Supply chains in times of crisis: Evidence from Kenya's production network*

Peter Wankuru Chacha † Benard Kipyegon Kirui ‡ Verena Wiedemann§

July 2023

Abstract

Trading relationships between suppliers and buyers play a key role in transmitting both local and international shocks. We use transaction-level data from Kenya to study the relevance of a firm's domestic network position and links to international supply chains in determining its trajectory during the COVID-19 crisis. We document that firms with high exposure to import and export markets tend to be larger, older, and employ more workers. The specialisation of direct importers, often intermediaries, on international markets made them very vulnerable to the initial COVID-19 shock. Exporters, one-third of whom operate in primary sectors, experienced a less severe decline in sales. We find that both importers and exporters adjust their domestic supply chains in response to international trade shocks - before and during the crisis alike. Sourcing from international markets does not crowd out domestic purchases, while sales abroad and at home can act as substitutes. Diversified domestic supply chains helped firms to mitigate the impact of the COVID-19 crisis and recover more strongly.

*We thank the Kenya Revenue Authority (KRA) for their collaboration. Romeo Ekirapa, Simon Mwangi, and Benard Sang provided excellent technical support and advice. A related project on tax incentives conducted jointly by the authors for KRA with assistance from the data support team led to this work. We thank Daniela Villacreces Villacis for her excellent research assistance. We further thank seminar and conference participants at the CSAE Research Workshop, the CSAE Annual Conference, the Oxford Applied Micro Workshop, and the Oxford Firms Discussion Group, the STEG Annual Conference, the World Bank ABCDE Conference, the WCP Virtual International Conference, the Research Conference on Sustainability in Global Value Chains, and the Jeune Street Seminar Series for comments and feedback. We received valuable guidance from Chris Woodruff and have benefited greatly from discussions with and feedback from Vatsal Khandelwal, Hannah Zillessen, Luke Heath Milsom, Sanghamitra Warrier Mukherjee, and Raphael Bradenbrink. We gratefully acknowledge financial support from the Private Enterprise Development in Low Income Countries (PEDL) programme, a joint initiative by the Centre for Economic Policy Research (CEPR) and the UK Foreign, Commonwealth & Development Office (FCDO). Verena Wiedemann further acknowledges funding from the Oxford Economic Papers Research Fund (OEP) and the German National Academic Scholarship Foundation. This study has been approved by the Department of Economics Research Ethics Committee at Oxford (protocol no.ECONCIA20-21-23), and the Kenyan National Commission for Science, Technology and Innovation (protocol no.NACOSTI/P/20/5923). The views in this paper are those of the authors, and do not necessarily represent those of the KRA or any other institution the authors are affiliated with.

†International Monetary Fund

‡Kenya Revenue Authority and Privatization Commission

§Department of Economics, University of Oxford

1 Introduction

The COVID-19 pandemic threw a new spotlight on the role of supply chain structures in firm dynamics. Previous research has documented the key role of interdependencies that arise through firm-to-firm trade in the transmission and amplification of shocks.[1] The present paper relies on administrative firm- and transaction-level data from Kenya, East Africa's largest economy, to document firm dynamics in response to the COVID-19 crisis. The setting enables us to study the role of a firm's supply chain position in determining its trajectory during times of heightened uncertainty and recovery from a severe aggregate shock. We focus on three aspects of the firm's network position: the degree of exposure to international supply chains, diversification and complexity of its domestic network.

While only a small share of firms worldwide participates in international supply chains, non-participants are indirectly linked to them via domestic buyers and suppliers (Ahn et al., 2011; Abel-Koch, 2013; Bernard et al., 2015; Dhyne et al., 2021; Grant and Startz, 2022). Customs data, the most popular sources to trace global supply chains at the firm and transaction level, typically capture only firms that directly import and export. As a result, firms with indirect exposure remain understudied compared to their relative importance in many low- and middle-income economies (Ahn et al., 2011). A key contribution of our paper is its ability to combine domestic firm-to-firm transaction-level data with customs data, allowing us to trace the indirect exposure of Kenyan private sector firms to global value chains.

The purpose of this paper is three-fold: First, we document the degree to which formal firms in Kenya's private sector are directly or indirectly embedded in international supply chains. We find that only a few large firms have strong direct or indirect linkages to international supply chains. These firms are key to the Kenyan economy, both in terms of their share of total sales and employment. On the export side, the linkage is dominated by primary sectors, while imports are dominated by the wholesale and retail sectors.
Second, we provide evidence on the response of firms to international shocks, both during the years immediately prior to the COVID-19 crisis and during the crisis itself. We find that the COVID-19 crisis had an almost universally negative effect on major firm outcomes. Average firm-level sales dropped by 56 percent in April 2020 relative to January 2020, taking seasonal

[1] See, among others, Acemoglu et al. (2012); Gabaix (2011); Barrot and Sauvagnat (2016); Huneeus (2018); Bernard and Moxnes (2018); Carvalho and Tahbaz-Salehi (2019); Carvalho et al. (2021); Kashiwagi et al. (2021); Korovkin and Makarin (2022); Arkolakis et al. (2023).

fluctuations into account.[2] The downturn was smaller for exporters, which experienced a drop of 47 percent, and firms with indirect links to import markets, which saw a decline of less than 20 percent during the peak of the crisis. We then combine the data with information on global trade flows to study how firms respond to international trade shocks. We are not only able to study how firms with indirect linkages to international supply chains respond to the shocks but also how firms adjust their domestic supply chain in response to changes in world demand and supply. We find that sourcing from international and domestic markets is complementary for Kenyan firms, while exports and domestic sales can be substitutes. More favourable shocks to world supply supported the recovery process of Kenyan firms via imports. On the flip side, we find a particularly pronounced direct pass-through of import and export shocks during the peak of the crisis. It highlights the downsides of links to international markets.

Finally, we show how firm dynamics during the COVID-19 crisis differed for firms with highly diversified domestic supply chains, i.e. a larger set of active domestic supplier or buyer relationships, relative to those with less diversification. Firms with a highly diversified domestic buyer base lost, on average, 4 percent less of their sales relative to their less diversified peers. Firms with upstream diversification (a larger supplier base) recovered more strongly.

This paper is related to and contributes to several strands of literature. First, we contribute to a large literature that shows exporting is a rare undertaking among firms, with only a small proportion participating in international trade (Bernard et al., 1995; Bernard and Jensen, 1999, 2004; Greenaway and Kneller, 2007; Wagner, 2007; Coulibaly et al., 2022).[3] Examining exporters' characteristics, the literature highlights that they differ from non-exporters in virtually all performance measures, even before entering export markets. Within Kenya, a number of studies have examined exporting at the firm-level (Rankin et al., 2006; Granér and Isaksson, 2009; Abala, 2013), relying on survey data and comparing attributes of Kenyan firms with findings from the rest of the world. A recent strand of papers on Kenyan exporters uses transaction-level customs data (Macchiavello and Morjaria, 2015; Chacha et al., 2017, 2018; Chacha and Edwards, 2019; Türkcan et al., 2022) to examine dynamics of firm-level exports,[4] including survival of trade relationships and adjustment along extensive and intensive margins in international trade. Nevertheless, in many contexts, a larger pool of firms imports or exports indirectly via wholesalers (Ahn et al., 2011; Abel-Koch, 2013; Bernard et al., 2015) or even longer chains of intermediation (Dhyne et al., 2021; Grant and Startz, 2022).[5] Two complementary approaches

[2] Including the hospitality sector, the average drop was as much as 67 percent.

[3] It is a precursor to the modern theory of international trade and firm heterogeneity (Pavcnik, 2002; Melitz, 2003; Bernard et al., 2003).

[4] Majune et al. (2020) study product-level dynamics and are thereby able to consider two decades of trade dynamics.

[5] A related, very active literature studies the role of intermediaries in (mostly domestic) agricultural and food

in the literature on global value chain participation of firms in low- and middle-income countries attempt to address the lack of data on indirect participants: The first strand focuses on specific sectors, often collecting targeted quantitative and qualitative primary data (Navas-Alemán, 2011; Startz, 2021; Foster et al., 2018; Bassett et al., 2021; Hansen et al., 2022). A second strand combines firm-level data with input-output tables to study firms in sectors with high exposure to global value chains (Del Prete et al., 2017; Amendolagine et al., 2019; Ndubuisi and Owusu, 2022). Our empirical set up bridges the two approaches by studying the nature of the exposure to international supply chains at the firm level for a large range of sectors, including services.[6] Transaction-level administrative data allow us to identify firms with indirect links to international markets in the context of Kenya.[7] It enables us to compare their characteristics to firms focused on domestic markets and track their trajectory during a global crisis, the COVID-19 pandemic. In doing so, we also complement a small set of papers that studies the response of domestic supply chains to international shocks (Huneeus, 2018; Boehm et al., 2019; Arkolakis et al., 2023). Our empirical setting shares the limitation with this literature in that we are unable to study the role of inventory in transmitting shocks along the supply chain.[8]

This paper links to a broader literature on the role of trade and global supply chains in the transmission of the COVID-19 shock (Majune, 2020; Berthou and Stumpner, 2022; Bassett et al., 2021; Fujiy et al., 2022; Lafrogne-Joussier et al., 2023). With the exception of Fujiy et al. (2022), the majority of the papers in this series rely on sector-level input-output tables (Barrot et al., 2021) or focus exclusively on international trade flows and direct exporters and importers (Majune, 2020; Berthou and Stumpner, 2022; Lafrogne-Joussier et al., 2023). Our paper complements existing studies, which also rely on more granular information but are focused on a specific industry, such as Bassett et al. (2021), who use a detailed mapping of the supply chain of small-scale fishing industries in four countries.

