as well as sector-specific linear trends. Columns (1) to (3) run regressions for exports of intermediates to China. Column 1 tests a parsimonious specification that only includes the U.S. vertical shock ($VS_{i,c,t}^{US\rightarrow CN}$), and columns 2 and 3 add other tariff shocks. In all columns, we find a negative and signifiant coefficient on the U.S. vertical shock in the first row. This implies that the industry-countries more exposed to the upstream propagation of the U.S. tariffs on China experienced a larger decline in their exports to China. To interpret, a one standard deviation rise in the U.S. vertical shock leads to a fall in the growth rate of exports in intermediates to China by around 5 percentage points. The coefficients on other tariff shocks are imprecisely estimated, with wrong signs for Chinese retaliatory tariffs and MFN tariffs.

One may question whether this U.S. vertical shock measure indeed captures the propagation of the U.S. tariffs via input-output linkages or whether it erroneously picks up any other forces driving a similar decline in overall exports to China. To examine this issue, we run separate regressions for exports of other end-use categories.[30] If the U.S. vertical shock measure truly identifies the upstream propagation of the U.S. tariffs on China, it would not

[30] Note that Table 1 reports different numbers of observations in regressions for each end-use category. This is because certain end-use products are entirely missing for some country-industry pairs. For instance, there is no capital goods in the CSIC industry 'Paper and paper products (22036)' for most countries.

Table 1: Impact of U.S.-China Tariffs on Third Country Exports to China

	Intermediate			Capital	Consumer	Total
	(1)	(2)	(3)	(4)	(5)	(6)
U.S. Vertical Shock $_{i,c,t}$	-5.219***	-5.116***	-5.073***	-1.295	-2.273	-2.640**
	(1.712)	(1.929)	(1.922)	(4.021)	(2.708)	(1.292)
U.S. Tariffs on China $_{i,t}$		-0.167	-0.109	-1.044	-0.343	-0.906
		(1.217)	(1.229)	(1.856)	(1.224)	(1.159)
Chinese Tariffs on U.S. $_{i,t}$			-2.120	2.472***	1.433	-0.239
			(1.731)	(0.862)	(2.127)	(0.986)
Chinese MFN Tariffs $_{i,t}$			0.238	-1.408	-1.264	-1.134
			(1.322)	(1.416)	(1.466)	(1.078)
Observations	24,748	24,748	24,748	9,351	14,383	27,788
Adj-R2	0.040	0.040	0.040	0.010	0.031	0.045
Industry-Country FE	✓	✓	✓	✓	✓	✓
Country-Time FE	✓	✓	✓	✓	✓	✓
Sector trend	✓	✓	✓	✓	✓	✓

Note: The dependent variable is the mid-point growth rate of country-industry pair exports to China, multiplied by 100. Columns (1) to (3) report regressions for intermediate goods, column (4) for capital goods, column (5) for consumer goods and column (6) for total exports to China. In column (6), the U.S. vertical shock is scaled by the shares of intermediates in total exports to China for each country-industry pair in 2016 ($\omega_{i,c}^{CN} * VS_{i(c),t}^{US \to CN}$). All shocks are standardized to have zero mean and unit variance. Standard errors are clustered by country-sector pairs in parentheses. Significance: *** p<0.01, ** p<0.05, * p<0.1.

exert equally strong influence on exports of non-intermediates. Columns (4) and (5) show the results for capital and consumption goods, respectively. We find no similar effect on non-intermediates, indicating that the U.S. vertical effect is particular to trade in intermediates. Instead, column (4) shows that Chinese retaliatory tariffs against the U.S. in the third row increased third countries' exports of capital goods to Chinese markets, which could possibly reflect substitutions for U.S. imports in the Chinese market ("trade diversion").[31]

To gauge the magnitude for total exports to China, column 6 scales the U.S. vertical shock by the shares of intermediates in total exports to China for each country-industry pair in 2016 ($\omega_{i,c}^{CN}$). It suggests that a one standard deviation increase in this scaled vertical shock ($\omega_{i,c}^{CN} * VS_{i,c,t}^{US \to CN}$) reduced the growth rate of total exports to China by 2.6 percentage points.[32] The positive effect of Chinese retaliations on capital goods, on the other hand, is entirely muted for total exports. To sum, these results provide strong evidence that the up-

[31]This indicates that the fall in exports of capital goods to China could have been far more severe in the absence of the trade diversion.

[32]When the U.S. vertical shock is scaled by non-intermediate share $(1 - \omega_{i,c}^{CN})$, the coefficient was -0.932 which is insignificant as expected, with the standard error of 0.962.

stream propagation of U.S. tariffs worked as the key channel through which the U.S.-China trade war affected the rest of the world.

Another important question is whether the U.S. vertical shock induced exporters in third countries to redirect their sales to other destinations. If successful, the negative upstream effect could have been partly compensated for by increased exports to other markets. We test this possibility by running regressions for these countries' exports to the U.S. or all other destinations as outcome variables. Columns (2) and (3) in Table 2 show no significant response in their exports to other destinations. Alternatively, we regress the growth rate of exports to China *relative* to the rest of the world:

$$\Delta g\_exv_{i,c,t}^{CN} = g\_exv_{i,c,t}^{CN} - g\_exv_{i,c,t}^{ROW}$$

If exporters in third countries managed to increase their exports to other destinations, the coefficient on the relative growth rate ($\Delta g\_exv_{i,c,t}^{CN}$) should be larger in absolute term. The result shows the opposite: the coefficient in column (4) is -4.035, slightly smaller than that of column (1) (-5.073) and significant at 5 percent. In sum, the U.S. vertical shock does not appear to have led to a re-routing of exports to other destinations at least over the time horizon we consider, and thus must have inflicted net losses upon third countries to the extent of reduced sales in Chinese markets.[33]

Table 2: Impact on Exports to Other Destinations

	China (1)	U.S. (2)	Other (3)	China-ROW (4)
U.S. Vertical Shock $_{i,c,t}$	-5.073***	-0.512	-0.921	-4.035**
	(1.922)	(1.833)	(0.781)	(2.028)
Observations	24,748	25,290	26,871	24,747
Adj-R2	0.040	0.036	0.150	0.029

Note: The dependent variable is the mid-point growth rate of country-industry pair exports of intermediates to each destination, multiplied by 100. Column (1) is the baseline for exports to China, the same as in column (3) of Table 1. Columns (2) and (3) are for exports to the U.S. or all other destinations combined. Column (4) is for the growth rate of exports to China relative to the rest of world ($\Delta g\_exv_{i,c,t}^{CN} = g\_exv_{i,c,t}^{CN} - g\_exv_{i,c,t}^{ROW}$). All columns include other tariff controls, industry-country and country-time fixed effects, as well as sector-specific linear trends. All shocks are standardized to have zero mean and unit variance. Standard errors are clustered by country-sector pairs in parentheses. Significance: *** p<0.01, ** p<0.05, * p<0.1.

[33] The absence of market-switching could be due to various frictions on international transactions including upfront entry costs that are likely to be country-specific, as discussed extensively in trade literature.

5.2 Robustness Check

This section discusses a series of additional estimations to check the robustness of our main results.

(Intensive Margin) We begin by replacing the outcome variable, the mid-point growth rate in equation (1), with log difference. In this case, all zero exports are dropped and thus we examine the impact on the intensive margin of exports. As reported in column (2) of Table 3, the coefficient becomes somewhat larger compared to the baseline column (1) (-5.073 $\rightarrow$ -6.579). This hints at the possibility that the adverse upstream effect of the U.S. tariffs was more pronounced on the intensive margin rather than on entry or exit.

(Sector-time Fixed Effects) Second, we replace sector-specific linear trends with sector-by-time fixed effects in which we exploit variations in tariffs over time across country-industries only *within* sectors. Column (3) shows that the U.S. vertical effect is still significant at 5% in this stringent specification, with the coefficient size essentially the same as the baseline.

