The Inflationary Effects of Global Supply Chain Shocks: Evidence from Swedish Microdata*

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Abstract

We compile a unique dataset linking micro price data underlying the official Swedish producer price index with administrative firm level data and provide new evidence on the inflationary effects of global supply chain shocks. For identification, we interact exogenous shocks to global supply chains obtained through a VAR model with firm-specific trade intensities. Shocks to global supply chains lead to a significant and persistent increase in producer prices with a peak response after two years. However, average responses mask significant heterogeneity across firms. Relatively larger firms, firms with stronger international linkages, firms with a lower inventory stock and firms with low labor costs increase prices more strongly.

Keywords: Global supply chain shocks, producer prices, micro data, firm characteristics, price setting
JEL Classification: E31, F14, F61

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1 Introduction

Over the past decades, globalization of trade has been accompanied by the increasing integration of global supply chains. The drawback is that firms become susceptible to disruptions in the supply of intermediate goods. Recent distortions such as natural disasters, the Covid-19 pandemic and geopolitical tensions have highlighted the vulnerability of supply chains and their critical role in economic activity. In particular, supply chain bottlenecks are considered a major driver of the surge in global inflation since 2021.

A recent literature estimates the macroeconomic consequences of supply chain disruptions (Carrière-Swallow et al., 2023; Burriel et al., 2023; Ascari et al., 2024; Laumer, 2023; Khalil and Weber, 2022; Finck and Tillmann, 2023; Liu and Nguyen, 2023; Elsayed et al., 2023; De Santis, 2023; Bai et al., 2024). The results suggest that supply chain shocks lead to a deterioration of economic activity and an increase in prices.[1] However, this literature focuses on the consequences for aggregate price levels, not dis-aggregate prices.

In this paper, we aim to fill this gap by estimating the causal effect of global supply chain disruption on the price setting of Swedish firms. We add to the small branch of the literature that traces the effects of supply chain disruptions on the firm-level. For that purpose, we compile a unique dataset linking micro price data underlying the official Swedish producer price index (PPI) with administrative firm level data. The dataset includes around 200,000 individual price observations from a bit less than 2,000 unique firms. This allows us to estimate the price-response at the product level. Thus, we can take full account of the heterogeneity of price setting. In addition, the rich set of firm level information allows us to shed light on differences in the responses of producer prices to supply disruptions across the distribution of firms.

Most papers drawing on micro data to study the adjustment to supply disruptions use data on firm-level quantities only. Boehm et al. (2019) estimates firm-level production elasticities between foreign and domestic inputs. The

[1] This result is also supported by quantitative general equilibrium models (di Giovanni, Kalemli-Özcan, Silva and Yildrim, 2022; Alessandria et al., 2023).

authors use the cross-country spillovers of the 2011 Tōhoku earthquake in Japan for identification and find that high degree of complementarity exists: a drop in imports leads to an almost one-for-one fall in output of Japanese affiliates based in the US. Carvalho et al. (2021) also exploit the 2011 earthquake and show that natural disasters propagate backwards and forwards through global supply chains. Lafrogne-Joussier et al. (2023b) compare firm-level data from France during the Covid-19 pandemic with pre-pandemic data. They show that firms relying on intermediate goods from China cut their input more strongly during the pandemic than other firms. di Giovanni, Levchenko and Mejean (2022) also use micro data on the value added of French firms. Foreign aggregate shocks, e.g. a recession abroad, hits relatively large firms more than relatively small firms.

Our paper contributes to the literature using micro-data to study the effects of supply chain bottlenecks on price setting rather than production quantities. Auer et al. (2019) estimate the cross-border transmission of cost increases based on input-output linkages using sectoral data across countries. Santacreu and LaBelle (2022) study the inflationary effect of supply chain bottlenecks during the Covid-19 pandemic. They regress the industry-specific changes in U.S. producer prices on measures of supply chain pressure interacting with the cross-industry variation in the dependence of intermediate goods across countries. Isaacson and Rubinton (2023) use data on the commodity-specific exposure of U.S. imports to international shipping prices. They find a small pass-through of changes in shipping costs to import price inflation. Meier and Pinto (2023) study the propagation of supply chain disruptions originating in China to sectoral U.S. data during the Covid-19 pandemic. For identification, they exploit pre-pandemic cross-sectional variation in the intensity of imported goods from China.

Lafrogne-Joussier et al. (2023a) use micro data underlying the French PPI over the period January 2018 to July 2022 as well as data on firms' exposure to imported goods and energy costs. They find that an increase in foreign costs by 10 percent causes output prices to increase by 0.74 percent. Acharya et al. (2024) exploit the variation in the perception of supply chain disruptions across European firms at the product-country level. The authors interact this perception with a dummy that reflect the Covid-19 pandemic.

After constructing the micro dataset, we proceed in three steps. First, we estimate a structural vector autoregression (VAR) for Sweden. The model contains data on aggregate macroeconomic variables as well as data on international container trade such as the number of container processed in the most important North Sea ports, the price of shipping a container and the Global Supply Chain Pressure Index of Benigno et al. (2022). The model is identified using a combination of conventional sign restrictions as well as narrative restrictions drawn from recent episodes of supply chain disruptions, i.e. the Tōhoku earthquake (2011), the Suez Canal obstruction (2021) and the Shanghai backlog as a consequence of the zero-Covid policy of Chinese authorities (2022). As a result, we obtain a series of structural supply chain shocks.

In the second step, we use the granular dataset on product-level producer prices underlying the Swedish producer prices index, combine it with administrative firm level data and estimate the response of individual prices to the aggregate supply chain shock in a panel local projection (Jordà, 2005) framework. Identification is achieved by combining the exogenous, aggregate shock with firm-specific export intensities. We use the share of exports in total sales as a proxy of a firm's exposure to global supply chains. The interaction with the firm-specific export intensity translates the aggregate shock into firm-specific supply chain disturbances.

We find that global supply chain shocks cause a significant and persistent increase in producer prices. Following a shock of one standard deviation, firms raise prices by about one percent. The price response peaks about two years after the shock occurred. Hence, firms pass the shortage of intermediate goods and their price increases to customers in terms of higher prices. Importantly, the average price response masks a considerable degree of heterogeneity in the extent of price adjustment across firms. We distinguish firms along the lines of key characteristics such as size, export intensity, cost structure, and different measures of inventory holdings. Relatively larger firms, firms with stronger international linkages, multi-product firms, firms with low labor costs and firms with a lower stock of inventories increase prices more strongly. Hence, the heterogeneity across firms matters for the pass-through of supply disruptions to prices.