Moreover, we speak to a small but growing literature that studies the relevance of supply chain diversification for firm dynamics in response to shocks (Freund et al., 2022; Kashiwagi et al., 2021; Lafrogne-Joussier et al., 2023; Boehm and Sonntag, 2023). In a paper closely related to ours, Lafrogne-Joussier et al. (2023) looked at French exporters studying the pass-through of

supply chains (Minten et al., 2012; Reardon et al., 2021; Bergquist and Dinerstein, 2020).

[6] These sectors tend to receive less attention relative to agriculture and manufacturing (Hansen et al., 2022).

[7] The availability of similar administrative records to the one used in this paper has enabled researchers to study a series of questions related to globalisation and domestic firm networks, mostly in high and upper middle income countries. Alfaro-Urena et al. (2022), for example, study the effects of joining the supply chain of multinationals operating in Costa Rica on local suppliers, Demir et al. (2022) look at the effect of import taxes on domestic firms, and Adão et al. (2022) examine the implications of international trade for inequality in Ecuador.

[8] The COVID-19 crisis led to heightened uncertainty about firm-level sales growth (Bunn et al., 2021). Greater volatility and uncertainty in forecasting demand, in turn, can exacerbate the misalignment of stock levels along supply chains, a distortion that leads to inefficiently high inventory levels and gets amplified upstream (the so-called bullwhip effect (Lee et al., 1997; Metters, 1997; Yao et al., 2021)). It would require us to observe either stocks, production output or order quantities on a monthly basis alongside sales (Yao et al., 2021).

the initial import shock triggered by the first lockdown in China in February 2020. Firms with geographically diversified international supply chains were not able to cope better with the shock than firms that solely relied on imports from China. In our setting, we find that diversification helped firms to mitigate the impact of the COVID-19 shock and allowed for a stronger recovery. Our setting complements theirs in that we provide evidence on the diversification of the domestic firm network and study a substantially broader set of firms with various degrees of exposure to international supply chains.

Finally, our paper contributes to evidence on the impact of the COVID-19 crisis on business outcomes, employment, and trade in Kenya (Shupler et al., 2020; Pape et al., 2020; Majune, 2020; Nordhagen et al., 2021; Kansiime et al., 2021; Egger et al., 2021; Kinyanjui et al., 2023; Kaberia and Muathe, 2021; Awori et al., 2022; Brooks et al., 2022). Relying on administrative records limits our analysis to the VAT-paying sector, which accounts for close to one third of Kenya's GDP (Chacha et al., 2022). We are therefore unable to trace the knock-on effects of international shocks to the informal sector.[9]

2 Data and context

2.1 Data description

We combine information from six different data sets collected by the Kenya Revenue Authority: (i) transaction-level data on domestic firm-to-firm trade from value-added-tax (VAT) records; (ii) import and export transactions from customs records; (iii) firm-level information on aggregate monthly sales, purchases, imports, and exports from VAT records; (iv) the monthly number of employees and payroll from pay-as-you-earn returns, (v) the value of end of year inventory holdings reported in annual corporate income tax (CIT) returns, and (vi) information on basic firm characteristics from registration forms. The data sets cover the period from January 2015 to March 2021 and can be linked through unique, anonymised firm identifiers. We restrict our analysis to private sector firms and firms with annual purchases greater than zero and annual sales of at least 5 million KES (approximately 37,000 USD) in at least one year that we observe in the data.

We use the transaction-level firm-to-firm data to construct a monthly supplier-buyer panel, capturing the monthly transaction volume and the number of transactions between each supplier-

[9] Dix-Carneiro et al. (2021) show that the informal sector can act as an unemployment buffer, but not a welfare buffer in the event of negative aggregate (trade) shocks. Mobility restrictions during the COVID-19 pandemic seem to have disproportionately affected small businesses below the VAT cut-off in low- and middle-income countries (Nordhagen et al., 2021).

buyer pair. We further compile a monthly firm panel detailing sales, purchases, imports, exports, number of employees, and total payroll. We complement this data with information on firm age, firm headquarter location, and the sector of operation collected from registration forms. The sector classification corresponds to the 4-digit International Standard Industrial Classification of All Economic Activities (ISIC) code. The customs data yields information on the origin/destination of imports/exports, as well as on 8-digit Harmonized System (HS) product codes,[10] quantity and value of the goods traded. Due to the reporting system implemented as part of the East African Community's (EAC) Single Customs Union, we are unable to map product-level details for trade with other EAC member states to the firm data. However, the information on total monthly imports and exports in the VAT data still captures aggregate trade with the EAC.

We complement the administrative data with monthly product-level customs data from UN Comtrade database to measure changes in world demand for products using 4-digit HS codes.[11] A number of important trade partners of Kenya, including China, Vietnam, and South Africa, do not report to the monthly database. Nevertheless, the export transactions that can be linked to the monthly UN Comtrade database represent 78 percent of the observed export volume. All variables denoted in monetary terms are deflated using the monthly consumer price index.

The data set covers 57,482 firms considering all the years between 2015 to 2021. For instance, in 2019, 44,888 formal firms participated in the firm-to-firm network, forming close to 1.5 million relationships among each other (see Table A2 in the appendix). Their domestic sales aggregated to 6,806 billion KES (about 62 billion USD) and they employed 14 percent of the urban working population in 2019. Between 2015 and 2020, the value-added generated by VAT-paying firms, on average, accounted for 34 percent of Kenya's GDP (Chacha et al., 2022). The largest sectors in terms of volume are wholesale and retail, and manufacturing (see Table A1 in the appendix).

2.2 Key events during the COVID-19 pandemic in Kenya

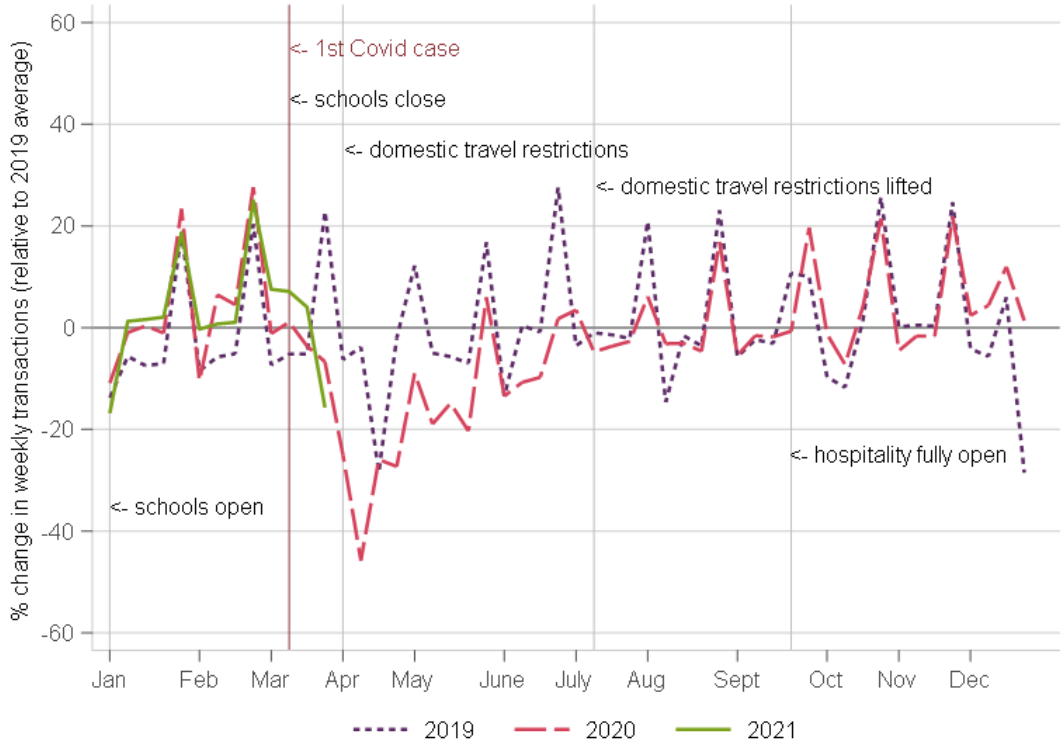
As a result of COVID-19-related shocks, Kenya faced its first recession in almost two decades in 2020.[12] The private sector in Kenya was first impacted by disruptions of its trade with China

[10] We aggregate products to the 4-digit level for the purpose of this paper and when linking the data with the UN Comtrade database below. While we lose out on some heterogeneity at the country-product level, as a result, this approach reduces the number of cases with potential mismatches due to classification errors. It further allowed for an easier cross-walk between cases where product classifications from previous HS nomenclatures were applied. We harmonise all HS codes to align with the HS Nomenclature 2012 Edition.

[11] https://comtrade.un.org/Data/bulk

[12] https://citizentv.co.ke/business/kenyas-economy-slumped-into-recession-after-18-years-in-september-5068864/#:~:text=The%20Kenyan%20economy%20sunk%20to,cent%20in%20the%20third%20quarter.