(Sensitivity to Outlier Countries) To ensure that our results are not driven by specific countries, we re-estimate dropping some outlier countries in terms of aggregate exports to China in 2016 - the two biggest (Korea, Japan) and the two smallest countries (Bulgaria, Greece). The coefficient in column (4) remains materially unchanged.[34]

(Difference-in-difference Specification) One potential problem in the estimating equation (2) is the unknown lag structure of the tariff effects. For instance, tariffs could have a delayed effect on trade due to delivery lags in cross-border shipments or fixed contracts between sellers and buyers. There is also a possibility of anticipation effects; Importers and exporters may have reacted to the announcements of new tariffs and shifted their contract decisions even months before a policy change comes into effect. To account for the potential lead or lag in tariff effects, we exploit the changes in the U.S.-China tariffs before and after 2018Q:1 when the U.S. government announced its initial plan to impose tariffs on China and treat a series of tariff changes since mid-2018 as a single event. Using this transformation, we test the following difference-in-difference specification:

[34] We confirm that dropping any individual country, sector or industry does not alter the size of the coefficient on the U.S. vertical shock, nor its significance significantly.

$$g\_exv^{CN}_{i,c,t} = \beta(\widetilde{VS^{US\to CN}_{i,c}} * D_t) + \gamma'(\widetilde{Z}_i * D_t) + \alpha_{i,c} + \eta_{c,t} + v_s t + \epsilon_{i,c,t} \tag{3}$$

where $\widetilde{X} \equiv \overline{X_{t\geq 18:\text{Q2}}} - \overline{X_{t<18:\text{Q2}}}$ with $\overline{X_{t\geq 2018:\text{Q2}}}$ denoting the average changes in X on and after 2018:Q2 and D_t is a time dummy equal to one if $t \geq$ 2018:Q2 and zero otherwise.[35] As reported in column (5), the U.S. vertical effect is larger than the baseline (-5.073 vs. -10.504), which is likely to be an upper bound of the U.S. vertical impact. To further examine how the U.S. vertical effect evolved over time, we run a more flexible regression adding a full set of quarterly dummies interacted with each tariff shock:

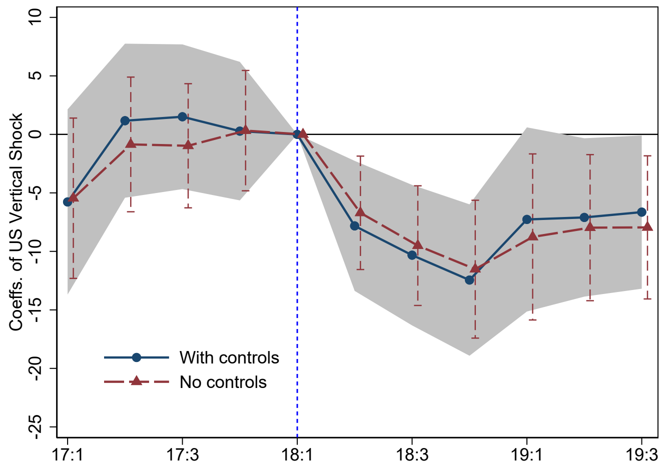
$$g\_exv^{CN}_{i,c,t} = \sum_t \beta_t(\widetilde{VS^{US\to CN}_{i,c}} * Q_t) + \sum_t \gamma'_t(\widetilde{Z}_i * Q_t) + \alpha_{i,c} + \eta_{c,t} + v_s t + \epsilon_{i,c,t},$$
$$\forall t \in \{2017{:}\text{Q1}, .., 2019{:}\text{Q3}\} \setminus 2018{:}\text{Q1} \tag{4}$$

where Q_t is an indicator for each quarter, with 2018:Q1 as the omitted category. This dynamic specification fully accounts for potential anticipatory or delayed effects and also serves as a diagnostic test for pre-trends. Figure 3 traces the point estimates and the 95% confidence intervals for the U.S. vertical shock over time. The red dashed line is estimated without including other tariff controls, while the blue line includes all other controls as well. Whether or not other controls are added, the estimated coefficients for the U.S. vertical shock are not different from zero until 2017:Q4, which confirms that our U.S. vertical effect is not driven by pre-existing trends. The negative upstream effect becomes significant from 2018:Q2 and strongest in 2018:Q4. Unsurprisingly, the latter is the period immediately after the third round of the U.S. tariff increases was undertaken, the largest in scale during 2018.

(Estimation at ISIC Level) Instead of adopting the proportionality assumption to build more granular vertical shocks, we may exploit the original ISIC sector-by-sector IO linkages in the WIOD at a cost of having fewer observations. To test for this, column (6) aggregates exports and tariff shocks at the country-sector level. The U.S. vertical shock at the sector level is estimated to be larger in magnitude than the baseline (-8.653 vs. -5.073) and significant at 5%, which is again supportive of our upstream propagation channel. We also find that, in comparison to the baseline, this aggregated measure tends to be statistically less significant in most specifications we conducted throughout the paper.

[35] In other tariff controls $(\widetilde{Z}_i * D_t)$, China's MFN tariff changes $(\Delta Tariff^{MFN}_{i,t})$ were not transformed as these would affect third countries' exports more immediately. Applying the same transformation to the MFN tariffs makes no difference in our results.

Figure 3: Dynamic Specification for U.S. Vertical Shock



Note: The figure plots the point estimates of the U.S. vertical shock for each quarter from the dynamic specification (equation 4). The dependent variable is the mid-point growth rate of country-industry pair exports of intermediates to China, multiplied by 100. The dashed red line represents the estimates without other tariff controls and the blue line plots the estimates including them. The dashed vertical line indicates 2018:Q1. The shaded areas (dotted vertical lines) indicate the 95% confidence intervals for the estimates with (without) other controls.

(Alternative Measure 2) We next run a regression using the alternative measure 2 of the U.S. vertical shock, which does not have cross-country variations ($\text{VS}_{i,t}^{US \to CN}$). We aggregate the industry-country specific export values by industries and control for industry and time fixed effects, along with sector-specific trends. Standard errors are clustered by ISIC sectors. Column (7) yields a somewhat larger estimate of -7.081, significant at 5%.

(Alternative Vertical Channels) As a final robustness check, we discuss a possibility of alternative vertical linkage channels. The focus of this paper is on the upstream propagation of the U.S. tariffs on China. It cannot be ruled out, however, that the Chinese retaliatory tariffs on U.S. imports generate a separate vertical effect of any sort through the globally interconnected supply chains. Further considering these alternative vertical channels could affect our result on the U.S. vertical effect. In Appendix B, we describe a simple theoretical framework to build measures of these alternative channels and check whether they alter our results. As reported in Appendix Table , we verify that the U.S. vertical shock remains robust to the inclusion of other alternative channels, with none of which being significant by themselves.

Table 3: Robustness on U.S. Vertical Effect

	Baseline (1)	Log growth (2)	Sector-time FE (3)	No Outliers (4)	Diff-in-Diff (5)	ISIC level (6)	Measure 2 (7)
$\text{VS}_{i,c,t}^{US\to CN}$	-5.073***	-6.579**	-5.021**	-5.131**		-8.653**	-7.081**
	(1.922)	(2.738)	(2.137)	(2.048)		(3.721)	(2.881)
$\widetilde{\text{VS}_{i,c}^{US\to CN}} * D_t$					-10.504***		
					(2.542)		
Observations	24,748	22,786	24,748	21,465	24,748	6,835	924
Adj-R2	0.0396	0.0517	0.0380	0.0357	0.0403	0.1258	0.345
Industry FE							✓
Time FE							✓
Industry-Country FE	✓	✓	✓	✓	✓		
Industry-Sector FE						✓	
Country-Time FE	✓	✓	✓	✓	✓	✓	
Sector trend	✓	✓		✓	✓	✓	✓
Sector-Time FE			✓				

Note: The dependent variable is the mid-point growth rate of exports of intermediates from 32 countries to China, multiplied by 100. Columns 1 to 5 are estimated at the country-industry level. Columns 6 and 7 are estimated at the country-sector level and at the industry level, respectively. All shocks are standardized to have zero mean and unit variance. Standard errors are clustered at the sector-country pair in parentheses except for column 7 in which standard errors are clustered at the sector level. Significance: *** p<0.01, ** p<0.05, * p<0.1.