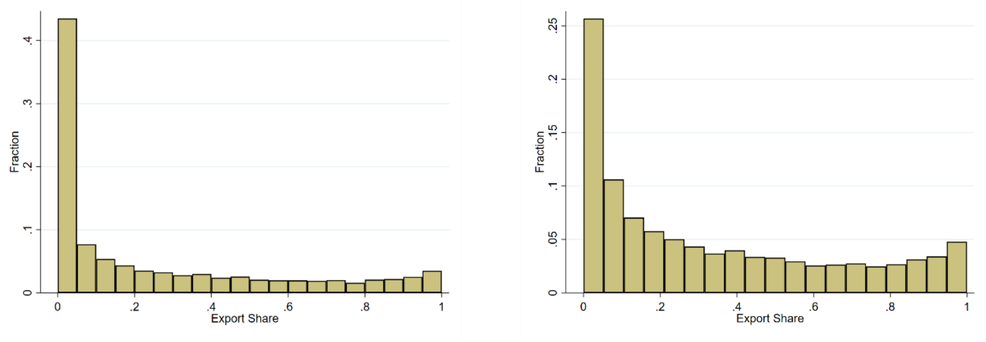
2 Microdata from Sweden

The price data are obtained from the micro dataset underlying the official Swedish producer and import price index (*Prisindex i producent- och importled*, PPI). The PPI data include monthly product-level prices for a representative sample of products produced in the Swedish domestic market or produced abroad and imported to Sweden. Thus, the data contain domestic, export and import producer prices. The unit of observation is the price of a product-level transaction, specifically referred to as a "product offering", which is a unique combination of a product sold by a particular firm. Firms that are selected from the sampling procedure are asked to report the price of a representative product they sell within a narrowly defined product code, given by the 8-digit Combined Nomenclature (CN) classification, and are required to respond by law. Our original PPI data cover the period January 1992 to September 2022 and include roughly 1.75 million product-month observations.

Below, we interact the aggregate global supply chain shocks with a firm-level measure on export intensity to obtain different treatment intensities across firms. Data on firm-level export intensity are collected from the microdata underlying the official Swedish industrial production index (*Industriproduktionsindex*, IPI). Both the PPI and IPI datasets are maintained by Statistics Sweden. The IPI data contain information on firms' total nominal net sales,[2] broken down into domestic and export sales. The data are based on a stratified sample of Swedish industrial firms above a certain *cut-off* (defined, within each industry, as the largest firms that together make up 95

[2]Before 2015, the micro-level variable underlying the official Swedish IPI was firm deliveries rather than net sales. In connection with the change to net sales, the construction of the IPI also underwent several methodological adjustments, for instance with respect to sampling design and estimation. These changes are accounted for in the construction of the official IPI series to avoid any time-series breaks and we follow Statistics Sweden's method for doing so in our data cleaning procedure.

Figure 1: Distribution of export intensities



(a) All firms (b) Only exporting firms

Notes: The figure shows the distribution of export intensity across Swedish firms. The data is collected from the microdata underlying the official Swedish industrial production index. Panel (a) includes all firms, while panel (b) excludes firms with an export intensity of zero.

percent of total sales) and are collected at the monthly frequency. Selected firms are required to respond and are asked to report their monthly total net sales to domestic and foreign customers in thousands of SEK. Our original IPI data include around 550,000 firm-month observations spanning between January 1998 and September 2022. We construct a firm-specific measure of export intensity as the ratio between export sales and totals sales (the sum of domestic and export sales).

Figure (1) depicts the cross-sectional distribution of the export intensity. As shown in panel (a), around 30% of all firms do not export at all. The distribution of the export intensity of the remaining firms, as shown in panel (b), is U-shaped. It is important to stress that Swedish firms stretch over the full range of export intensities from nearly zero to one. Put differently, the data exhibits sufficient variation to be used as a treatment variable that measures the firm-specific exposure to global supply chains. In the online appendix, we show a high cross-sectional correlation between the export intensity and the share of foreign value added in gross exports, which is a widely-used proxy for the backward participation in global supply chains.

Lastly, we utilize annual balance sheet and income statement data obtained from the credit bureau Upplysningscentralen (UC), covering the entire population of Swedish corporations (*aktiebolag*). In particular, we draw from this data source information on firms' total assets, inventories, and cost structure. The original UC data are available between 1989 and 2020.

A unique firm identifier allows us to merge information from all three datasets. Thus, we are able to link product-level prices from the PPI data to the firm-level for which we know export intensities from the IPI data and other real and balance sheet data from the UC data. This micro dataset enables us to investigate the inflationary effects of global supply chain shocks at the very granular level and makes it possible to test for important differences in pricing decisions across firms.

We perform several rounds of cleaning the raw data. With regards to the PPI data, we drop a small number of missing, erroneous (negative) or duplicated price observations. Furthermore, we restrict the sample to products belonging to product groups B and C as defined by the Swedish Standard for Product Classification by Industry (SPIN), i.e. products sold within the industrial sector. Hence, this is equivalent to the sample of firms present in the IPI data. In the baseline analysis, we only include the domestic part of the PPI, however, we also provide additional results only including export prices.

Concerning the IPI data, we drop one firm which displays extreme outlier values and adjust a small number of observations such that the sum of domestic and export sales is always equal to total sales, either by filling in missing values or by scaling total sales by the respective shares of domestic and export sales. Moreover, and as described above, we account for a methodological change in Statistics Sweden's data collection procedure, which involves using three months of overlapping data at the time of the change to compute a quota representing the effect on each firm's reported deliveries/sales. Scaling the series by this quota then allows us to obtain coherent numbers throughout the sample period.

We assemble the final dataset by merging the monthly product-level PPI price and firm-level IPI sales series, while at the same time merging additional variables constructed from the UC data. Our final dataset includes around

200,000 individual price observations from a bit less than 2,000 unique firms. Below, we draw on the following product and firm characteristics, respectively: firm size measured as (log) sales, the export intensity, the distinction between goods being exported and products sold at home, the ratio of inventories to sales, the number of products, the number of product groups and nominal unit labor cost defined as the ratio of the nominal wage bill and real sales. The online appendix reports summary statistics of the firm characteristics.