Figure 1: Weekly firm-to-firm transactions



The figure shows the evolution of the percentage change in the number of purchase transactions relative to the weekly average number transactions in 2019. The data includes the universe of input VAT transactions reported by any tax filing entity.

in early 2020.[13] The first domestic COVID-19 case was reported in early March and a series of measures to contain the spread of the virus was introduced.[14] Figure 1 depicts key events of the COVID-19 crisis in Kenya alongside the count of firm-to-firm transactions in 2019, 2020 and the first quarter of 2021.

Starting in mid-March of 2020 the Government of Kenya closed national borders, restricted domestic travel, banned public gatherings, closed schools, and later imposed a night-time curfew. The number of firm-to-firm transactions started to fall substantially in the second half of March before the recovery process started to kick in around mid-April. By early July, major domestic travel restrictions had been lifted and by September, the evolution of inter-firm transactions had largely caught up with the regular fluctuations experienced in 2019. In March 2021, Kenya experienced its third and till that date largest wave of COVID-19 cases. Another round of containment measures was imposed.[15] Overall, the transaction-level records suggest both a

[13] See for example Majune (2020) on lockdown policies and trade flows in and out of Kenya.

[14] https://www.covidlawlab.org/wp-content/uploads/2020/06/MOH-Press-Statement-on-the-Update-of-Coronavirus-in-the-Cou pdf

[15] For a summary of key policy responses see, for example: https://www.imf.org/en/Topics/imf-and-covid19/Policy-Responses-to-COVID-19#K.

sharp initial downturn between March and April 2020 and a relatively swift recovery. Going forward, we define April to June 2020 as the peak months of the COVID-19 crisis and any of the subsequent months as the recovery phase.

2.3 Fluctuations in major firm-level outcomes during the COVID-19 crisis

To examine the evolution of key firm-level outcomes during the COVID-19 pandemic in Kenya, we first regress firm-level outcomes on a series of time dummies, firm-, and 2-digit sector-month-fixed effects.[16] The coefficient for January 2020 is normalised to zero. The results plotted in Figure 2 show that domestic sales of the average firm drop by 67 percent in April relative to January 2020. We further compare the trends in key firm-level outcomes to 2019 trends during the same window in Figure A1 in the appendix. Despite the number of buyers and suppliers falling by as much as 20 percent at the peak of the crisis relative to January 2020, domestic firm-to-firm relationships bounce back relatively swiftly (see bottom two graphs of Figure A1). Exports and imports took a much smaller hit than domestic trade flows and even rose to above pre-pandemic levels by the second half of 2020. It is important to bear in mind that the, on average, smaller dip in imports and exports is also driven by the fact that very few firms import and export directly. Therefore, we use a more nuanced measure of exposure to international supply chains in the following sections of the paper to obtain a better understanding of the trajectory of firms linked to international markets.

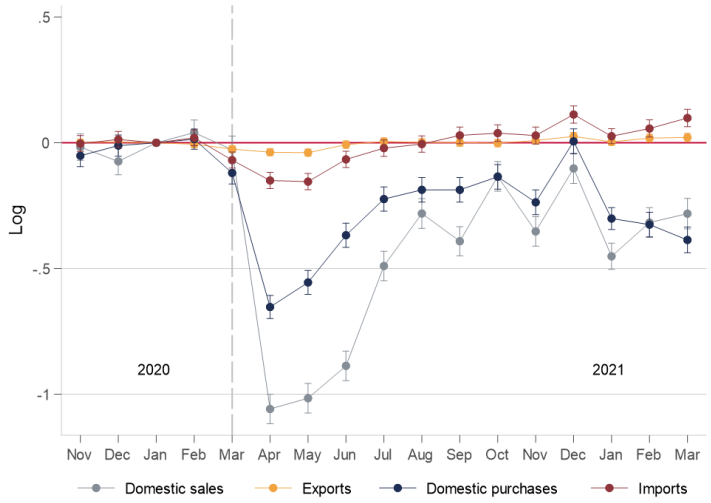
We then exclude firms from the hospitality sector, which has been disproportionately affected by the pandemic, to address concerns regarding the impact of outliers in the hospitality sector being the key driver of results.[17] Much of the subsequent analysis further relies on being able to observe a firm's links with other firms in the domestic network. Therefore, we exclude firms that do not have at least one up- or downstream linkage to another domestic firm.

[16]
$$y_{it} = \beta \text{ preC19} + \sum_{k=1}^{2} \tau_{-k} \text{ jan2020}_{t-k} + \sum_{k=1}^{14} \tau_{+k} \text{ jan2020}_{t+k} + \phi_i + \eta_{sm} + \varepsilon_{it}$$

where y_{it} denotes the firm-level outcome, ϕ_i firm FEs, η_{sm} 2-digit sector-month FE, and ε_{it} the error term, which is clustered at the firm level.

[17] Restaurants and hotels faced major restrictions up until September 2020. Their initial lack of recovery until the last quarter of 2020 therefore primarily reflects a response to targeted policy measures.

Figure 2: The evolution of major firm-level outcomes during the COVID-19 crisis: Sales, purchases, imports, and exports



Regression of firm-level outcomes on a series of monthly time dummies. All outcomes are in log(+1) terms. Standard errors are clustered at the firm-level and the error bars show the 95 percent confidence intervals. The regressions include data from April 2015 to March 2021.

3 Links to international supply chains and firm dynamics during the COVID-19 crisis

In this section we take a closer at the characteristics of Kenyan firms with strong direct and indirect linkages to international supply chains, their trajectory during the COVID-19 crisis, and their response to international shocks.

3.1 Measuring direct and indirect exposure to international supply chains

The data for 2018 indicate that only 11 percent of the firms import directly; however, as many as 90 percent of the firms that year buy from an importing firm. While virtually all firms in the network are linked to at least one importer or one exporter, these links tend to be very weak.[18] To get a more complete picture of the extent of indirect exposure to international supply chains, following Dhyne et al. (2021), we compute each firm's total exposure to foreign demand r_{iX}^{total} and foreign inputs r_{iM}^{total}. In other words, we consider the share of a firm's sales or purchases

[18]This result is entirely driven by a majority of firms buying from highly connected firms which happen to import directly in one way or another. Of all firms, 88 percent buy from a firm that is both (i) a direct importer and (ii) in the 90^{th} percentile of the outdegree distribution (i.e. firms with a lot of buyers). This pattern, in turn, is rooted in the underlying fundamental network structure of firm networks, including Kenya's firm network (Chacha et al., 2022), where less connected nodes tend to link with highly connected nodes. The resulting negative correlation between a firm's own degree and the average degree of the firm's trade partners is referred to as disassortative mixing by degree (Newman, 2018) (or sometimes negative degree assortativity in the empirical literature on production networks (Bernard and Moxnes, 2018)). Disassortative mixing by degree can be found in most other types of networks, with some notable exceptions like social networks (Newman, 2018).

that is ultimately sold to or sourced from international markets. Focusing on exports for now, a firm's full exposure to foreign demand r_{iX}^{total} is the sum of its own share of total output that is directly exported r_{iX}^{direct} and the export share of its buyers, the buyers' buyers and so on ($r_{iX}^{indirect}$). Having constructed the adjacency matrix A of the domestic firm-to-firm network,[19] we use the following linear system to compute the total exposure to foreign demand:

$$r_X^{total} = (I - A)^{-1} r_X^{direct}$$

A key element of the above equation is $(I - A)^{-1}$, which can be interpreted as the firm-level version of the Leontief inverse. It captures the total impact or exposure of element i to j, both directly and indirectly (Sargent and Stachurski, 2022). i and j correspond to firms in our case rather than sectors in the classic version of the Leontief.[20] The total exposure to import markets can be computed following a similar approach, except that the elements of the adjacency matrix now correspond to the inputs i purchases from j divided by i's total intermediate inputs (Dhyne et al., 2021).

3.2 Firm characteristics and links to international supply chains

Five percent of the average firm's sales are ultimately absorbed by foreign demand, while eight percent of its inputs were sourced abroad in 2018. In the following, we distinguish[21] among:

(i) firms with high direct exposure to exports and imports,

- i.e. $r_{iX}^{direct} \geq 0.25$ and $r_{iM}^{direct} \geq 0.25$

(ii) firms with high total exposure (direct plus indirect),

- i.e. $r_{iX}^{total} \geq 0.25$ and $r_{iM}^{total} \geq 0.25$, but $r_{iX}^{direct}, r_{iM}^{direct} < 0.25$

(iii) firms that export (import) less than 25 percent.

- i.e. $r_{iX}^{total} < 0.25$ and $r_{iM}^{total} < 0.25$

Key firm characteristics of the firms in each group are summarised in Table 1. While as little as nine percent of all firms are highly exposed to import markets, these firms capture more than half of the total sales volume reported in 2018. Notably, the 657 firms with high indirect

[19] Element i, j of the adjacency matrix A corresponds to the share of i's output that is sold to j.

[20] $(I - A)^{-}1$ is further proportional to the Bonacich-Katz centrality $(I - \beta A)^{-1}$, which captures the firm's importance as a supplier of intermediate inputs in the network (Acemoglu et al., 2012; Sargent and Stachurski, 2022).