5.3 Quantifying U.S. Vertical Effect

This section quantifies the magnitude of the U.S. vertical effect for each country. To that end, we first calculate how much the U.S. vertical effect contributed to the realized declines in the growth rate of exports to China between the post-shock period ($t \geq$ 2018:Q2) and the pre-shock period ($t <$ 2018:Q2) in two steps. First, we compute the predicted growth rate of exports to China for each country and each quarter using the estimate ($\widehat{\beta}_1$) in column 6 of Table 1 and the U.S. vertical shocks:

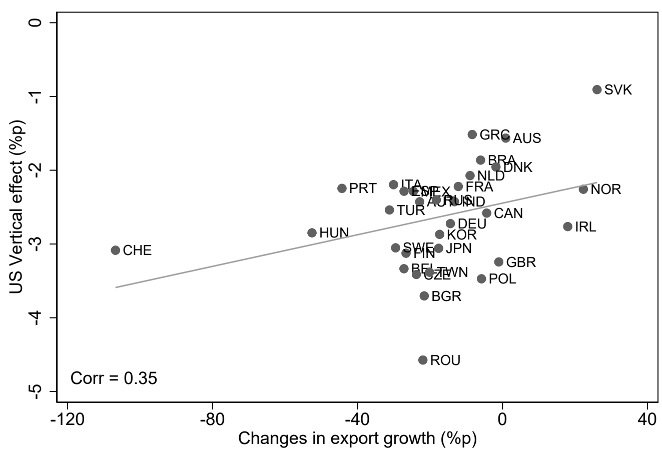
$$\widehat{X_{c,t}^{CN}} = \sum_i \theta_{i,c,t,t-4}^{CN} \big(\widehat{\beta}_1 * \omega_{i,c}^{CN}\, VS_{i,c,t}^{US\to CN}\big)$$

where $\theta_{i,c,t,t-4}^{CN} = \frac{exv_{c,i,t}^{CN} + exv_{c,i,t-4}^{CN}}{exv_{c,t}^{CN} + exv_{c,t-4}^{CN}}$ is the average weight of industry i in country c's total export to China between quarter t and $t-4$. Next, changes in the average growth rate of exports between the post-shock period ($t \geq 18:Q2$) and the pre-shock period ($t < 18:Q2$) are computed as:

$$\widehat{\Delta X_c^{CN}} = \frac{\sum_{t\geq 18:Q2} \widehat{X_{c,t}^{CN}}}{N_{t\geq 18:Q2}} - \frac{\sum_{t<18:Q1} \widehat{X_{c,t}^{CN}}}{N_{t<18:Q2}}$$

where $N_{t\geq 18:Q2}$ ($N_{t<18:Q2}$) is the number of quarters for the post (pre) -shock period which is 6 (5) in our sample. The U.S. vertical effect is estimated to have lowered the growth rate of exports by 2.7 percentage points on average across countries. The actual change in the growth rate of exports to China before and after 2018:Q1 is -17.9 percentage points. Thus, the U.S. vertical effect is responsible for roughly 15% of the fall in the export growth to China. Figure 4 plots the predicted (y-axis) versus the actual changes (x-axis) in the growth rate of exports across countries. The correlation of 0.35 implies that the U.S. vertical effect is an important predictor for the actual declines in exports to China across countries.[36] Romania (-4.6%p), Bulgaria (-3.7%p) and Taiwan (-3.4%p) saw larger drops in their export growth to China due to the U.S. vertical effect, while Slovakia (-0.9%p) and Australia (-1.6%p) experienced much milder falls.

Figure 4: U.S. vertical Effect vs. Export Growth to China



Note: The figure plots the actual changes in the growth rate of exports to China between the pre-shock average (2017:Q1-2018:Q1) and the post-shock average (2018:Q2-2019:Q3) for each country (x-axis) and the predicted changes due to the U.S. vertical effect (y-axis), both in percentage points.

As a final stage, we calculate losses of exports in terms of GDP for each country (ΔR_c), taking into account the relative importance of Chinese markets:

$$\Delta R_c = \frac{\widehat{\Delta X_c^{CN}} * exv_{c,2017}^{CN}}{GDP_{c,2017}}$$

where $exv_{c,2017}^{CN}$ and $GDP_{c,2017}$ are total exports to China and GDP of country c in 2017, respectively. The full results are reported in Appendix Table A2. The U.S. vertical effect

[36] In case Switzerland (CHE) which records the largest drop in exports to China is excluded, the correlation becomes 0.37. One may wonder whether countries with a higher share of intermediates in their exports to China ($\omega_{i,c}^{CN}$), regardless of their exposures to the U.S. vertical shock, experienced a larger fall in their export growth. However, the correlation between the changes in their export growth and their intermediate shares was merely -0.07, and thus the initial share of intermediate cannot explain much part of the changes in exports.

turns out to have reduced the GDP for third countries by -0.06% on average. Taiwan was most severely hurt by the upstream effect of the U.S. vertical shock with an estimated GDP loss of 0.53 percent, which is followed by Korea (0.26 percent). Note that these two countries were the largest suppliers to China primarily in high-tech intermediates (e.g. semiconductors) and heavily export-driven economies. On the other hand, Turkey was much less affected (less than 0.01 percent) due to its smaller reliance on Chinese markets.

5.4 Discussion

The previous section proposes that the U.S. tariffs on China incurred an average GDP loss of -0.06% for third countries through upstream propagations. For comparison with the direct effect of the trade war, Fajgelbaum, Goldberg, Kennedy and Khandelwal (2019) estimate that U.S. import tariffs and retaliatory tariffs from trading countries in 2018 resulted in losses to U.S. consumers and firms by up to 0.27% of GDP.[37] One might question how a demand shock in one single export market could create such large changes in Chinese producer's input demand, even considering the importance of the U.S. market for China and the size of tariff changes.

One potential mechanism that could explain this large short-run elasticity would be inventory adjustments as pointed out by Alessandria, Kaboski and Midrigan (2010) and Bems, Johnson and Yi (2013). Specifically, the former study shows that economies of scale in transportation and delivery lags for cross-border shipments give agents incentives to hold large inventories of imported goods. In response to a negative demand shock, imports may decline more than proportionally to demand changes because the desired level of inventories should also fall, amplifying the overall effect on imports.[38] While Alessandria, Kaboski and Midrigan (2010) focus on inventories of final goods, the mechanism may apply to either U.S. wholesalers of Chinese imports or Chinese producers importing intermediates or both. The next section tests the role of sector-level inventory holding by both the U.S. and China in the effect of the U.S. vertical shock.

The possibility that the economic impact of the U.S.-China trade war may be greater than their trade exposure to one another is also raised by Handley, Kamal and Monarch (2020) in their study on U.S. exporters. They find the estimated effects of the U.S. import tariffs on U.S. exports through rising foreign input costs is much large compared to what

[37]Once U.S. tariff revenues and other general equilibrium effects are accounted for, they suggest that the losses could have been reduced to 0.04% of GDP.

[38]The magnitude of this mechanism could be huge. Alessandria, Kaboski and Midrigan (2010) suggest that inventory adjustments account for up to 20% of the drop in U.S. imports during the trade collapse of 2008-2009. The impact could be largely heterogeneous across industries as well. In their case study on the U.S. auto industry, imports fell by more than twice the sales of imported autos during the same period.

appears to be a fairly small cost shock in the aggregate. Likewise, for Chinese producers, the unprecedented tariff shocks from the largest export market (the U.S.) and a huge uncertainty going forward might have had a much larger impact on their activity than the size of tariffs.[39] And some Chinese firms might have even been forced to exit from exporting and importing altogether.[40] The vertical measure would probably capture part of these effects beyond the immediate tariff-induced impact on their input demand.

It is also important to note that the analysis in this paper is necessarily short-run in nature and the long-run effects of the trade war may differ. The longer-run effects of the tariffs should depend on whether firms see the trade war as transitory or permanent (Flaaen and Pierce (2019)). If permanent, for instance, less productive Chinese firms with a high reliance on the U.S. market are more likely to exit from exporting while surviving firms would seek to diversify their export market portfolios away from the U.S. to reduce the future risk. In either direction, these will all affect the long-run response of the China's trades with other countries.

5.5 Heterogeneity in U.S. Vertical Effect

In this section, we explore potential heterogeneity in the U.S. vertical effect.

5.5.1 Decomposition: Own vs Other Sectors

It is known that firms use a large fraction of inputs from their own industries and some papers focus on this within-industry input reliance in analysing the supply chain impact of economic shocks.[41] This section examines to what extent the upstream effect of the U.S. tariffs on a foreign input industry is attributed to demand falls from the same versus other sectors in China. To see this, I decompose the U.S. vertical shock as follows:

[39] Literature including Handley and Limão (2015) highlights the importance of trade policy uncertainty for trade and investment decisions.

[40] One related hypothesis could be the presence of a global component of fixed export cost. For instance, Mau (2017) argues that firms should pay not only the conventional destination-specific fixed cost but a global (product-specific) fixed cost of exporting which results in economies of scale in serving multiple destinations. This implies that a negative demand shock in one foreign market, particularly a large one (the U.S.), could induce Chinese firms to exit not only from the affected market but also from other destinations due to the increased per destination global fixed cost, which would result in much larger fall in their input demand.