3 Deriving the supply chain shock: the VAR model

We are interested in the structural vector autoregression of the form

$$\mathbf{y}_t'\mathbf{A}_0 = \mathbf{c} + \mathbf{y}_{t-1}'\mathbf{A}_1 + ... + \mathbf{y}_{t-p}'\mathbf{A}_p + \boldsymbol{\varepsilon}_t', \tag{1}$$

where $\mathbf{y}_t$ is an $n \times 1$ vector which contains the endogenous variables, $\mathbf{A}_1, ..., \mathbf{A}_p$ are $n \times n$ matrices of parameters and $\mathbf{c}$ is a $1 \times n$ vector of parameters. $\boldsymbol{\varepsilon}_t$ is an $n \times 1$ vector of structural shocks and $\mathbf{A}_0$ is an invertible $n \times n$ matrix which contains the contemporaneous relationships among the endogenous variables. This model can be rewritten in a compact form as

$$\mathbf{y}_t'\mathbf{A}_0 = \mathbf{x}_t'\mathbf{A}_+ + \boldsymbol{\varepsilon}_t',$$

where $\mathbf{x}_t$ is a $(np+1) \times 1$ vector given as $\mathbf{x}_t' = \left[1, \mathbf{y}_{t-1}', ..., \mathbf{y}_{t-p}'\right]$ and $\mathbf{A}_+' = \left[\mathbf{c}' \ \mathbf{A}_1' ... \mathbf{A}_p'\right]$ is of the dimension $(np+1) \times n$.

We adopt the model specification as in Finck and Tillmann (2023) but re-estimate the model for the case of Sweden. The vector of endogenous variables comprises six variables, which are divided into two blocks. The first block includes three variables that reflect the business cycle in Sweden, i.e. industrial production, the index of consumer prices and the import price index. These series are included in natural logs (times 100) and are taken from Statistics Sweden.

The second block consists of the remaining three variables reflecting international container shipping and global supply chains, respectively. The first is the RWI/ISL container throughput index provided by the Leibniz-Institut für Wirtschaftsforschung (RWI) in Essen, Germany, and the Institute of Shipping Economics and Logistics (ISL) in Bremen, Germany.[3] In the absence of data on container throughput at Swedish ports, this series should be a good approximation of container trade in Sweden.

The second shipping variable is the HARPEX PETERSEN Charter Rates Index which reflects the worldwide price development on the charter market for container ships. The HARPEX tracks prices for container shipment of semi-finished or finished products.

The last variable we include in our VAR is the Global Supply Chain Pressure index (GSCPI) provided by the Federal Reserve Bank of New York (Benigno et al., 2022). These authors construct a summary indicator of global supply chain pressure based on Purchasing Managers' Index (PMI) surveys for manufacturing firms in different countries, measure of transportation cost such as the HARPEX and the Baltic Dry Index and indicator of airfreight costs.

In order to identify global supply chain shocks, we follow Antolín-Díaz and Rubio-Ramírez (2018) and combine conventional sign restrictions and narrative restrictions. Narrative restrictions are meant to constrain the admissible set of structural parameters by ensuring that around selected historical events the structural shocks, historical decompositions (or both) align with the established narrative.

We restrict three of our six endogenous variables, while the impulse responses of the remaining three variable are left unrestricted. Importantly, we do not impose any price response following the supply chain shock and thus we are agnostic about the inflationary effects of the identified shocks.[4]

[3]The index reports the (seasonally adjusted) number of processed containers in the North Range, i.e. the ports of Le Havre, Zeebrugge, Antwerp, Rotterdam, Bremen/Bremerhaven and Hamburg. These are the most important ports for container trade in the euro area. See Döhrn and Maatsch (2012) and Döhrn (2019) for more information on the RWI/ISL index.

[4]In contrast, other papers identify a supply chain shock by directly imposing a negative co-movement between prices and output (Ascari et al., 2024).

We assume that a supply chain shock leads to an increase in the HARPEX, i.e. to an increase in charter rates for container vessels. This increase is accompanied by a reduction in the number of containers being processed, i.e. a reduction in the container throughput. This negative co-movement therefore identifies a supply shock. Finally, in order to distinguish our supply chain shock from any other supply shock, such as technology or oil price shocks, we assume that the shock also increases supply chain pressure. We therefore additionally restrict the response of the global supply chain pressure index and assume that this index rises after a supply chain shock.[5] All restrictions hold on impact and for the two subsequent months.

In addition to the conventional sign restrictions, we also use narrative restrictions. We exploit the same episodes of supply chain disruptions as in Finck and Tillmann (2023), i.e. the Tōhoku earthquake (2011), the Suez Canal obstruction (2021) and the Shanghai backlog as a consequence of the zero-Covid policy of Chinese authorities (2022). We impose the restriction that the supply chain shock in all three periods must be positive, i.e. restrictive. Moreover, we assume that the shock in March 2011 (Tōhoku earthquake) is the most important driver of the GSCPI. The online appendix contains the aggregate impulse response functions. In line with other studies (Ascari et al., 2024), we find that an exogenous increase in global supply chain disruptions lead to a significant fall in industrial production coupled with a rise in import and consumer prices.

4 The firm-responses to supply chain shocks

To evaluate the effects of global supply chain shocks on Swedish producer prices, we use panel local projections (Jordà, 2005) at the individual product level and estimate for each horizon $h = 0, ..., 36$, the following equation

$$\begin{aligned} \log\left(p_{i,j,f,t+h}\right) - \log\left(p_{i,j,f,t-1}\right) &= \alpha_{j,h} + \alpha_{m,h} + \beta_h \left(share_{f,t} \times shock_t\right) \\ &\quad + \gamma_h X_{t-1} + u_{i,j,f,t+h}, \end{aligned} \tag{2}$$

[5] Importantly, an increase in the GSCPI is supply-side driven by design, as the GSCPI is purged of demand-driven factors.

where $p_{i,j,f,t}$ is the price of product i, belonging to product-group j and produced by firm f in month t. $\alpha_{j,h}$ are product group fixed effects to filter out any unobserved heterogeneity across product groups. $\alpha_{m,h}$ are monthly fixed effects to control for seasonal price movements. A vector X_t collects additional aggregate control variables including 12 lags of the unemployment rate and of log industrial production. $u_{i,j,f,t+h}$ is the standard error term. $shock_t$ is the aggregate global supply shock that we obtain from the VAR model as described in Section 3. The variable $share_{f,t}$ is the firm-specific export intensity that we construct from the IPI data as the ratio between a firms' export sales to total sales (the sum of domestic and export sales). By interacting the aggregate shock measure with the firm-specific export intensity, we allow for different shock treatments across firms. In particular, we assume that a firm with a higher (lower) lower export intensity is more (less) affected by disruptions to global supply chains. Export intensity can be seen as a proxy for forward integration into supply chains and thus the more (less) integrated a firm is, the stronger (weaker) is the impact of global supply chain shocks. We are mainly interested in the coefficient β_h which measures how prices change over the h periods when a firm-specific shock to global supply chains happen in t. Throughout, we use Driscoll and Kraay (1998) standard errors, which take into account the potential residual correlation across firms, as well as serial correlation and heteroskedasticity among the residuals over time.