[21] The 25% cut-off aligns with the one used in Dhyne and Duprez (2015) when discussing the exposure of Belgian firms to export markets. For exports, the chosen cut-off at 25% corresponds to total export exposure r_{iX}^{total} of firms in the 95th percentile. For imports (r_{iM}^{total}), it is close to the 90th percentile.

imports account for 28 percent of the total sales across all firms in that year. Likewise, on the downstream side, only five percent of the firms are highly exposed to export markets but account for 13 percent of total sales. In Belgium, 10 percent of firms - twice as many as in Kenya - directly or indirectly export 25+% of their output (Dhyne and Duprez, 2015). Importantly, Kenyan firms with strong linkages to international supply chains also employ substantially more workers on average and tend to be older.

Table 1: Summary statistics for firms directly and indirectly linked to international supply chains in 2018

Exports

export group	# of firms	% of sales	Age	Sales		Employment		No. buyers	No. suppliers	% sales to HH
			avg	avg	sd	avg	sd	avg	avg	avg
No/low exports	46,193	87	9	115	1,773	15	149	28	25	40
25%+ total exports	1,456	2	11	98	438	25	120	24	32	1
25%+ direct exports	863	11	15	717	2,122	147	636	19	60	28

Imports

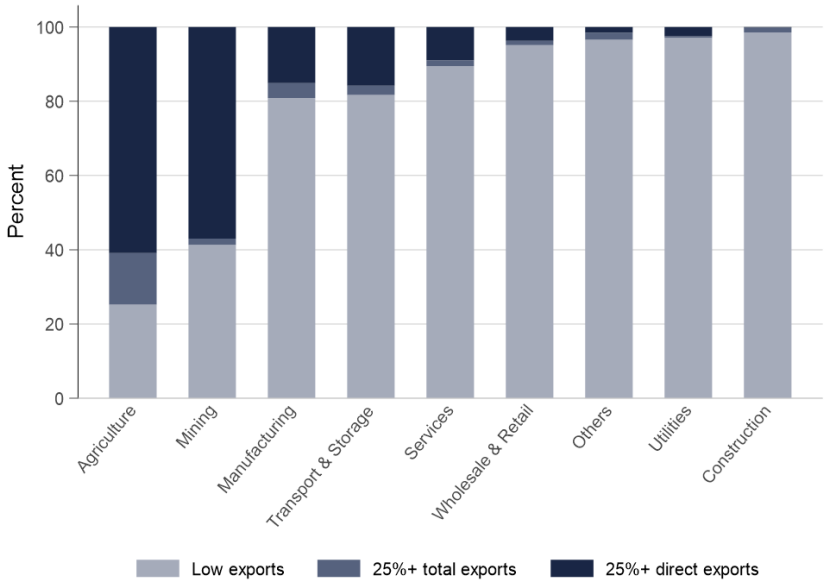
import group	# of firms	% of sales	Age	Sales		Employment		No. buyers	No. suppliers	% sales to HH
			avg	avg	sd	avg	sd	avg	avg	avg
No/low imports	44,002	43	9	60	368	12	124	16	23	40
25%+ total imports	657	28	18	2,497	11,816	277	966	354	118	3
25%+ direct imports	3,853	29	11	436	3,311	34	131	94	45	26

The table groups firms by their exposure to international supply chains. Total export and total import exposure are the sum of both direct and indirect exposure. The category for 25%+ total exposure excludes any firms that are part of the 25%+ direct exposure group. The number of buyers and suppliers refers to domestic suppliers and buyers only. % sales to HH captures the share of domestic sales outside the network - mostly to consumers.

Primary sectors dominate Kenya's exposure to export markets. Of the large formal agricultural firms captured in the administrative data, over 70 percent of their sales are destined for export markets, mostly through direct exports, but in some cases also indirectly (see top panel of Figure 3). Close to half of the output of mining and quarrying firms is exported. This is followed by 20 percent of each manufacturing output and the transportation sector. Jointly those two sectors capture a relatively larger share of the formal economy (see Table A1), while sourcing most of their inputs from international markets (see bottom of Figure 3). Figure 3 further highlights that exposure to import markets is less concentrated in specific sectors and that indirect linkages to import markets play a much bigger role for upstream supply chains than exports do for downstream supply chains.

Figure 3: Output share of firms by strength of links to international supply chains

Indirect and direct exporters



Indirect and direct importers

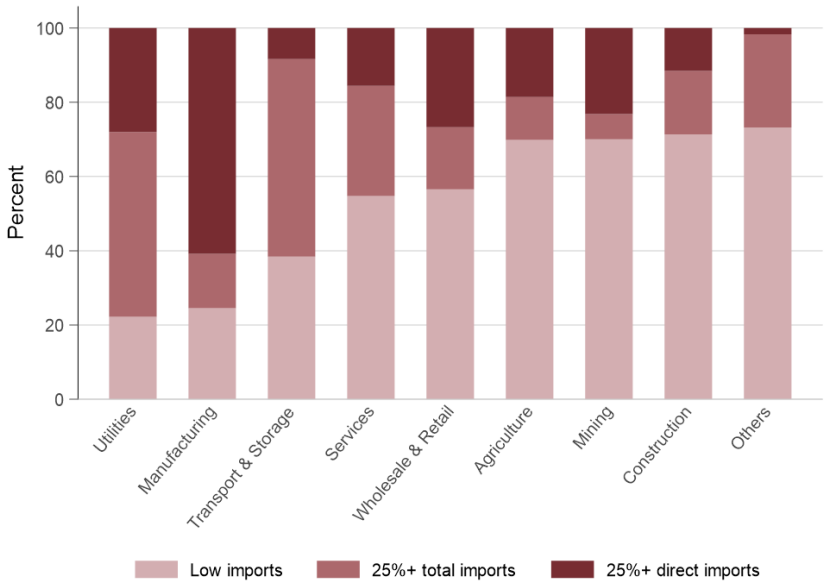


Figure 3 categorises firms by their degree of exposure to international supply chains and plots their sales (exports)/input (imports) share by sector in 2018. Total export (import) exposure is the sum of both direct and indirect exposure to exports (imports). The category for 25%+ total exposure excludes any firms that are part of the 25%+ direct exposure group.

3.3 The trajectory of firms with strong linkages to international supply chains during the COVID-19 crisis

Next, we examine the trajectory of firms with different degrees of exposure to international supply chains during the crisis. We start with the simple categorisation of firms into import-

ers and exporters[22] and plot the evolution of their sales relative to those with no direct prior links to international supply chains in Figure 4a.[23] We record three main findings: First, the downturn for direct importers starts in February 2020; at the height of the lockdowns in China. Second, sales of direct importers drop by a similar margin compared to sales of firms without any direct links to international supply chains. They initially recover more swiftly but stagnate in the second half of 2020. Third, at the lowest point of their trajectory in May 2020, sales of exporters drop by only 47 percent relative to January 2020 and bounce back quickly.

In Figures 4b (exports) and 4c (imports), we now draw on the more nuanced measure to distinguish between firms that face a high direct versus high indirect exposure to international supply chains, respectively. For the case of exports, direct exporters, which specialise in international markets, hit their lowest point in May.[24] By July, these firms reach their pre-pandemic level of sales. However, firms with indirect links to export markets only reach their January sales level by the end of 2020. A dominating factor for these differential trends is the sector in which direct and indirect exporters operate.[25] Direct exports are dominated by firms exporting agricultural products, the demand for which was barely affected by the pandemic or even increased (that is, the demand for vegetable exports). Indirect exporters operate in a wider range of sectors, with a substantial proportion in transport and logistics as well as manufacturing.

Turning to indirect importers, we find a relatively small initial downturn of less than 20 percent on average but levels of sales that remain below those of January 2020 until the end of our data set, March 2021. The descriptive statistics in Section 3.2 highlight the older age profile and larger size of firms with high indirect exposure to import markets. These characteristics often coincide with greater firm resilience. In addition, larger firms often have a more diversified demand profile that helped them to buffer the initial shock (also see Section 4 below).
Direct importers, many of whom act as intermediaries, were hit the hardest by the initial down-

[22] We classify a firm as an importer (exporter) if more than 10% of their inputs (sales) are directly sourced from (sold) abroad.

[23] We again rely on the same event study specification as above including firm- and sector-month-fixed effects as well as normalising the coefficient for January 2020 to zero.

[24] May coincides with Mother's Day in many European export destinations for Kenya's flower exporters.