[41] As evidenced by the diagonal elements of most IO tables, the largest share of input purchases for an output industry usually comes from its own industry. As a study using information other than the IO tables, Handley, Kamal and Monarch (2020) exploit the firms' imports of the same HS 4-digit categories as their export products in evaluating the supply chain effect of the U.S. import tariffs on the U.S. exporters.

$$VS_{i,c,t}^{US\rightarrow CN} = \underbrace{\sum_{k\in J_i}\theta_{k,i,c}^{F}\psi_k^{US}\Delta\tau_{k,t}^{US\rightarrow CN}}_{\text{Vertical shock from own sectors}} + \underbrace{\sum_{k'\notin J_i}\theta_{k',i,c}^{F}\psi_{k'}^{US}\Delta\tau_{k',t}^{US\rightarrow CN}}_{\text{Vertical shock from other sectors}}$$

where k and k' again denote the CSIC output industry in China and i, c indicates the CSIC input industry i in origin country c. J_i denotes the ISIC 2-digit sector to which the CSIC industry i belongs. The first component of the above decomposition corresponds to the upstream effect of falling demand from the own sector in China ($k \in J_i$) while the second component captures that from other sectors in China ($k \notin J_i$). Column (1) in Table 4 shows that a decline in exports of industry i to China is driven by falling demand from both the same Chinese sectors hit by U.S. tariffs ($k \in J_i$) and other sectors ($k \notin J_i$). But the impact from same output sectors is larger in magnitude than that from other sectors (-6.130 vs. -3.368). This indicates that the within-sector input use is indeed quantitatively more significant in channelling the vertical propagation of the U.S. tariff shocks.[42]

5.5.2 Durability

Next, we check whether the upstream effect of the U.S. tariffs varies depending on the type of U.S. imported products from China. We pay particular attention to durability within consumption goods, regarding the argument that import demand for durable goods is more volatile and showed much larger reductions during the 2008 global financial crisis (Levchenko, Lewis and Tesar (2010)). To analyse this, recall that the U.S. tariffs on Chinese outputs at the CSIC industry level ($\Delta\tau_{j,t}^{US\rightarrow CN}$) are constructed by weight-averaging the HS 6-digit product level (p) tariffs. It can thus be decomposed back into tariffs on non-consumption goods ($1 - C_p$) and on consumption goods (C_p). Based on the classification by UN BEC, I further split the tariffs on consumption goods into that on durables (d_p) and non-durables ($1 - d_p$):

$$\begin{aligned}\Delta\tau_{j,t}^{US\rightarrow CN} &= \sum_{p\in j}[\omega_p^{US} * (1 - C_p)\Delta\tau_{p,t}^{US\rightarrow CN} + \omega_p^{US} * C_p\Delta\tau_{p,t}^{US\rightarrow CN}] \\ &= \sum_{p\in j}[\omega_p^{US} * (1 - C_p)\Delta\tau_{p,t}^{US\rightarrow CN} + \omega_p^{US} * d_p\Delta\tau_{p,t}^{US\rightarrow CN} + \omega_p^{US} * (1 - d_p)\Delta\tau_{p,t}^{US\rightarrow CN}]\end{aligned}$$

where ω_p^{US} denotes the share of product p in 2016 U.S. imports from Chinese output industry

[42] Note that these coefficients estimate the effects of a one standard deviation increase in each component of shocks. If we consider the actual changes in each shock component between pre- and post-2018.Q1 periods, the vertical effect from other sectors contributes less than a tenth to the total vertical effect.

j and C_p is a dummy equal to one if product p belongs to consumption goods and d_p is a dummy for durables within consumption goods. Using this decomposition, we build and test the significance of the following versions of the U.S. vertical shock that are specific to a subset of Chinese products:

$$
\begin{aligned}
\textit{No-Cons}\ VS_{i,c,t}^{US\to CN} &= \textstyle\sum_j \theta_{j,i,c}^F \psi_j^{US} (\sum_{p\in j} \omega_p^{US} * (1-C_p)\Delta\tau_{p,t}^{US\to CN}) \\
\textit{Cons}\ VS_{i,c,t}^{US\to CN} &= \textstyle\sum_j \theta_{j,i,c}^F \psi_j^{US} (\sum_{p\in j} \omega_p^{US} * C_p\Delta\tau_{p,t}^{US\to CN}) \\
\textit{Durable}\ VS_{i,c,t}^{US\to CN} &= \textstyle\sum_j \theta_{j,i,c}^F \psi_j^{US} (\sum_{p\in j} \omega_p^{US} * d_p\Delta\tau_{p,t}^{US\to CN}) \\
\textit{No-Durable}\ VS_{i,c,t}^{US\to CN} &= \textstyle\sum_j \theta_{j,i,c}^F \psi_j^{US} (\sum_{p\in j} \omega_p^{US} * (1-d_p)\Delta\tau_{p,t}^{US\to CN})
\end{aligned}
$$

Column (2) in Table 4 shows that the U.S. vertical shock related to non-consumption goods ($\textit{No-Cons}\ VS_{i,c,t}^{US\to CN}$), intermediate and capital, is highly significant with a similar magnitude to the benchmark. While the vertical shock related to consumption goods ($\textit{Cons}\ VS_{i,c,t}^{US\to CN}$) is not different from zero, the vertical shock stemming from the durable goods, a subset of consumption goods, is significant. It also remains significant in column 3 when the shock from consumption goods ($\textit{Cons}\ VS_{i,c,t}^{US\to CN}$) is replaced by that from non-durables ($\textit{No-Durable}\ VS_{i,c,t}^{US\to CN}$). These results are indicative of a stronger upstream effect of a trade shock given to durable goods with highly volatile demand. Quantitatively, the vertical shock arising from durables in consumption goods is responsible for around 20% of the total vertical effect, while the remaining 80% is attributed to the vertical shock related to non-consumption goods.

5.5.3 Inventory Adjustment

As a final extension, we test the role of inventories held by the U.S. and China, respectively. Unfortunately, detailed data for imported inventory holdings are not available. We turn to ISIC sector-level data from the national IOs for both countries over 2010-2014, which are compiled in the WIOD. To examine the role of U.S. inventories first, we build an 'inventory-augmented' U.S. vertical shock measure as follows:

$$
\textit{US-Inv}\ VS_{i,c,t}^{US\to CN} = \textstyle\sum_j Inv_s^{US} * \theta_{j,i,c}^F \psi_j^{US} \Delta\tau_{j,t}^{US\to CN}
$$

where Inv_s^{US} denotes the 2010-2014 average of U.S. imported inventories as a ratio of total imports in ISIC sector s to which industry i belongs to. Our hypothesis is that the U.S.

sectors holding larger imported inventories should reduce their imports from China by more, which in turn leads to a larger reduction in China's demand for foreign inputs. Columns (4) and (5) show that, whether sectoral trends are added or not, the inventory-augmented shock ($US\text{-}Inv\ VS^{US\to CN}_{i,c,t}$) does not play a meaningful role, beyond the original vertical shock ($VS^{US\to CN}_{i,c,t}$). Its coefficient was negative as expected, but was not statistically significant possibly due to high collinearity with the original shock.[43] We next examine the inventories held by China, which could affect their demand for foreign inputs more directly. We use the ratio of imported inventories in China's total imports for each sector (Inv^{CN}_s), again averaged over 2010-2014. Using this measure is based on an assumption that parts of these inventories are intermediates in each sector that will be consumed by output sectors in subsequent periods.[44] Columns (6) and (7) add the interaction term between the U.S. vertical shock ($VS^{US\to CN}_{i,c,t}$) and the imported inventory ratio in China (Inv^{CN}_s). In column 6 where sectoral trends are not included, we obtain a negative coefficient of -1.025 for the interaction term, which is significant at 10 percent, implying that Chinese industries holding larger imported stocks reduced imports of intermediates by more in response to U.S. tariffs. But this effect turns insignificant in column 7 where sectoral trends are added. All in all, the role of inventory adjustments in amplifying the vertical impact was not so strongly supported, despite the expected signs of coefficients. This would be partly due to the use of limited data with only 22 distinct sectoral values for imported inventories.

6 Firm-level Evidence from Korea

The analysis thus far presents cross-country evidence of the upstream effect of the U.S. tariffs on China. Using balance sheets for a sample of Korean manufacturers, I further implement a firm-level analysis to see how the industry-specific tariff shocks affected individual firms. Korea is an important testing ground for this, as the single largest exporter to China with its deep engagement in global value chain (Antràs and Chor (2018)).[45] Figure 5 depicts overall performance of Korean firms in our sample amid the U.S.-China trade war. Among others, we find that sales growth became sluggish since mid-2018 and then plunged into negative territory following the third round of the U.S. tariff hikes against China. Similarly, we see a

[43]The correlation between the original and the inventory-augmented vertical shocks is 0.75 between 2018:Q2-2019:Q3 - the period when massive tariff changes occurred.