To investigate potential state-dependencies in the inflationary effects of global supply shocks over time and across firms, we extend the linear specification (2) and estimate a set of different interacted panel local projections of the following form

$$\begin{aligned} \log\left(p_{i,j,f,t+h}\right) - \log\left(p_{i,j,f,t-1}\right) &= \alpha_{j,h} + \alpha_{m,h} \\ &+ I_{f,t-1}\left[\alpha_h^{High} + \beta_h^{High}\left(share_{f,t} \times shock_t\right)\right] \\ &+ \left(1 - I_{f,t-1}\right)\left[\alpha_h^{Low} + \beta_h^{Low}\left(share_{f,t} \times shock_t\right)\right] \\ &+ \gamma_h X_{t-1} + u_{i,j,f,t+h}, \end{aligned} \tag{3}$$

where $I_{f,t-1}$ is a dummy variable that captures the specific interaction we are

Table 1: Firm Characteristics Overlap

	Export Intensity	Total Sales	Inventory Ratio	Multiple Products	Multiple Product Groups
Export Intensity	100	73	39	85	77
Total Sales	53	100	45	89	78
Inventory Ratio	40	63	100	82	67
Multiple Products	50	73	47	100	86
Multiple Product Groups	53	74	45	100	100

Notes: The table displays the percentage overlap between firm indicators. Rows denote the indicator, and column values refer to the percentage overlap. For example, 45% of all month-firm observations for which a firm is denoted as "large" (as measured by total sales) overlap with observations in which the same firm also had a high (i.e., above average) inventory ratio.

interest in. In particular, when testing for state-dependencies across time like the aggregate pressure on supply chains, $I_{f,t-1} = I_{t-1}$, and thus the state is the same across all firms but varies across the time dimension, months in our data. In contrast, when we are interested in looking for particular firm characteristics that could significantly influence the inflationary effects of supply chain shocks such as size or export intensity, the interaction dummy varies across firms and months. We include a one-period lag of $I_{i,t-1}$ in the regressions in order to minimize contemporaneous correlations between the shock and the state variable. Given our specification, β_h^{High} provides an estimate of the price-response in state $High$, whereas β_h^{Low} provides the estimate in state Low.

Specifically, we condition the effect of supply chain disruptions on firm characteristics, each transformed into a binary state variable $I_{f,t-1}$: a natural starting point is to compare the response of small and large firms. Hence, the first characteristic is size. Firms are considered small (large) if their (log) sales are below (above) the median of the distribution of firms at time t. It is important to stress that in all our estimated state-dependent models, the distinction across firms is dynamic. Thus, the status of firms can change if their sales increase or decrease relative to their peers over the sample period.

Second, we distinguish firms with a low and a high export intensity. Third, we differentiate products being exported and products sold at home. Firms selling their products globally might be subject to a more intense competition than firms selling to Swedish households and firms. The latter could potentially pass-on higher costs for intermediate goods to customers more easily than the former. Our data set does not only contain price data on goods sold in the Swedish market, but also on exported goods.

Fourth, to the extent the global supply shock disrupts the sourcing of raw materials, we expect that a low stock of inventories prompts firms to raise prices more strongly. Hence, we condition the impact of the shock on the stock of inventories. We scale the stock of inventories by the level of sales for each firm and again split the sample at the median of the cross-sectional distribution.

Another determinant of the price-response is the firm's product portfolio, which is our fifth firm characteristic. A firm selling multiple products is more exposed to supply shortages than a single-product firm because it relies on a broader set of inputs. We expect that multi-product firms raise their prices more strongly than single-product firms.

The distinction between single- and multi-product firms is not informative about the exposure to supply chain shocks if the multiple products are closely related and rely on a similar set of intermediate goods. As a seventh characteristic, we also distinguish between the number of different product groups.

Finally, we shed light on the cost structure of firms as a determinant of the size of the price adjustment. Suppose the production is labor intensive, that is, unit labor costs are relatively high. This implies that the firm spends relatively less on intermediate inputs and the shock to supply chains has a small impact on total costs. Therefore, the firm should raise prices modestly if exposed to supply disruptions. Another firm with relatively low unit labor costs should raise price more aggressively. We define nominal unit labor cost as the ratio of the nominal wage bill and real sales.

Importantly, these properties of firms are not orthogonal. To what extent do the classifications of firms into different types overlap across indicators?

For example, are firms classified as large also classified as having a high inventory ratio? We calculate the percentage overlap between selected firm indicators and document it in Table (1). For each indicator, the row provides the percentage overlap with other indicators.[6] Consider again firm size: 45% of all month-firm observations for which a firm is classified "large" based on total sales overlap with observations in which the same firm is classified as having a high inventory ratio. Likewise, large firms tend to be classified as multiple product firms and firms selling multiple product groups. Overall, the extent of overlap is not too large such that our analysis of the response to shocks conditional on different firm characteristics is not obfuscated by coinciding classifications.

5 Results

We now study the response of producer prices to the global supply chain shock. The size of the shock is one standard deviation. All figures show the estimated β_h coefficients together with a 90% confidence band constructed from Driscoll-Kraay (Driscoll and Kraay, 1998) standard errors.

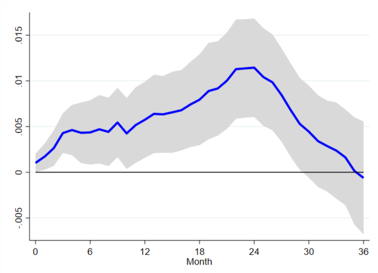
5.1 Baseline results

Panel (a) of Figure (2) shows the response in our baseline model. A supply chain disruption causes a significant increase in domestic producer prices. The price increase becomes significant one month after the shock and reaches a maximum of one percent after about two years. Thus, producers raise goods prices and pass a part of the higher costs of intermediate goods to customers. As the model is linear, this also implies that a relaxation of supply chain stress contributes to a drop in producer prices.

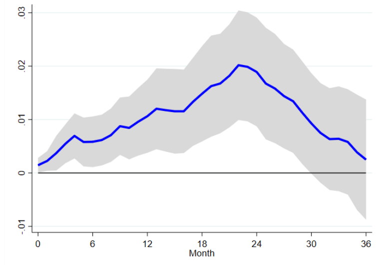
Panel (b) of Figure (2) reports the estimated impulse response function from an alternative specification, in which we weight each price by its weight in the aggregate Swedish producer price index. The results remain qualitatively unchanged: the global supply chain shock prompts firms to set a

[6] The appendix shows the unconditional correlations of selected firm characteristics.