[25] Other facts that could contribute to this trajectory are inventory holdings by exporters or a time lag due to already placed international orders or international shipping times. Unfortunately, we do not observe monthly inventory levels of firms in the administrative records. If we consider inventory levels at the end of the previous fiscal year as an imperfect proxy, we find that firms with a high exposure to export markets tend to hold less inventory than their peers with little exposure. At the end of 2019, the value of inventory held by direct exporters is equivalent to 38 days of their average daily sales volume. For indirect exporters it is 51 days, and 66 days for all other firms. Even within their 4-digit sector exporters (direct and indirect) are disproportionately less likely to feature in the top quartile of inventory holdings. In Appendix C.1 we explore the trajectory of firms with high inventory levels in more detail and compare it to our results on supply chain diversification in Section 4.

turn. Their sales started declining substantially from February 2020 onward, falling by 20 percent in March and 60 percent in April and May relative to the average for January 2020. While their downturn was even more pronounced than for the average firm without any or with only weak linkages to import markets, their initial recovery was swifter. However, their imports again stalled in the last quarter of 2020 and remained well below pre-pandemic levels until (at least) March 2021.[26] Domestic sales of these firms largely trail their imports, which evinces their role as intermediaries.[27] Section 3.4 shows that the pass-through of direct import shocks to firm sales is particularly high during both the crisis peak and the recovery. These results seemingly contradict those of Figure 2, which shows that imports start to rise above January 2020 levels by August for the average firm (as do import volumes overall[28]). However, this increase is driven less by firms that previously specialised in imports and more by firms that have not imported before, or only to a limited extent. Figure B1 shows that firms that source disproportionately less of their inputs from import markets account for an increasingly larger (but still small) share of aggregate import volumes - a trend that pre-dates the pandemic.[29]

[26] We are unable to unpack the extent to which this is driven by global shipment cost dynamics and container shortages that were prevalent around the time.

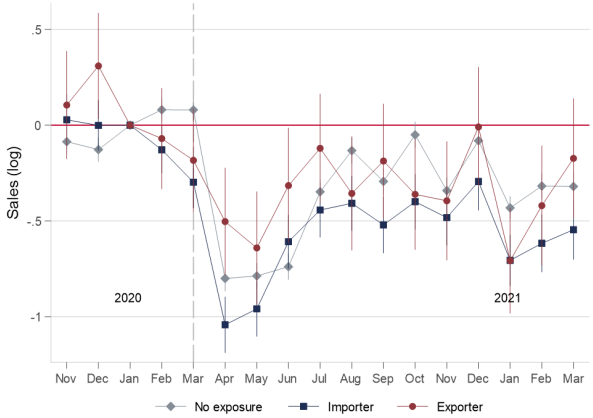
[27] Graph available on request.

[28] See https://pedl.cepr.org/publications/domestic-and-international-trade-flows-during-covid-19-pandemic-evidence-kenya%E2%80%99s

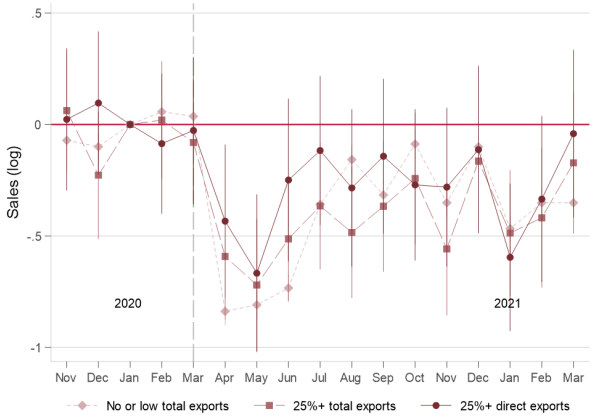
[29] This trend is also reflected in the time series of aggregate import volumes rather than shares attributed to each group of firms.

Figure 4: Firm-level exposure to international supply chains and firm sales during the crisis and recovery

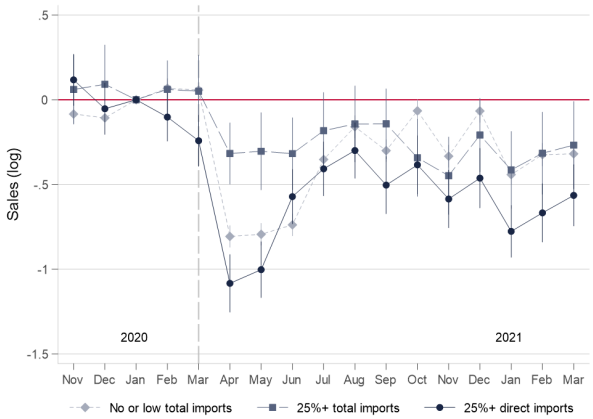
a) Importers and exporters



b) Indirect and direct exporters



c) Indirect and direct importers



Regression of firm-level outcomes on a series of monthly time dummies and include firm fixed effects and cluster standard errors at the firm level. The error bars show the 95-percent confidence intervals. The regressions for the COVID-19 period include data between November 2019 and March 2021.

3.4 Pass-through of shocks to import and export markets and domestic supply chains

So far we have focused on differences in firm dynamics based on their pre-COVID links to supply chains. To get a better understanding of the response of domestic supply chains to international shocks, we further exploit the fact that the COVID-19 shock was nowhere near universal. More specifically, we exploit the heterogeneity in supply and demand to and from worldwide markets across countries and product categories.

Empirical strategy

We deploy a shift-share design approach popularised by Hummels et al. (2014) and subsequently applied in settings similar to ours, such as Huneeus (2018); Dhyne et al. (2021). The measure consists of two components. The first is the shares $\omega_{i,c,p,t-12}$,[30] which capture a firm i's exports of product p to country c as a share of the firm's total revenues of the last 12 months at time $t-12$.[31] The second is, the change in demand WID for (supply WES of) product p by country c from all other countries, excluding Kenya.[32] In a nutshell, firm-level changes in foreign demand FD and foreign supply FS are defined as:

$$\Delta \log FD_{it} = \sum_{c,p} \omega_{i,c,p,t-12} \Delta \log \ WID_{c,p,t}, and$$

$$\Delta \log FS_{it} = \sum_{c,p} \omega_{i,c,p,t-12} \Delta \log \ WES_{c,p,t}.$$

Crucially, here we do not assume exogeneity of the exposure to international shocks (that is, the shares)[33] but instead seek to exploit variation in changes in demand and supply at the country-product level.[34] In our setting, we observe 12,244 unique country x product pairs for exports and 29,815 pairs for imports. To compute the shocks, we consider the month-over-month changes between the current and the same months in the previous year (for example, April 2020 vs April 2019). The observed average export and import shocks are 2 percent and 3 percent respectively

[30] For the computation of the shares we hold the country-product shares fixed in the same month of the previous year, i.e., for April 2020 we compute the shares based on import and export transactions between May 2018 and April 2019.

[31] Or the share of total inputs (intermediate inputs plus payroll) in the case of imports.

[32] The data to construct the shock measure was retrieved from the UN Comtrade database. Products p are defined by 4-digit HS codes (see Section 2.1). https://comtrade.un.org/Data/bulk

[33] A concern is that characteristics of firms selecting into certain country-product markets - e.g., better access to credit or risk management capacities (Sheffi, 2015) - correlate with their ability to respond to negative shocks.

[34] Drivers of such variation in the demand for or supply of products by specific countries can, for example, be policy measures and changes in behaviour (such as lockdowns or working from home) during the COVID-19 pandemic.

(see Table B1). We summarise key properties of the underlying shares and shocks in Table B1. We follow Dhyne et al. (2021)'s estimation strategy to simultaneously estimate the pass-through of both direct and indirect import and export shocks. However, being able to rely on more granular monthly data instead of annual data, we define the relevant adjacency matrix as the network observed in the same month of the previous year, taking into account all firm-to-firm relations in the 12 months leading up to it (that is, to compute the indirect exposure for April 2020, we consider all firm-to-firm relationships between May 2018 and April 2019). While this approach is computationally intensive and involves inverting $(I - A)$ for every single month in the data set, it is crucial for holding the predictive power of the foreign demand and supply measure constant at any point. The full exposure to export shocks becomes:[35]

$$Z^X = (I - A)^{-1} r_F \Delta \log FD$$

At the firm-level, we split Z^X_{it} into its direct and indirect components and ultimately estimate the following specification:

$$\Delta y_{it} = \beta_1 Z^{X_{direct}}_{it} + \beta_2 Z^{X_{indirect}}_{it} + \gamma_1 Z^{M_{direct}}_{it} + \gamma_2 Z^{M_{indirect}}_{it} + \eta_s + \phi_{sy} + \varepsilon_{it} \tag{1}$$

y_{it} denotes the change in (log) firm-level outcomes of firm i in month t relative to the same month in the previous year. We further controlled for two-digit sector-date-fixed effects. The first-difference approach is crucial to isolate the shock variation from the variation in exposure shares in the case of panel data with time variation in the exposure to shocks (Borusyak et al., 2022). While the month-over-month first difference introduces more noise on the left-hand side, the shock measure gains in predictive power. We control for firm age to address the fact that younger firms typically experience more pronounced growth patterns. Finally, we control for the contemporaneous sum of shares and their interaction with the control variable (log) firm age, a crucial addition for contexts where the shares do not sum to 1 (Borusyak et al., 2022). In our case, the sum is not 1 because we do not capture imports and exports of all relevant countries in the UN Comtrade database and miss out on product-level trade with EAC member countries in the customs data. Relying on the 12-month difference for firm outcomes comes with the caveat of losing observations at the extensive margin where either the current or lagged observation is zero. This issue is particularly prevalent for the count of buyers and suppliers, where using log+1 as the outcome greatly distorts the results. We, therefore, restrict the sample to firms which have at least one supplier in both periods in order to hold the sample of firms constant.

[35] Following the notation introduced in Section 3.1.

Only when looking at the number of buyers and employment will the sample size again drop due to fewer firms also having domestic buyers and formal employees.