[44]Defever, Imbruno and Kneller (2020) show that wholesalers - the key agent holding inventories - play an important role of supplying foreign intermediate inputs and they cover around 21.4% of total intermediate imports for Chinese manufacturing sectors in 2002.

[45]Besides that, the merchandise exports account for over 30% of the Korea's GDP. This may imply that a large fraction of Korean manufacturing firms engage in exporting - particularly to China as their largest foreign market - and should thus be exposed to the U.S.-China trade war either directly or indirectly.

Table 4: Heterogeneity in U.S. Vertical Effect

	Decomposition	Durability		U.S. Inventories		CN Inventories	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
$VS^{US\to CN}_{i,c,t}$				-3.927*	-3.427	-3.925**	-4.869**
				(2.348)	(2.520)	(1.778)	(1.903)
VS from Own sector$^{US\to CN}_{i,c,t}$	-6.130***						
	(2.339)						
VS from Other sectors$^{US\to CN}_{i,c,t}$	-3.368**						
	(1.574)						
No-Cons $VS^{US\to CN}_{i,c,t}$		-5.144***	-5.169***				
		(1.770)	(1.775)				
Cons $VS^{US\to CN}_{i,c,t}$		1.097					
		(1.723)					
Durable $VS^{US\to CN}_{i,c,t}$		-3.169**	-2.593**				
		(1.375)	(1.105)				
No-Durable $VS^{US\to CN}_{i,c,t}$			0.685				
			(1.398)				
US-Inv $VS^{US\to CN}_{i,c,t}$				-0.431	-2.034		
				(1.662)	(2.291)		
$VS^{US\to CN}_{i,c,t} * Inv^{CN}_s$						-1.025*	-0.794
						(0.592)	(0.826)
Observations	24,748	24,748	24,748	24,748	24,748	24,748	24,748
Adj-R2	0.040	0.040	0.040	0.037	0.040	0.037	0.040
Industry-Country FE	✓	✓	✓	✓	✓	✓	✓
Country-Time FE	✓	✓	✓	✓	✓	✓	✓
Sector trend	✓	✓	✓		✓		✓

Note: The dependent variable is the mid-point growth rate of country-industry pair exports of intermediates to China, multiplied by 100. All columns include other tariff controls. All the shocks are standardized to have zero mean and unit variance. Standard errors are clustered at the country-sector pair in parentheses. Significance: *** p<0.01, ** p<0.05, * p<0.1.

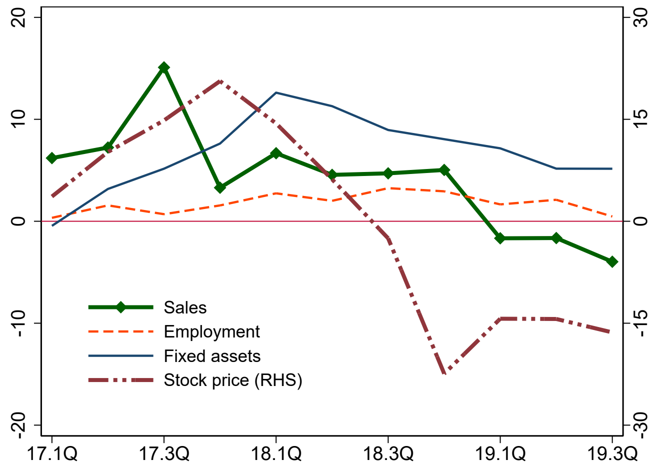
sharp decline in stock returns (right y-axis), weighted by firm sales for 2016. Employment and fixed investment, by contrast, do not exhibit such a precipitous fall, implying that the trade war impact was not so immediate as on firm sales.

To formally assess how the trade war affected Korean firms, we run regressions for individual firms' performance against industry-level tariff shocks:

$$\Delta \log(Y_{f,i,t}) = \beta(\omega_i^{CN} * VS^{US\to CN}_{i,t}) + \gamma'(\omega_i^{CN} * Z_{i,t}) + X_{f,t} + \alpha_f + \delta_t + \upsilon_s t + \epsilon_{f,i,t} \tag{5}$$

where $\Delta \log(Y_{f,i,t})$ is the four-quarter log difference in sales, stock prices and market capitalizations for Korean manufacturing firm f in industry i. Sales are deflated by the sector-level producer price. Stock prices and market capitalizations are constructed by averaging the monthly closing prices within each quarter. $VS^{US\to CN}_{i,t}$ is the U.S. vertical shock with no

Figure 5: Performance of Korean Firms amid U.S.-China Trade War



Note: Figure plots the four-quarter log difference in aggregate sales, employment and fixed assets (all left y-axis) and stock prices (right y-axis) for the sample of Korean manufacturing firms. Stock prices are weighted by firm sales for 2016. Source: KISVALUE.

country subscript c as it is specific to Korea. $Z_{i,t}$ denotes the set of other tariff controls ($\Delta Tariff_{i,t}^{US\to CN}$, $\Delta Tariff_{i,t}^{CN\to US}$ and $\Delta Tariff_{i,t}^{MFN}$) and $X_{f,t}$ is a set of firm controls including the four quarter-lagged values of capital intensity, total assets, firm age and credit score. I add firm (α_f) and time fixed effects (δ_t), along with the sector-specific liner trends ($v_s t$). It is likely that the tariff shocks associated with China might have a larger effect on firms in industries with a higher reliance on Chinese markets. We therefore adjust each tariff shock by China's share in each Korean industry's 2016 exports (ω_i^{CN}). Standard errors are clustered by CSIC industries, but the results remain essentially the same when clustered by ISIC sectors.

Table 5 shows the results. As in the cross-country analysis, all the shocks are standardized to have zero mean and unit variance for readability. Column (1) estimates the U.S. vertical effect only, and columns (2) to (3) add other tariff shocks. More stringently, column (4) controls for firm fixed effects and columns (5) to (7) test the difference-in-difference specification ('DiD'), using the same transformation of tariff shocks in the previous section. All columns commonly show the significant adverse impact of the U.S. vertical shock on firms' sales growth. According to columns (1) to (4), a one standard deviation rise in the U.S. vertical shock reduced the firms' sales growth by 3.2 to 4.3 percentage points. As an alternative quantification, the U.S. vertical impact knocks 1.2 to 2.1 percentage points off the post-2018:Q1 sales growth relative to that of the pre-2018:Q1 period.[46] The difference-

[46]This magnitude seems somewhat large given that the U.S. vertical effect on Korea's export growth to China was -4.2 percentage points in the previous section.

in-difference specification in column 5 shows a relatively larger estimate of -6.075, similarly to the cross-country analysis. Columns 6 and 7 turn to the impact on stock returns and market capitalizations, using the difference-in-difference specification. The U.S. vertical effect is found to have dragged down the firm market values by about 5 percentage points, which is largely similar in magnitude to that on sales growth. These suggest that investors became increasingly jittery over a repercussion of the U.S.-China trade war on Korean upstream firms.

Table 5: Impact of U.S.-China Trade War on Korean Firms

	Sales					Stock price	Mkt Cap.
					DiD	DiD	DiD
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
U.S. Vertical Shock$_{i,t}$	-3.276***	-2.511***	-2.761***	-4.381***	-6.075***	-5.332*	-5.991**
	(0.701)	(0.827)	(0.949)	(1.341)	(1.640)	(2.929)	(2.593)
U.S. Tariffs on China$_{i,t}$		-0.879	-0.921	-0.606	0.606	0.430	0.582
		(1.139)	(1.108)	(1.462)	(2.099)	(2.744)	(2.475)
Chinese Tariffs on U.S.$_{i,t}$			0.509	0.786	0.765	1.662	1.303
			(0.653)	(0.770)	(0.909)	(1.414)	(1.549)
Chinese MFN Tariffs$_{i,t}$			-0.017	0.174	0.478	-0.196	-0.343
			(0.408)	(0.423)	(0.476)	(1.134)	(1.095)
Observations	10,568	10,568	10,568	10,568	10,568	9,812	9,812
Adj-R2	0.0408	0.0408	0.0408	0.134	0.134	0.302	0.297
Firm controls	✓	✓	✓	✓	✓	✓	✓
Firm FE				✓	✓	✓	✓
Time FE	✓	✓	✓	✓	✓	✓	✓
Sectoral trend	✓	✓	✓	✓	✓	✓	✓

Note: The dependent variable is the four-quarter log difference in quarterly firm sales in column 1 to 5, stock prices in column 6 and market capitalizations in column 7, all multiplied by 100. Columns 5 to 7 use the transformed tariff shocks $\widetilde{X} * D_t$, where $\widetilde{X} \equiv \overline{X_{t\geq 18:\text{Q2}}} - \overline{X_{t<18:\text{Q2}}}$ with $\overline{X_{t\geq 18:\text{Q2}}}$ denoting average tariff shocks (X) on and after 2018:Q2, and D_t denoting a time dummy equal to one if $t \geq$ 18:Q2 and zero otherwise. All the shocks are standardized to have zero mean and unit variance. Standard errors are clustered at the CSIC industry in parentheses. Significance: *** p<0.01, ** p<0.05, * p<0.1.