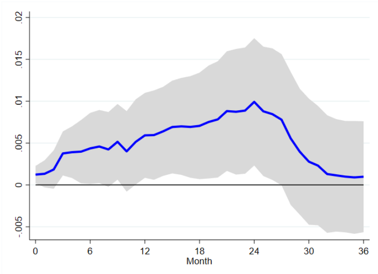
Figure 2: Response of product-level producer prices



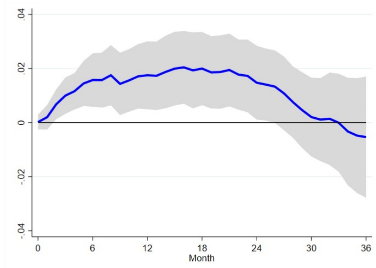
(a) baseline model



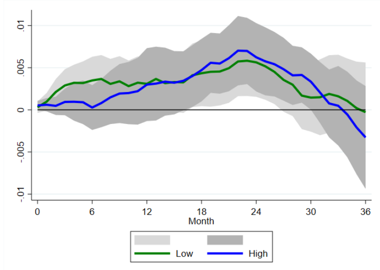
(b) weighted price observations model



(c) including time fixed effects



(d) reduced form shock



(e) Global supply chain pressure index

Notes: The figure shows the response of firm-level producer prices to a global supply chain shock. The 90% confidence band is based on Driscoll-Kraay standard errors.

significantly higher domestic price. Interestingly, the size of the effect is slightly larger than in the baseline model.

In order to control for aggregate determinants of price-setting not captured by the control variables in the vector X_t, we estimate a model specification with time fixed effects. The results in Panel (c) of Figure (2) show that producers start to raise prices in the first months after the shock with the peak response occurring about two years after the shock. This effect is still statistically significant at a 90% level, though the confidence bands are slightly wider than in our baseline model.

The previous results were based on the structural supply chain shock derived from the identified VAR model. To gauge the robustness of the estimated effects, we use an alternative shock series. As a reduced-form shock, we use the residual from a regression of the Global Supply Chain Pressure Index (Benigno et al., 2022) of three lags of itself as well as current realizations and three lags of world industrial production (in log differences), Global Economic Conditions and the real price of oil (in log differences). The variable Global Economic Conditions is taken from Baumeister et al. (2022). In addition, we include a dummy for the global financial crisis, the Covid-19 pandemic and the Russian invasion of Ukraine.

Panel (d) of Figure (2) shows response of producer prices to the reduced-form shock. The shape and the magnitude of the response are similar to the responses in the baseline model shown in Panel (a). Importantly, the response to the structural shock is estimated more precisely. Take the response at $h = 18$ as an example. The 90% confidence band is narrower if we use the structural shock compared to the confidence band surrounding the reduced form shock. Thus, the identifying assumptions imposed on the VAR model, from which the shock is derived, lead to more precise estimates.

Does the impact of the structural shock on producer prices in Sweden depend on the level of supply chain pressure prevailing in the world economy? To address this question, we let the shock interact with the level of the Global Supply Chain Pressure Index of Benigno et al. (2022). Thus, in contrast to the analysis in the following subsection, we investigate state-dependent responses in the time-dimension rather than the cross-sectional dimension.

Panel (e) in Figure (2) reports the estimated impulse responses functions for states of high and low supply chain pressure. Evidently, the responses of Swedish firms do not depend on the general level of supply chain pressure. Hence, we can conclude that the scope for time-dependent heterogeneity is limited and proceed investigating the extent of cross-sectional heterogeneity in price adjustments.

5.2 The heterogeneity of responses across firms

We now turn to the results from the empirical model that allows the effect of global supply chain shocks to be state-dependent. This allows us to shed light on the heterogeneity of price responses across firms.[7]

Panel (a) of Figure (3) reveals important differences between small and large firms in the pass-through of supply chain shocks. We find that large firms raise prices, while small firms do not. Put differently, large firms pass-on higher costs in terms of higher prices. Smaller firms, in contrast, do not charge significantly higher prices.

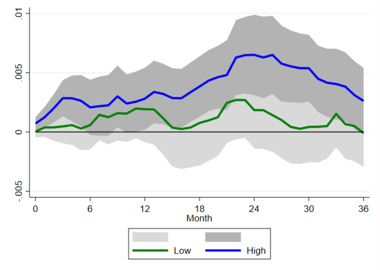
Panel (b) of Figure (3) shows that the price responses differ between firms with a low and high export intensity. Export-intensive firms raise prices as a response to the shock. The response is highly statistically significant over more than two years. Firms with a low-export intensity also set a higher price, though this response is not statistically significant. Hence, the transmission of the global supply chain shock to price setting is particularly pronounced for export-intensive firms.

Panel (c) of Figure (3) reveals that the price increase is higher when the product is sold at the domestic market. This is consistent with the notion that more fierce price competition on export markets limits firms' scope for price increases.

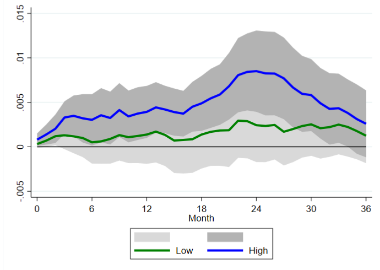
In Panel (d) of Figure (3), we compare the responses of firms with a high and low stock of inventories, respectively. The results show that firms

[7] The magnitude of the impulse responses in the state-dependent model is not directly comparable to the responses in the linear baseline model. Since the intercept term of the regression model interacts with firm characteristics, we control for an additional average effect across firms in the state-dependent model, which affects the size of the coefficients.

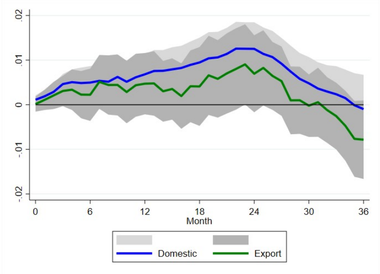
Figure 3: State-dependent response of product-level producer prices



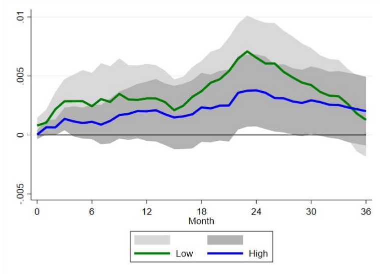
(a) size



(b) export intensity



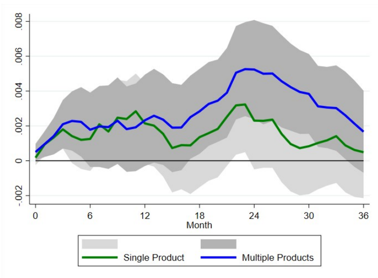
(c) export vs domestic market



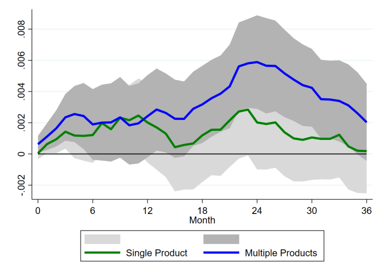
(d) inventories

Notes: The figure shows the response of firm-level producer prices to a global supply chain shock. The 90% confidence band is based on Driscoll-Kraay standard errors.