Results

The results show that international supply and demand shocks not only impact firm-level exports and imports but are also passed on through domestic supply chain linkages. Moreover, they are associated with changes in the domestic production network (see Table 2). Unsurprisingly, direct import and export shocks have the strongest effects on firm-level imports and exports. A 10 percent increase in world demand results in a 3.7 percent increase of exports by Kenyan firms. A shock of the same magnitude to the world supply of products usually purchased by Kenyan firms increases imports by 8.6 percent. Note that most export and import shocks we observe in the data are much smaller in magnitude than a 10 percent shift. Only firms in the 1st and 99th percentiles experienced shocks of a magnitude well above 10 percent during our sample period. During the peak of the COVID-19 crisis, some firms saw a decline in demand for their products by as much as 82 percent, while other firms experienced a 76 percent boost. We, therefore, re-estimate Equation 1 interacting each of the shock measures with two dummy variables for the crisis peak and the recovery phase (see Figure B2). It shows that the strong pass-through of import and export shocks is primarily driven by the large shocks that hit firms during the COVID-19 crisis.

Nevertheless, we observe a pass-through of international shocks to domestic supply chains in the pre-COVID-19 period as well. Domestic purchases of importers increase. Firms exposed to indirect import shocks through their suppliers export more but also concentrate their inputs on fewer suppliers while keeping overall purchase levels unchanged. The latter dynamic is reversed during the recovery period from the crisis. Here, indirect import shocks result in more domestic supplier relationships. Further, indirect import shocks have a strong positive effect on domestic sales, purchases, and the number of buyers in the second half of 2020 and the first quarter of 2021. This suggests that the bouncing back of international supply chains very much supported the recovery trajectory of Kenyan firms.

A positive export shock increases upstream participation in international supply chains, leading to more imports. On average, the increase in imports does not crowd out domestic inputs. Rather, there is a crowding-in effect, as firms indirectly exposed to export shocks increase their domestic sales. These firms, in turn, increase their domestic purchases and the number of suppliers. The finding supports the interpretation that shocks to foreign demand pass through

Table 2: Firm response to international supply and demand shocks

	Imports	Exports	Domestic sales	Domestic purch.	No. of suppliers	No. of buyers	No. employees
export direct	0.266*	0.387*	0.154	0.053*	0.035*	-0.074**	0.008
	(0.147)	(0.205)	(0.138)	(0.030)	(0.019)	(0.030)	(0.019)
export indirect	0.007	0.037	0.735*	0.177	0.125*	0.047	0.006
	(0.250)	(0.227)	(0.429)	(0.132)	(0.068)	(0.056)	(0.073)
import direct	0.870***	0.002	0.248**	0.105***	0.034**	0.055***	0.023*
	(0.162)	(0.074)	(0.105)	(0.029)	(0.014)	(0.017)	(0.012)
import indirect	0.083	0.278***	-0.166***	-0.001	-0.021***	-0.001	0.002
	(0.113)	(0.087)	(0.039)	(0.017)	(0.008)	(0.010)	(0.011)
No. of observations	950,713	950,713	950,713	950,713	950,713	594,342	607,403
No. of firms	40243	40243	40243	40243	40243	27597	23711
R2	0.076	0.107	0.150	0.157	0.197	0.256	0.361
Firm FE	✓	✓	✓	✓	✓	✓	✓
Sector-date FE	✓	✓	✓	✓	✓	✓	✓

The results present the estimation of Equation 1 regressing the respective shock measures on the change in logged firm-level outcomes relative to the same month in the previous year as well as firm- and sector-date-fixed effects. Standard errors are clustered at the firm level. We further control for the sum of shares and firm age (log) weighted by the sum of shares. The regressions include data from April 2018 to March 2021.

to domestic suppliers. During the peak of the COVID-19 crisis, firms exposed to less negative direct or indirect export shocks see less of a decline in their domestic purchase volume and the number of suppliers. The effect size is, however, quite small for direct export shocks, with a 10 percent increase in foreign demand leading to an increase in the number of domestic suppliers of only 0.5 percent. The estimated effect is more substantial for firms exposed to indirect export shocks, where a 10 percent shock results in a 4 percent increase of links to suppliers.

While we do not detect a statistically significant response of domestic sales to foreign demand shocks, the number of domestic buyers declines as a result of an increase in foreign demand. We observe a similar pattern for the case of indirect import shocks, where firms start to export more but sell less domestically as a result of a positive import shock. Jointly, these results suggest - a perhaps surprising - substitution effect between sales to international supply chains and domestic supply chains, at least for the average firm.

Overall, we find that both the downstream substitution and upstream complementary patterns between foreign and domestic markets predate the pandemic. At the same time, however, the direct pass-through of both import and export shocks to major outcomes is particularly pronounced during the peak of the COVID-19 crisis. So, while domestic supply chains do benefit from favourable conditions in international markets, it also implies that they are also vulnerable to the attached downside risk.

4 Network position and firm resilience

Finally, we take a closer look at the relevance of a firm's domestic network position for its trajectory during the COVID-19 crisis. Here we consider diversification of domestic up- and downstream supply chains on both the extensive and the intensive margin and the number of up- and downstream sectors as a proxy for the complexity of the supply chain. We find that downstream diversification is beneficial during times of severe economic downturn. Meanwhile, upstream diversification of suppliers improves firm recovery as demand picks up, but stories of supply chain backlogs start to make headlines worldwide.

4.1 Measuring diversification and complexity of domestic supply chains

In the following, we again fix the firm's network in the same month of the previous year and consider all suppliers (or buyers) the firm has interacted with during the past 12 months (rolling network).

Diversification

Diversification can take place along both the extensive and the intensive margins.

On the extensive margin, we look at the number of suppliers (buyers) the firm has within each 4-digit sector it purchases from (sells to). For firms purchasing (or selling to) more than one 4-digit sector, we consider the weighted average number of suppliers (buyers). To account for differences across sectors, age cohorts and firm size, we first group firms based on their 2-digit sector, age cohort[36] and sales quartile.[37] We then define a firm as highly diversified if the number of suppliers (or buyers) within the sector-cohort-size bin lies above its peers in the same 4-digit sector. Even within each sector-age-sales bin, we still see sizeable differences between firms that are highly diversified on the extensive margin versus those with little diversification (see Table C2 for downstream diversification and Table C1 for upstream supply chains). Firms with higher downstream diversification, for example, have more employees, are more likely to be direct importers, and have larger sales. Many of the noted differences, such as firm age, are statistically significant but not sizeable. For firms with a high degree of upstream diversification, the sales and age gap to less diversified firms is even smaller, while the gap is similar for purchases (about 5 million KES in each case). While the results below are robust to alternatively grouping firms into sales tertiles or deciles, we cannot fully rule out any size effects that correlate with our measure of diversification to drive some of the results.

[36] The respective cohorts are < 5 years, 5-10 years, 11-20 years and 20+ years.

[37] Conditioning on 4-digit sectors would come with the caveat of having too few firms in some of the age-cohort bins.

On the intensive margin, diversification essentially corresponds to the concentration of sales and purchases. We use the Herfindahl–Hirschman Index (HHI), which can take a value between 0 (least concentrated) and 1 (highly concentrated).

Number of up- and downstream sectors

The delay or failure of a small input can often result in the break-down of an entire product (Kremer, 1993). Thus, supply chains with a large number of inputs might be particularly fragile during times of crisis when the probability of delays or shortages increases steeply. We look at the number of 4-digit sectors a firm sources from (sells to) as a proxy for the complexity of its supply chain. Firms sourcing from an above-median number of industries within their 4-digit sector are categorised as having complex supply chains.

Empirical strategy

With those measures at hand, we estimate an adapted version of the event-study specification in Section 2.3. In our preferred specification we pool the month dummies into pre-COVID (November 2019 to March 2020), COVID peak (April to June 2020), and recovery phase (July 2020 to March 2021) and interact them with the respective diversification and complexity measure N_{it}:

$$\begin{aligned} y_{it} = \quad & \beta_1 N_{it} + \beta_2 C19_{pre} + \beta_3 C19_{pre} * N_{it} + \beta_4 C19_{peak} + \beta_5 C19_{peak} * N_{it} \\ & + \beta_6 C19_{recov} + \beta_7 C19_{recov} * N_{it} + \beta_8 X_i + \delta_{st} + \phi_i + \varepsilon_{it} \end{aligned} \tag{2}$$

y_{it} denotes firm-level outcomes of firm i in month t in log (+1) terms. We further control for 2-digit sector-month FE (δ_{st}) and firm FE (ϕ_i). To ensure the firm's network position is not primarily driven by its proximity to final demand and/or international markets, we controlled for whether the firm is an importer or an exporter and for its shares of sales to domestic entities outside the network. We further account for firm age (log) and the average N_{it} for the firm's 4-digit sector to capture sector-level shocks - for example, due to the exit of a key supplier.

β_1 (for N_{it}) is identified by firms moving in and out of respective diversification and complexity categories over time. β_2, β_4, β_6 are identified by within-firm and calendar-month variation relative to the pre-COVID years 2015-2019. β_3, β_5 and β_7 rely on the same source of variation, but are interpreted as interaction terms. Figure 5 plots the respective point estimates and confidence intervals.

As an alternative specification, we again start out from the same event-study approach, but this time normalise the coefficients for each group of firms to January 2020. While the interpretation of this specification is more straight-forward and exactly mirrors the specification in Section

2.3, it relies heavily on the firm's relative performance in the anchor month January 2020 (see Figures C3 for the results).