Finally, we test the dynamic specification using a full set of quarterly dummies interacted with tariff shocks as in the previous section. Appendix Figure A1 demonstrates that the U.S. vertical shock substantially reduced the sales growth of Korean firms and its impact persisted throughout the whole period since 2018:Q1. Overall, these lend further support to the claim that the upstream propagation of the U.S. tariffs is a key channel for the spillovers of the U.S.-China trade war.

7 Concluding Remarks

In this paper, we investigate how the U.S.-China tariff war in 2018-19 affected third country exports. Using an industry-country specific measure of input-output linkages, we find that the U.S. tariffs on Chinese imports had a significant upstream effect on third countries. Given that there was no re-directing of exports to other destinations facing the trade war, this upstream effect must have inflicted net losses on these countries. The importance of this vertical channel is also confirmed in firm-level analysis on Korean manufacturing sectors. Firms in industries more exposed to the vertical shock of the U.S. tariffs experienced a substantial decline in their sales growth and market values.

The cross-border upstream propagation of local trade policy changes, as found in this paper, illustrates how tightly productions are interconnected across countries and industries along the global supply chain. Further research using more detailed data on ideally firm-to-firm international transactions, accounting for firm heterogeneity, would be welcome in exploring the spillovers of economic shocks through global production networks.

Lastly, we find little evidence of other classical channels - trade diversions driven by China's retaliations, in particular. This should not be asserted as absence of such effects, however. Uncovering these alternative channels would require a more disaggregated product-level analysis, as in previous literature, over different time spans. This is also an avenue for future research for a better understanding of the consequence of the trade war.

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A More Statistics and Results

Table A1: Chinese Standard Industry Classification (CSIC)

CSIC-5	Industry Description	ISIC Rev. 4
01001	Farming	A01
02002	Forestry	A02
03003	Animal production	A01
04004	Fishery	A03
05005	Support service to farming, forestry etc.	A03
06006	Mining and washing of coal	B
07007	Extraction of crude petroleum and natural gas	B
08008	Mining of ferrous metal ores	B
09009	Mining of non-ferrous metal ores	B
10010	Mining and quarrying of non-metallic mineral	B
11011	Mining support activity etc.	B
13012	Manufacture of grain mill products	C10-C12
13013	Manufacture of prepared animal feeds	C10-C12
13014	Manufacture of crude and refined oil from vegetable	C10-C12
13015	Manufacture of sugar	C10-C12
13016	Slaughtering and processing of meat	C10-C12
13017	Processing of aquatic products	C10-C12
13018	Processing of other foods	C10-C12
14019	Manufacture of convenience food products	C10-C12
14020	Manufacture of milk and dairy products	C10-C12
14021	Manufacture of flavoring and ferment products	C10-C12
14022	Manufacture of other food products n.e.c	C10-C12
15023	Alcohol and alcoholic beverages	C10-C12
15024	Soft drink and refined tea products	C10-C12
16025	Tobacco products	C10-C12
17026	Spinning, weaving and fishing of cotton and chemical fibers	C13-C15
17027	Spinning, weaving and fishing of wool	C13-C15
17028	Spinning, weaving and fishing of bast and silk fibers	C13-C15
17029	Knitted and crocheted fabrics and articles, except apparel	C13-C15
17030	Made-up textile articles, except apparel	C13-C15
18031	Textile wearing apparel	C13-C15
19032	Leather, fur, feather and its products	C13-C15
19033	Footwear	C13-C15
20034	Processing of timbers and manufacture of wood products etc.	C16
21035	Furniture	C31_C32
22036	Paper and paper products	C17
23037	Printing and reproduction of recording media	C18
24038	Stationeries, musical instruments, products of arts, crafts, toys etc.	C31_C32
25039	Refined petroleum products, processing of nuclear fuel	C19
25040	Coke products	C19
26041	Basic chemicals	C20
26042	Fertilizers	C20
26043	Pesticides	C20
26044	Paints, printing inks, pigments and similar products	C20
26045	Synthetic materials	C20

CSIC-5	Industry Description	ISIC Rev. 4
26046	Special chemical products	C20
26047	Daily-use chemical products	C20
27048	Pharmaceutical products	C21
28049	Chemical fibers	C20
29050	Rubber products	C22
29051	Plastic products	C22
30052	Cement, lime and plaster	C23
30053	Products of plaster and cement and similar products	C23
30054	Brick, stone and other building materials	C23
30055	Glass and glass products	C23
30056	Ceramic and porcelain products	C23
30057	Refractory products	C23
30058	Products of graphite and other non-metallic minerals	C23
31059	Manufacture and casting of basic iron and steel	C24
31060	Processing of steel rolling processing	C24
31061	Ferroalloy	C24
32062	Manufacture and casting of non-ferrous metals and related alloys	C24
32063	Processing of non-ferrous metals rolling	C24
33064	Fabricated metal products, except machinery and equipment	C25
34065	Manufacture of boiler and prime mover	C28
34066	Metalworking machinery	C28
34067	Lifting and handling equipment	C28
34068	Pump, valve, compressor and similar machinery	C28
34069	Movie, office machinery and equipment, of projector and camera	C28
34070	Other general-purpose machinery	C28
35071	Machinery for mining, metallurgy, and construction	C28
35072	Machinery for chemical industry, timber, non-metal processing	C28
35073	Machinery for agriculture, forestry, animal production and fishery	C28
35074	Other special purpose machinery	C28
36075	Motor vehicles, except parts and accessories for motor vehicles	C29
36076	Parts and accessories for motor vehicles	C29
37077	Railway transport equipment	C30
37078	Boats and ships and floating devices	C30
37079	Other transport equipment	C30
38080	Generator and electric motors	C27
38081	Equipments for power transmission and distribution and control	C27
38082	Wire, cable, optical cable and electrical goods	C27
38083	Batteries	C27
38084	Household appliances	C27
38085	Other electrical machinery and equipment	C27
39086	Computer	C26
39087	Communication equipment	C26
39088	Broadcasting, television equipment, of radar and related equipment	C26
39089	Audiovisual apparatus	C26
39090	Electronic components and parts	C26
39091	Other electronic equipment	C26
40092	Measuring instruments and meters	C26
41093	Other manufacture	C31_C32

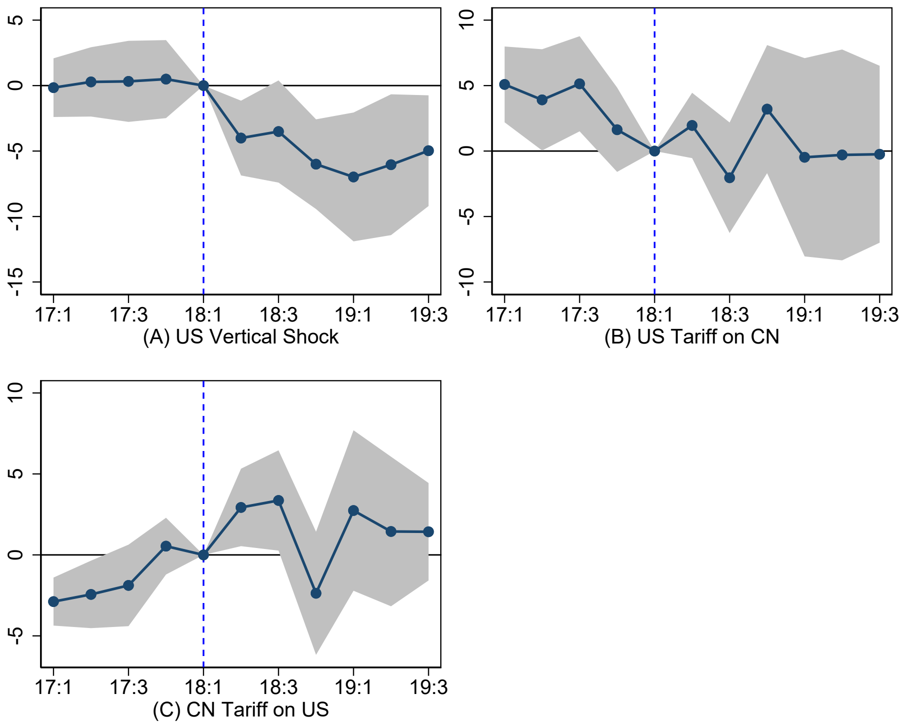
Note: Table lists 93 agriculture, mining and manufacturing industries in Chinese Standard Industrial Classification (CSIC) and the corresponding 2-digit sector codes from the fourth revision of International Standard Industrial Classification (ISIC).