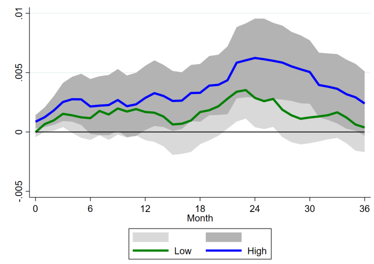
Figure 4: State-dependent response of product-level producer prices



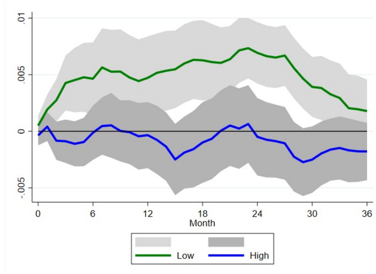
(a) single- vs multi-product firms



(b) single- vs multi-product firms (product groups)



(c) number of products over number of product groups



(d) unit labor cost

Notes: The figure shows the response of firm-level producer prices to a global supply chain shock. The 90% confidence band is based on Driscoll-Kraay standard errors.

with a low stock of inventories indeed raise their prices more strongly than firms with a high stock. While the response of low inventory-firms is highly significant, the response of high inventory-firms remains insignificant for most parts of the projection horizon. Hence, a low stock of inventories amplifies the inflationary impact of supply bottlenecks. This finding is consistent with the results of Alessandria et al. (2023).

We expect that multi-product firms raise their prices more strongly than single-product firms as the latter is more exposed to supply shortages than a single-product firm because it relies on a broader set of inputs. Panel (a) of Figure (4) shows that this conjecture is supported by the data. The response of multi-product firms is stronger than that of single-product firms, which remains mostly insignificant.

Panel (b) of Figure (4) shows the impulse responses when we distinguish between the number of different product groups. The empirical finding remains unchanged: firms with a more diversified set of products, here approximated by multiple product groups, respond to the supply chain shock by setting a higher price than firms producing a single product group.

An alternative way to express the exposure of firms with a diversified set of products to supply bottlenecks is to look at the ratio of the number of products to the number of product groups. This ratio is a measure of the degree of specialization of a firm's set of products. If a firm produces five products from just one product group, this firm is considered very specialized. If the firm produces five products in two product groups, the firm is less specialized and the ratio is smaller. The more specialized the firm is, the more likely the firm is to suffer from shortages of intermediate products and, hence, the higher will be the pressure to raise prices. Panel (c) of Figure (4) shows the responses when we spilt the firms along the median of the ratio of the number of products and the number of product groups. The results support our intuition: more specialized firms, i.e. firms in the upper half of the distribution of the ratio of products to product groups, set a higher price than less specialized firms. Thus, our results remain qualitatively unchanged if we condition the effect of the supply chain shock on the number of different products, the number of product groups or the ratio of the two characteristics.

Finally, we split the observations between firms with high and low unit labor costs, defined as the ratio of the nominal wage bill and real sales. Panel (d) of Figure (4) supports our notion: after a supply chain shock, firms with relatively low labor costs raises prices strongly. In contrast, firms with relatively high labor costs do not raise prices.

6 Conclusions

Disruptions of global supply chains are seen as a major driver of the surge in inflation after the Covid-19 pandemic. In this paper, we studied the quantitative impact of supply chain shocks on producer prices in Sweden. We assemble a unique data set linking micro data underlying the official Swedish producer price index with administrative firm level data. Importantly, we interact the supply chain shock with firm-specific export intensities as a measure of value chain participation.

An adverse supply chain bottleneck causes a significant and relatively persistent increase in producer prices. Our micro data allows us to uncover a significant degree of heterogeneity in the responses across firms. Firms which are relatively large, have a relatively high export intensity, maintain a low level of inventories, sell more than a single product, sell their goods at home and have relatively low unit labor costs exhibit a significantly stronger price response than other firms.

Our findings help understand the source of the surge in inflation after 2021 and its fall in 2023, when pressure on global supply chains eased. The enormous heterogeneity in the adjustment of prices across firms makes the design of appropriate stabilization policies in light of supply chain shocks, in particular monetary policy, challenging.

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Appendices

These online appendices are not part of the published paper.

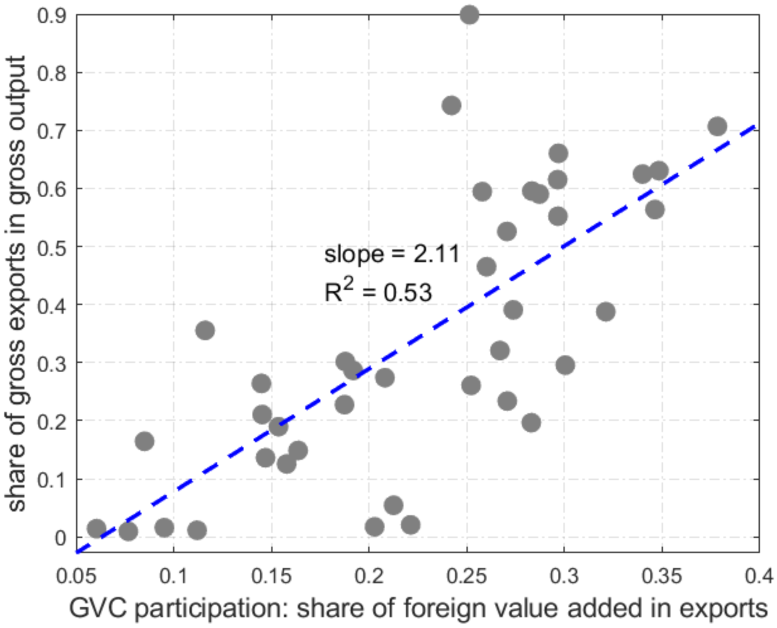
Appendix A Supply chain participation

A widely-used proxy for the backward participation in global supply chains is the share of foreign value added in gross exports (Johnson and Noguera, 2012; Cigna et al., 2022; Georgiadis et al., 2023). Unfortunately, this ratio is not available at the firm level. To support our choice of the export intensity as an alternative measure of supply chain participation, Figure (A.1) plots the correlation of the export intensity and the share of foreign value added in gross exports for 40 Swedish industries. The data are taken from the Trade in Value Added (TiVA) statistics of the OECD and captures the year 2019, i.e. the last year before the pandemic. We find a high cross-sectional correlation between both measures at the sectoral level, which lends support to our choice of the treatment variable.