Finally, we are interested in the network position's relevance for the pass-through of shocks to import and export markets. Here we run the specification from Section 3.4 but interact the shock measures with the respective network position measure of choice N_{it}. The results are presented in Figure C4.

4.2 Results

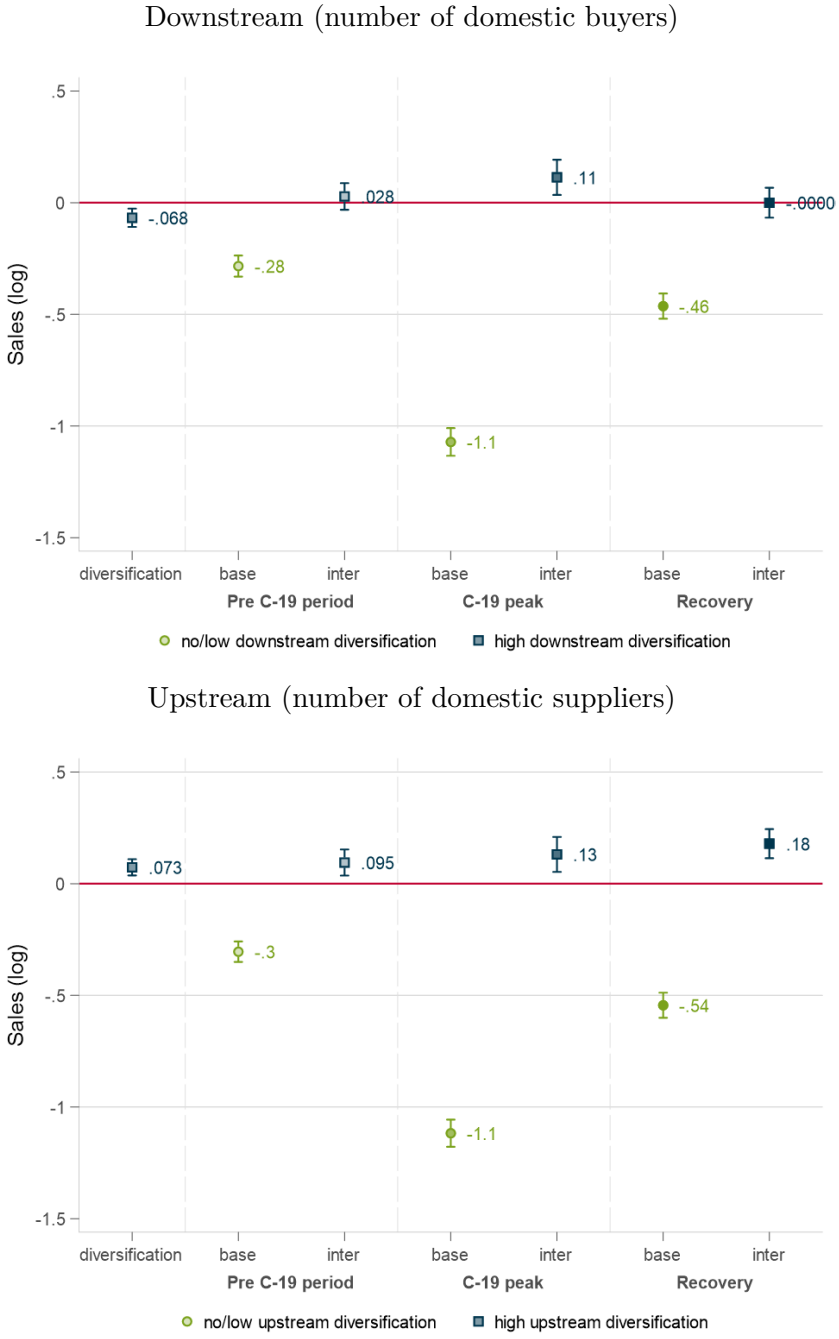
Diversification

We find that firms with a greater degree of downstream diversification face a less drastic downturn during the peak of the crisis (top panel of Figure 5). Firms with below median diversification see their sales drop by an average of 67 percent during the peak months, while the sales of firms with a high degree of diversification drop by an average of 63 percent. Firms with more upstream diversification recover more strongly (bottom panel of Figure 5). The strong positive effects are primarily driven by the firm trajectory in the last quarter of 2020 and the first quarter of 2021 (see dashed blue line in the right top row panel of Figure C3), when stories of supply chain backlogs started to make headlines worldwide. Average sales of firms with high upstream diversification decline by 30 percent relative to the pre-COVID period in comparison to a 42 percent decline for the less diversified firms.[38]

Both estimates hinge on the assumption that the outcomes of more and less diversified firms followed a parallel trend prior to the COVID-19 crisis. We do not see any meaningful diverging pre-trends in the event study plots of Figure C3 for either upstream and downstream diversification, and we cannot reject the null that the coefficient for downstream diversified firms is zero. However, when we estimate specification 2 for firms with a high degree of upstream diversification, the pre-COVID coefficient is significantly different from zero at the 5-percent level. While the effect size is almost double during the recovery phase and quite substantial in economic terms, we cannot entirely rule out the possibility of differential pre-trends driving the upstream results.

[38] In Appendix C.1, we compare the size of the effects of the diversification of upstream supply chains to the trajectory of firms with high levels of inventory. Both are very similar in size. The estimated difference in firm-level outcomes for firms with high pre-crisis levels of inventory is, further, very close to the estimates in Lafrogne-Joussier et al. (2023). Lafrogne-Joussier et al. (2023) focus on export volumes of French exporters as they faced supply issues during the initial lockdown in China in 2020.

Figure 5: Supply chain diversification and firm sales during the crisis and recovery phase



The above graphs present the results from estimating Equation 2. We control for firm age, share of sales to final domestic demand, share of highly diversified firms in the firm's own 4-digit sector, and import and export status. The pre-COVID-19 (C-19) phase corresponds to November 2019 to March 2020, the COVID-19 peak is April to June 2020, and the recovery July 2020 to March 2021.

Figure 6 plots the results for diversification on the intensive margin. While we again struggle to rule out differential pre-trends, the results largely mirror those for diversification on the extensive margin. Conditional on the number of buyers, firms with a larger concentration of sales among their buyers faced a more drastic decline in their sales during the crisis peak.

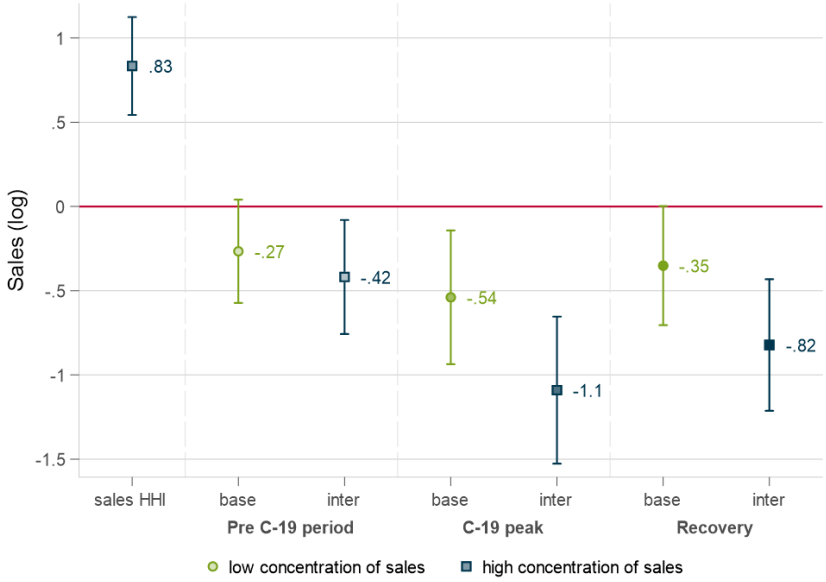
Finally, we interacted our proposed measures for supply chain diversification with the firm's

direct and indirect exposure to international shocks (see Section 3.4). Unsurprisingly, the response of firm sales to international shocks is more pronounced for less diversified firms than for their highly diversified peers.[39] Assuming a linear relationship, this implies that firms can benefit more from positive shocks but are also more vulnerable to negative ones. Note that the proposed specification, following Borusyak et al. (2022), controls for the firm's total exposure (the shares) to the shock at any given point (see Section 3.4). However, we are unable to provide clear insights as to whether the results are primarily driven by (i) a change in the composition of the sources of exposure (a firm's total import share might remain constant, but now purchases it from two suppliers instead of one) or (ii) the firm's ability to respond better to the shock as a result of having a more diversified network.