Table A2: Exports Values and U.S. Vertical Effect, by Country

Country	Export value (bil US$)	Intermediate share (%)	U.S. vertical effect (%p)	GDP loss (%)
Australia	67.8	91.5	-1.564	-0.081
Austria	4.4	43.3	-2.428	-0.026
Belgium	8.6	61.5	-3.335	-0.058
Brazil	47.5	94.2	-1.863	-0.050
Bulgaria	0.7	92.6	-3.704	-0.053
Canada	16.9	75.8	-2.581	-0.026
Czechia	2.4	57.1	-3.413	-0.042
Denmark	3.4	46.6	-1.956	-0.021
Finland	3.6	75.3	-3.125	-0.046
France	21.3	33.7	-2.221	-0.018
Germany	96.0	46.6	-2.723	-0.073
Greece	0.5	69.9	-1.516	-0.004
Hungary	2.7	36.2	-2.848	-0.058
India	12.5	81.2	-2.426	-0.012
Ireland	4.9	64.7	-2.764	-0.053
Italy	16.1	39.1	-2.196	-0.018
Japan	126.0	63.6	-3.059	-0.089
Korea	142.0	72.6	-2.870	-0.264
Mexico	5.3	64.6	-2.287	-0.010
Netherlands	13.4	46.0	-2.073	-0.034
Norway	1.9	59.8	-2.258	-0.010
Poland	2.3	69.4	-3.472	-0.015
Portugal	1.0	45.1	-2.246	-0.010
Romania	0.8	76.4	-4.573	-0.019
Russia	40.3	80.5	-2.402	-0.074
Slovakia	1.4	22.5	-0.907	-0.013
Spain	7.1	58.4	-2.285	-0.012
Sweden	6.8	46.8	-3.052	-0.040
Switzerland	24.2	63.5	-3.085	-0.106
Taiwan	88.7	76.7	-3.383	-0.531
Turkey	2.7	82.7	-2.539	-0.009
UK	21.0	50.7	-3.243	-0.021

Note: Columns 1 and 2 represent total exports from 32 countries to China in 2017 and the shares of intermediates among their exports. Column 3 reports the predicted changes in the growth rate of exports to China between the pre-shock period (2017Q:1-2018:Q1) and the post-shock period (2018Q:2-2019:Q3) due to the U.S. vertical shock. Column 4 estimates the GDP loss due to the U.S. vertical shock. Source: UN Comtrade, Eurostat, Taiwan Customs, IMF and author's calculations.

Figure A1: Dynamic Specification for U.S.-China Tariffs on Sales Growth of Korean Firms



Note: Figure plots regressions with full time dummies interacted with each tariff shock on the growth rate of sales for Korean firms. Shaded areas indicate 95% confidence intervals.

B Theoretical Framework for Vertical Effects

This appendix describes a simple theoretical framework to illustrate how U.S.-China tariff changes are associated with China's demand for third countries' intermediate inputs. Then, we derive the empirical measures of each vertical shock. The main purpose is to show that the vertical effect due to US tariffs on Chinese imports, the focus of our research, is robust to inclusions of alternative vertical channels related to Chinese tariffs on the U.S.. The framework is in a partial equilibrium setting and focuses on the short-run impacts of the U.S.-China tariffs. For simplicity, we assume one representative firm in each industry-country pair.

B.1 Technology

Consider a representative Chinese firm in tradable industry i that uses labour and multiple imported intermediate inputs to produce a single differentiated product in the following Cobb-Douglas production function:

$$Y_i = A_i L_i^{\alpha_i} \left(\prod_{j=1}^{N} \prod_{c=1}^{N_c} X_{i,j(c)}{}^{\gamma_{i,j(c)}} \right) \tag{B1}$$

where A_i denotes firm productivity which is exogenously given, L_i is labor and $X_{i,j(c)}$ indicate foreign imported input varieties j from origin country c that firm i uses, respectively. N and N_c denote the numbers of industries and origin countries, respectively. Constant returns to scale implies $\alpha_i + \sum_c^{N_c} \sum_j^{N} \gamma_{i,j(c)} = 1$. Total production cost is[47]:

$$TC_i = wL_i + \textstyle\sum_j \sum_c \tau_{j(c)} v_{j(c)} X_{i,j(c)} \tag{B2}$$

where w is nominal wage and $v_{j(c)}$ is the unit producer price of foreign intermediate input $j(c)$ in the importer's currency and $\tau_{j(c)}^{CN}$ is the Chinese ad valorem tariff imposed on input j from origin country c. Cost minimization yields marginal cost as:

$$c_i = \frac{w^{\alpha_i}}{A_i \Omega_i} \left[\prod_{j=1}^{N} \prod_{c=1}^{N_c} \left(\tau_{j(c)} v_{j(c)} \right)^{\gamma_{i,j(c)}} \right] \tag{B3}$$

where $\Omega_i = \alpha_i^{\alpha_i} \prod_{j=1}^{N} \prod_{c=1}^{N_c} (\gamma_{i,j(c)}{}^{\gamma_{i,j(c)}})$ is a collection of technology parameters.

[47]For simplicity, we do not consider firm entry into exporting that would incur additional fixed costs.

B.2 Profit Maximization

The Chinese firm sells its product to home and foreign markets. We assume that each firm faces monopolistic competition in each market and consumers have a CES preference over differentiated products with elasticity of substitution between products common across destinations (σ). Then, the residual demand faced by a firm i in home and foreign market d are, respectively:

$$Q_i^H = \left(\frac{p_i}{P}\right)^{-\sigma} E \qquad Q_i^d = \left(\frac{\tau_i^d p_i^d}{P_d}\right)^{-\sigma} E_d \tag{B4}$$

where E and E_d are demand shifters and P and P_d are price indices for home and foreign market d. p_i and p_f^d are the prices set by Chinese firm i for home (H) and foreign market d. τ_i^d is the tariff imposed on Chinese firm i's exports by importing country d. Profit maximization in each market yields the common optimal price:

$$p_i = p_i^d = \frac{\sigma}{\sigma - 1} c_i \tag{B5}$$

Market clearing for firm f's output yields:

$$Y_i = Q_i^H + \sum_d Q_i^d \tag{B6}$$

B.3 Foreign input demand

Let's turn to Chinese demand for non-U.S. imported inputs. Combining the equations (B3)-(B6) together with the first-order condition for $X_{i,j(c)}$ in the cost minimization problem yields

$$\ln X_{i,j(c)} = \ln \gamma_{i,j(c)} - \ln v_{j(c)} + \ln c_i + \ln \left[Q_i^H + \sum_d Q_i^d\right] \tag{B7}$$

To focus on the short-run impact of tariffs, we assume that the terms related to firm technology ($A_i, \alpha_i, \gamma_{i,j(c)}$ and Ω_i) and macroeconomic factors (w, E, E_d, P, P_d, $\forall d$) are not affected by the changes in tariffs between the U.S. and China. We further assume that the unit producer prices of foreign inputs ($v_{j(c)}$) also remain unchanged. Total differentiation of equation (B7) with respect to U.S. tariffs on China τ_i^{US} and China's retaliatory tariffs on U.S. inputs $\tau_{j(US)}^{CN}$ leads to:

$$d \ln X_{i,j(c)} = \underbrace{-\sigma\psi_i^{US} d\ln\tau_i^{US}}_{\text{Vertical effect due to US tariff}} + \underbrace{(1-\sigma)\sum_j \gamma_{i,j(US)} d\ln\tau_{j(US)}}_{\text{Vertical effect due to China tariff}} \tag{B8}$$

where $\psi_i^{US} = \frac{Q_i^{US}}{Q_i^H + \sum_d Q_i^d}$ denotes the fraction of Chinese firm i's total output exported to U.S. markets and $\gamma_{i,j(US)}$ is the cost share of input j sourcing from the U.S..