Appendix B Summary statistics

Table (B.1) shows the summary statistics on the main firm characteristics in our data set. Each variable is the average of the available firm observations. The unconditional moments reported in the table reflect the distribution of the firm-specific averages across firms. Two observations are particularly noteworthy. First, the unconditional price setting frequency is higher for products destined for the export market compared to the domestic market. This is consistent with the notion of fiercer competition on the global market. Second, the inventory ratio is surprisingly low. On average, firms hold inventories worth only 2% of their total sales. Despite the low average level of inventories, there is substantial variation in the inventory ratio across firms.

Figure A.1: Industry-specific export intensities vs. value chain participation



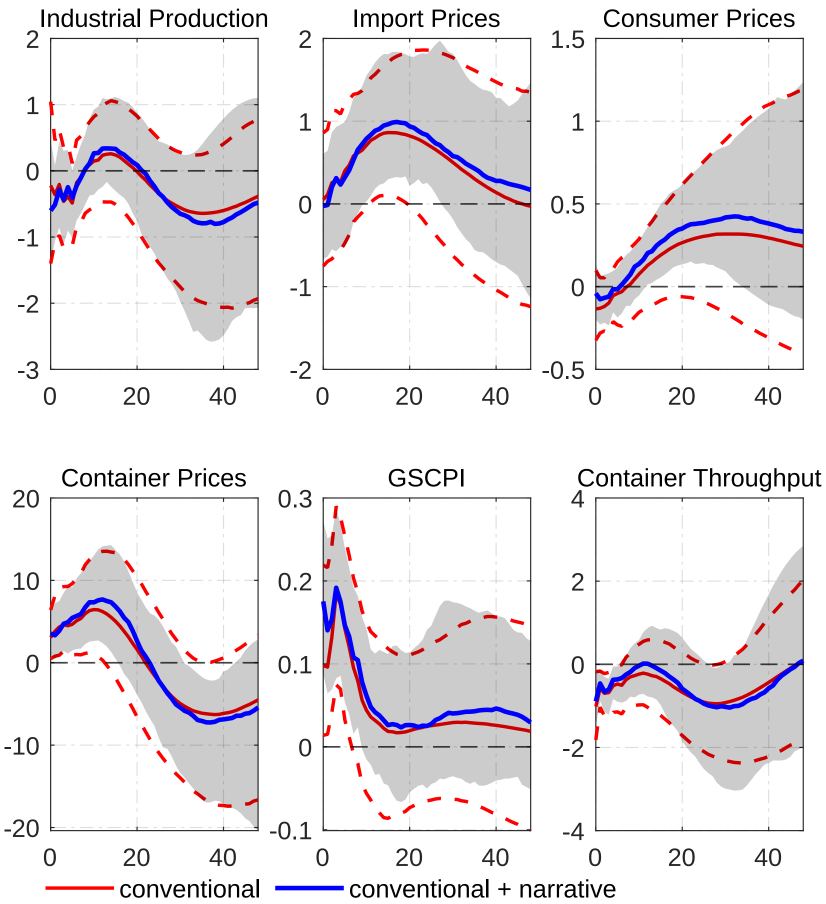
Notes: The figure shows the ratio of gross exports to gross output and the share of foreign value added of gross exports for 40 Swedish industries in 2019. The data is from the Trade in Value Added (TiVA) statistics of the OECD.

Appendix C Aggregate effects of a global supply chain shock

Figure (C.2) shows the aggregate effects of a global supply chain shock on the Swedish economy. The red-solid lines correspond to the medians across all models that satisfy the conventional sign restrictions, while the blue-solid lines correspond to the medians across all models that additionally satisfy our narrative restrictions. The dashed lines mark the 90 percent credible bands for the conventional restrictions, while the shaded areas correspond to the 90 percent credible bands that additionally satisfy the narrative restrictions.

On impact, container prices rise by about two percent and continue to rise until they reach a peak after one year, with prices rising by about eight percent. Hereafter, container prices fall below the mean, even though this

Figure C.2: Aggregate effects of a supply chain shock



Notes: The red-solid line corresponds to the median of the draws that satisfy the conventional sign restrictions, while the blue-solid line corresponds to the median of the models that satisfy both the conventional sign restrictions and the narrative restrictions. The dashed lines mark the 90 percent credible bands for the conventional restrictions, while the shaded areas correspond to the 90 percent credible bands that additionally satisfy the narrative restrictions

Table B.1: Summary statistics

	mean	median	std.dev.	25th %ile	75th %ile
Export Intensity	0.36	0.28	0.32	0.06	0.64
Log Sales	16.83	16.73	1.25	15.98	17.55
Price Freq. (Domestic Market)	0.39	0.28	0.32	0.06	0.64
Price Freq. (Export Market)	0.68	0.86	0.35	0.36	0.98
Labor Costs	25.60	24.66	13.46	16.04	33.10
Inventory Ratio	0.02	0.01	0.05	0.01	0.03
Number of Products	3.50	2.00	5.62	1.00	3.50
Number of Product Groups	2.32	2.00	2.75	1.00	2.50

Notes: The table shows the summary statistics on the main firm characteristics in our data set. Each variable is the average of the available firm observations. The statistical moments reflect the distribution of the firm-specific averages across firms.

effect is only borderline significant. We see that the number of containers being processed falls by almost one percent on impact and only returns to its mean at the end of the forecast horizon. This effect is significant only for the first three periods. Also, we see that the pressure on supply chains jumps on impact. Supply chain pressure decreases very gradually and only returns to its mean after one year.

Importantly, the information from the three narrative restrictions matters: We see that the impact response of the GSCPI is greater in magnitude if we impose narrative restrictions on the model. Also, note that uncertainty around the impulse responses of container prices and container throughput decreases noticeably once narrative restrictions are imposed.

Turning to the Swedish business cycle variables, a few things stand out. First, although the responses of these three variables remain unrestricted, all impulse responses point in the direction we would expect. This is true for both the draws that only satisfy the traditional sign restrictions and the draws that also satisfy the narrative restrictions. For instance, after a global supply chain shock, industrial production in Sweden falls noticeably by almost one percent after about two years. The delayed response of industrial activity could be due to the fact that on average firms can still draw on stocks of intermediate products before supply bottlenecks become binding.

Consumer prices and import prices, on the other hand, increase by about half a percent and one percent, respectively. Second, all these responses are insignificant when only the conventional sign restrictions are considered. If, on the other hand, the narrative restrictions are also taken into account, we see that the uncertainty of the responses decreases noticeably. This can be observed especially for the reactions of consumer prices and import prices. Hence, we now find that a supply chain shock triggers a significant adjustment of consumer prices and import prices.

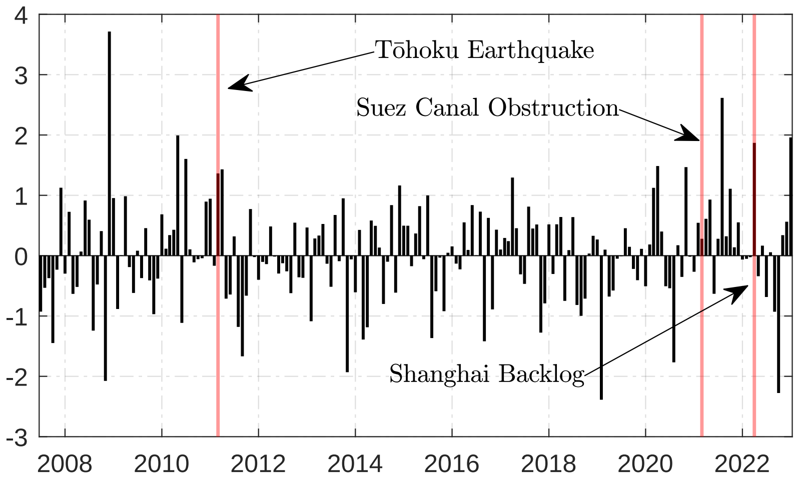
Overall, we find that a supply chain shock has qualitatively similar effects on consumer prices and industrial production as a conventional supply shock identified by a rise in prices and a fall in production. In our case, however, the reactions of these variables are left unrestricted. In the main paper, we use the granular dataset discussed in the previous section and estimate the response of individual prices to the global supply chain shock in a panel local projection framework.

Figure (C.3) shows the posterior median of the supply chain shock from the VAR model, that we use for the estimation of local projections in the main part of the paper.

Appendix D Firm characteristics

In the main paper, we show the overlap of state variables. In order to complement this, Table (D.2) documents the unconditional correlation of selected firm properties. Large firms, i.e. firms with high log sales, tend to have a higher export intensity, though the correlation is relatively small ($\rho = 0.31$). Large firms also are more likely to be multi-product firms ($\rho = 0.35$) and sell multiple product groups ($\rho = 0.29$). Overall, the correlations are relatively low.

Figure C.3: Estimated global supply chain shock over time



Notes: The figure shows the posterior median of the estimated global supply chain shock that satisfies both conventional and narrative sign restrictions. The arrows highlight the three established historical events mentioned in the main text.

Appendix E Including the unconditional effect of supply shocks

In our our baseline specification, we regress product-specific prices on the interaction term between the supply chain shock and the firm-specific export intensity. The coefficient on this interaction term provides us with the effect of the supply chain shock on the prices set by firm f conditional on the supply chain integration of that specific firm. We now report the results from an augmented specification that does not only include the interaction term, but also includes the supply chain shock and the export intensity as separate explanatory variables. Our aim is to show that the main findings of the paper remain unchanged if we include these variables separately.

In Equation (E.1), $\beta_{1,h}$ reflects the unconditional effect of the supply chain shock, $\beta_{2,h}$ reflects the effect of the export intensity on price setting and $\beta_{3,h}$ is the coefficient on the interaction term that corresponds to the estimated

Table D.2: Correlation of firm characteristics

	Export Intensity	Total Sales	Price Freq.	Inventory Ratio	Labor Costs	# Products	# Product Groups
Export Share	1.00						
Log Sales	0.31	1.00					
Price Freq.	0.11	0.24	1.00				
Inventory Ratio	-0.16	-0.14	-0.08	1.00			
Labor Costs	-0.15	-0.47	-0.24	-0.09	1.00		
# Products	0.08	0.35	0.15	-0.02	-0.17	1.00	
# Product Groups	0.12	0.29	0.13	-0.05	-0.12	0.88	1.00

Notes: The table shows the unconditional correlation of selected firm characteristics.

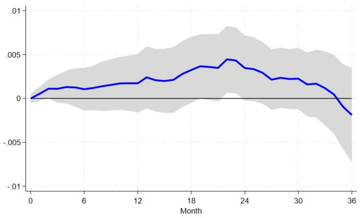
β_h coefficient in the main part of the paper, i.e.

$$\begin{aligned} \log\left(p_{i,j,f,t+h}\right) - \log\left(p_{i,j,f,t-1}\right) &= \alpha_{j,h} + \alpha_{m,h} + \beta_{1,h}\left(shock_t\right) + \\ &\quad \beta_{2,h}\left(share_{f,t}\right) + \\ &\quad \beta_{3,h}\left(share_{f,t} \times shock_t\right) + \\ &\quad \gamma_h X_{t-1} + u_{i,j,f,t+h}. \end{aligned} \tag{E.1}$$

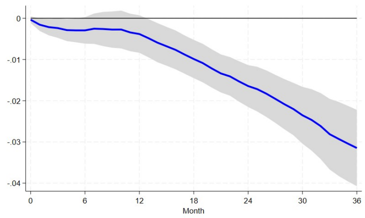
The remaining parts of the regression equation are left unchanged. Panel (a) in Figure (E.4) depicts the estimated coefficient on the supply chain shock as a function of the projection horizon h. The impact of the shock becomes significantly positive after two years only. Overall, the quantitative effect is small. Hence, the unconditional effect of the shock remains muted, i.e. the effect irrespective of an individual firm's exposure to supply chains.

The effect of the export intensity on prices is shown in Panel (b) of Figure (E.4). An increase in the export intensity results in a lower price. This is consistent with the notion of more intense competition for globally active firms. However, we should not over-interpret this coefficient because there is little variation in the export intensity over time and, more importantly, fluctuations in the export intensity are to some extent anticipated. Since these fluctuations do not come as a surprise, the estimated coefficient does not allow for a causal interpretation. Panel (c) of Figure (E.4) reports the

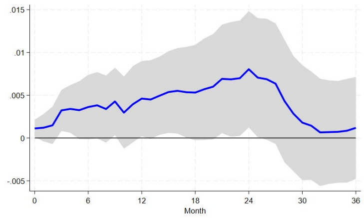
Figure E.4: State-dependent response of product-level producer prices



(a) coefficient on shock



(b) coefficient on export intensity



(c) coefficient on interaction term

Notes: The figure shows the response of firm-level producer prices to a global supply chain shock. The 90% confidence band is based on Driscoll-Kraay standard errors.

key finding of this robustness check. The coefficient on the interaction term remains significantly positive if we include the shock and the export intensity as separate variables. Compared to the baseline results reported in Figure (2) of the main paper, the response is a bit smaller. Hence, we find a significant degree of heterogeneity in the responses to the shock. It remains imperative to study the impact of supply bottlenecks across firms with different characteristics as the unconditional effect remains small.