For non-U.S. foreign input supplier $j(c)$ ($\forall c \neq US$), the total demand change from across all Chinese tradable industries, with $X_{j(c)} = \sum_i X_{i,j(c)}$, can be expressed as:

$$\begin{aligned} d\ln X_{j(c)} &= \sum_i \theta^F_{i,j(c)} d\ln X_{i,j(c)} \\ &= \sum_i \theta^F_{i,j(c)} \Bigg[-\sigma\psi_i^{US} d\ln\tau_i^{US} + (1-\sigma)\sum_j \gamma_{i,j(US)} d\ln\tau_{j(US)} \Bigg] \end{aligned} \tag{B9}$$

where $\theta^F_{i,j(c)} = \frac{X^F_{i,j(c)}}{\sum_i X^F_{i,j(c)}}$. Equation (B10) shows that the vertical linkage effect associated with U.S. tariffs ($d\ln\tau_i^{US}$) is definitely negative as a demand-side effect. The sign of the vertical effect related to Chinese tariffs ($d\ln\tau^{CN}_{j(US)}$, $\forall j$) is determined by $(1-\sigma)$ which is negative as long as $\sigma > 1$. To interpret, there are two different channels through which Chinese tariffs on U.S. inputs could affect its demand for other foreign inputs. First is a "substitution effect". The higher U.S. input prices due to Chinese tariffs will result in substitution of the U.S. imports into the other countries' inputs. This is conceptually identical to the trade diversion effect mentioned in the text, except that the substitution effect in this section holds for intermediate inputs only. Second is that, due to complementarity between different inputs, higher U.S. input prices driven by Chinese tariffs increase the production cost of Chinese firms. The resulting demand fall and profit loss of Chinese producers would eventually lead to a fall in China's demand for every input, not only U.S. inputs. This negative "production cost effect" is more pronounced if consumers are more price-elastic (higher σ).

So far, we assumed that the price index in Chinese market (P) remains unchanged. We may go one step further by relaxing this assumption and allowing Chinese retaliatory tariffs on U.S. imports of final goods in industry i ($\tau_{i(US)}$) to shift Chinese price index ($P = \left[p_i^{1-\sigma} + \sum_c (\tau_{i(c)} p_{i(c)})^{1-\sigma}\right]^{\frac{1}{1-\sigma}}$) upward, thereby strengthening the price competitiveness of Chinese producers in their home market. And this will lead to an increase in foreign input demand by Chinese producers. Incorporating this additional effect yields:

$$d\ln X_{j(c)} = \sum_i \theta^F_{i,j(c)} \Bigg[-\sigma\psi_i^{US} d\ln \tau_i^{US} + \sigma\psi_i^H \eta_{i(US)} d\ln \tau_{i(US)} + (1-\sigma)\sum_j \gamma_{i,j(US)} d\ln \tau_{j(US)} \Bigg] \tag{B10}$$

where $\psi_i^H = \frac{Q_i^H}{Q_i^H + \sum_d Q_i^d}$ is the fraction of Chinese industry i's total output sold in Chinese home market and $\eta_{i(US)}$ is the U.S. market share in Chinese markets of that industry i. The additional term $(\sigma\psi_i^H \eta_{i(US)} d\ln \tau_{i(US)})$ captures the potential gains in home market for Chinese producers due to Chinese tariffs on U.S. final goods.

B.4 Linking theory to data

To build an empirical counterparts of each vertical shock from U.S.-China tariffs that are consistent with equation (B10), we exploit the industry-level IO tables described in the text. The underlying assumption is that individual firms do not deviate systematically from the aggregate input-output structure of the industries to which they belong.

Two **NxN** matrices are constructed. First is $\theta^{\mathbf{F}}_{\mathbf{c}}$, which is obtained by dividing China's intermediate imports from each origin country c for each input-output industry pair by China's total intermediate import of a given input industry from the origin country. $\gamma_{\mathbf{US}}$ is a matrix for the cost share of each U.S. input in each Chinese industry's total output. Both $\theta^{\mathbf{F}}_{\mathbf{c}}$ and $\gamma_{\mathbf{US}}$ build on the origin country-specific import matrix that is constructed by disaggregating the sector-level World IO table proportionally to the industry-level Chinese detailed IO table.

$$\theta^{\mathbf{F}}_{\mathbf{c}} = \begin{bmatrix} \theta^F_{1,1(c)} & \theta^F_{1,2(c)} & \cdots & \theta^F_{1,N(c)} \\ \theta^F_{2,1(c)} & \theta^F_{2,2(c)} & \cdots & \theta^F_{2,N(c)} \\ \vdots & \vdots & \ddots & \vdots \\ \theta^F_{N,1(c)} & \theta^F_{N,2(c)} & \cdots & \theta^F_{N,N(c)} \end{bmatrix} \quad \gamma_{\mathbf{US}} = \begin{bmatrix} \gamma_{1,1(US)} & \gamma_{1,2(US)} & \cdots & \gamma_{1,N(US)} \\ \gamma_{2,1(US)} & \gamma_{2,2(US)} & \cdots & \gamma_{2,N(US)} \\ \vdots & \vdots & \ddots & \vdots \\ \gamma_{N,1(US)} & \gamma_{N,2(US)} & \cdots & \gamma_{N,N(US)} \end{bmatrix}$$

We use $\psi^{\mathbf{US}}$, $\psi^{\mathbf{H}}$ and $\eta^{\mathbf{US}}$ to denote **Nx1** vectors for ψ_i^{US}, ψ_i^H and η_i^{US}, constructed using Chinese detailed IO for 2012 and trade share between the US and China for 2016. Likewise, $\tau^{\mathbf{US}}_{\mathbf{CN,t}}$, $\tau^{\mathbf{CN}}_{\mathbf{J(US),t}}$ and $\tau^{\mathbf{CN}}_{\mathbf{US,t}}$ are vectors of U.S. tariffs on China at time t, Chinese tariffs on U.S. intermediates and on U.S. non-intermediates within each CSIC industry, respectively. Then, we may write (B10), the **Nx1** vectors of vertical shocks are derived as follows:

$$\textit{Vertical Shock from US tariffs} = \theta^{\mathbf{F}}_{\mathbf{c}} * (\psi^{\mathbf{US}} \circ \boldsymbol{\Delta}\tau^{\mathbf{US}}_{\mathbf{CN,t}}) \tag{B11}$$

$$\textit{Vertical Shock from CN tariffs on US inputs} = \theta^{\mathbf{F}}_{\mathbf{c}} * (\gamma_{\mathbf{US}} \circ \boldsymbol{\Delta}\tau^{\mathbf{CN}}_{\mathbf{J(US),t}}) \tag{B12}$$

$$\textit{Vertical Shock from CN tariffs on US final goods} = \theta^{\mathbf{F}}_{\mathbf{c}} * (\psi^{\mathbf{H}} \circ \eta^{\mathbf{US}} \circ \boldsymbol{\Delta}\tau^{\mathbf{CN}}_{\mathbf{US,t}}) \tag{B13}$$

where $\circ$ denotes element-wise multiplication. The formula (B11) is a vector expression of the benchmark measure 1 of the U.S. vertical shock in the text except, that we use the U.S. share in the China's total export of industry i as ψ_i^{US} in practice, not the U.S. share in China's total output of that industry, based on the discussion in section 4.1 of the main text. (B12) and (B13) express the newly-constructed measures of vertical shocks related to Chinese tariffs on U.S. imports of intermediates and final goods, respectively.

Table B3 shows the results including two additional vertical channels of (B12) and (B13), along with the U.S. vertical effect (B11). These two alternative shocks related to Chinese retaliatory tariffs were not statistically significant. The U.S. vertical effect, on the other hand, remains highly significant with little changes in magnitude across different specifications. These confirm that the U.S. vertical shock is the major channel in propagations of the U.S.-China tariff shocks to third countries at the current level of aggregation and the time horizon.

Table B3: Testing for Alternative Vertical Shocks

	(1)	(2)	(3)	(4)
Vertical Shock from US tariffs on Chinese goods	-5.073***	-4.496**	-5.220***	-4.573**
	(1.922)	(1.981)	(1.918)	(1.980)
Vertical Shock from CN tariffs on US inputs		1.642		1.894
		(1.351)		(1.355)
Vertical Shock from CN tariffs on US final goods			-1.329	-1.495
			(0.942)	(0.940)
Observations	24,748	24,748	24,748	24,748
Adj-R2	0.040	0.040	0.040	0.040

Note: The dependent variable is the mid-point growth rate of country-industry pair exports of intermediates to China, multiplied by 100. All columns include other tariff controls, industry-country and country-time fixed effects, as well as sector-specific linear trends. All shocks are standardized to have zero mean and unit variance. Standard errors are clustered by country-sector pairs in parentheses. Significance: *** p<0.01, ** p<0.05, * p<0.1.