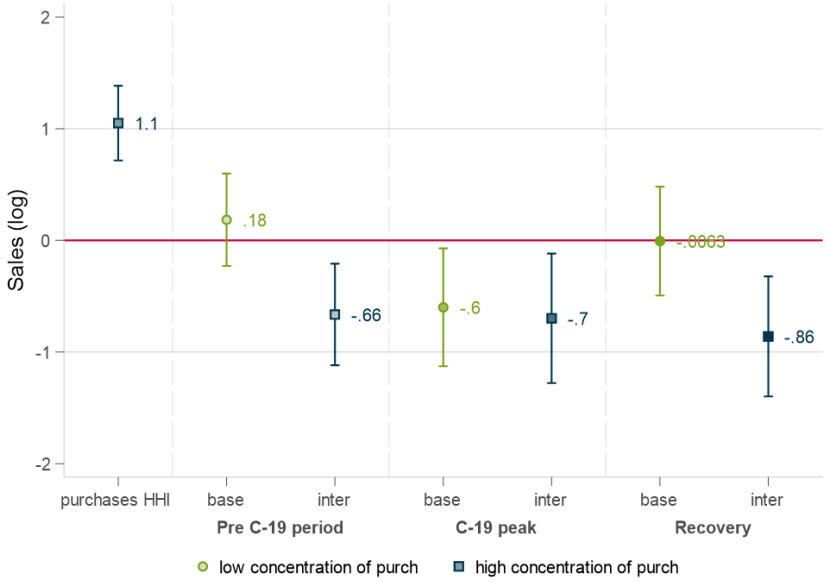
[39] Unfortunately, we lack the power to detect meaningful effects when interact all of the shock measures and network measures with COVID-period dummies.

Figure 6: Concentration of sales and purchases (HHI) and firm sales during the crisis and recovery phase

Domestic sales



Domestic purchases



The above graphs present the results from estimating Equation 2. We controlled for firm age, share of sales to final domestic demand, the average concentration of sales/purchases in the firm's own 4-digit sector, and import and export status. The pre-C-19 phase corresponds to the period from November 2019 to March 2020, the C-19 peak is from April to June 2020, and the recovery is from July 2020 to March 2021. We further control for diversification along the extensive margin.

Number of upstream and downstream sectors (complexity)

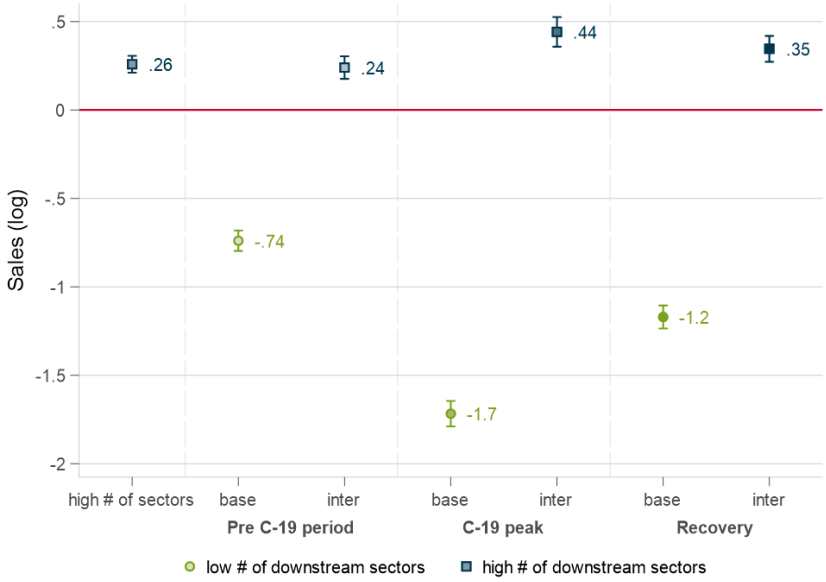
Looking at the number of sectors the firm purchases from or supplies to, the coefficients plotted in Figure 7 suggest a very similar story for complexity relative to diversification. Firms with

above-median complexity relative to their peers in the same 4-digit sector fare better during the pandemic. Crucially, however, they are already on a favourable trend in the pre-pandemic period. Therefore, the results suggest that the observed patterns are, if anything, indicative of a complex supplier network serving as a proxy for a number of relevant firm characteristics, such as high productivity and managerial capital.[40] To test for the robustness of the results, we again draw on the event-study specification and normalise all coefficients to January 2020. Using this approach the results suggest a parallel pre-trend for firms with above and below median supply chain complexity. The bottom left panel of Figure C3 suggests that, especially during the peak of the crisis, firms selling to a larger number of 4-digit sectors face a smaller loss in their sales. One potential explanation is that selling to more downstream sectors serves as a form of diversification, which helps firms smooth the shock in times of a severe demand shock. While the results leave room for different interpretations, they also highlight the need to test the sensitivity of the results using different base periods.

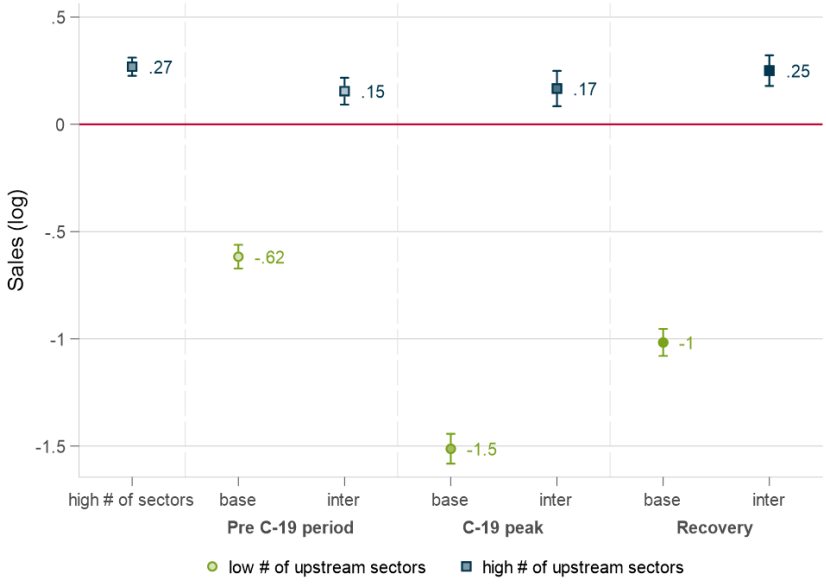
[40] Sheffi and Rice Jr (2005); Sheffi (2015) argue that more complex supply chains require firms to pay more attention to vulnerabilities and strategically invest in enhanced risk management capabilities. The results could thus reflect better preparedness of firms with more complex supply chains.

Figure 7: Supply chain complexity and resilience

Downstream (number of downstream 4-digit sectors)



Upstream (number of upstream 4-digit sectors)



The above graphs present the results from estimating Equation 2. We controlled for firm age, share of sales to final domestic demand, share of firms with above-median supply chain complexity in the firm's own 4-digit sector, and import and export status. The pre-C-19 phase corresponds to November 2019 to March 2020, the C-19 peak is within the period from April to June 2020, and the recovery is from July 2020 to March 2021.

5 Conclusion

We combine customs records with granular data on Kenya's domestic network of formal firms to map not only direct but, importantly, also indirect links of firms to international supply chains through domestic suppliers. Our findings reveal that only nine percent of Kenya's formal

firms source a significant amount of their inputs from abroad, and only five percent sell more than a quarter to international markets - either directly or indirectly through the domestic network. However, these firms are crucial for the economy, both in terms of their turnover and employment and their connections to domestic suppliers and buyers. This finding mitigates a widespread concern that firms with links to international supply chains - or more specifically, global value chains - in lower income economies remain largely separate from domestic supply chains (Amendolagine et al., 2019; Gereffi et al., 2005). Our analysis shows that shocks to the demand and supply of goods in international markets are passed on to domestic trade partners. While favourable import shocks helped firms recover from the COVID-19 crisis more swiftly, negative shocks during the peak of the crisis had adverse effects. This highlights the fact that links to international markets come with both opportunities and vulnerabilities. Moreover, our results suggest that international trade shocks can change the composition of the domestic supply chain, with firms responding to positive import shocks by concentrating their purchases on fewer domestic suppliers in pre-COVID times. Conversely, a stronger bounce back in the world supply of imported goods during the COVID-19 crisis led to a larger number of domestic suppliers being crowded in. Our analysis focuses on the short-run pass-through. A natural extension would be to look at medium- and long-run dynamics of the participation of firms in international supply chains and how these shape their domestic network.

References

Abala, D. O. (2013). Determinants of manufactured exports in kenya: an application of control function approach. *DBA Africa management review*, 3(1).

Abel-Koch, J. (2013). Who uses intermediaries in international trade? evidence from firm-level survey data. *The World Economy*, 36(8):1041–1064.

Acemoglu, D., Carvalho, V. M., Ozdaglar, A., and Tahbaz-Salehi, A. (2012). The network origins of aggregate fluctuations. *Econometrica*, 80(5):1977–2016.

Adão, R., Carrillo, P., Costinot, A., Donaldson, D., and Pomeranz, D. (2022). Imports, exports, and earnings inequality: Measures of exposure and estimates of incidence. *The Quarterly Journal of Economics*, 137(3):1553–1614.

Ahn, J., Khandelwal, A. K., and Wei, S.-J. (2011). The role of intermediaries in facilitating trade. *Journal of International Economics*, 84(1):73–85.

Alfaro-Urena, A., Manelici, I., and Vasquez, J. P. (2022). The effects of joining multinational supply chains: New evidence from firm-to-firm linkages. *The Quarterly Journal of Economics*, 137(3):1495–1552.

Amendolagine, V., Presbitero, A. F., Rabellotti, R., and Sanfilippo, M. (2019). Local sourcing in developing countries: The role of foreign direct investments and global value chains. *World Development*, 113:73–88.

Arkolakis, C., Huneeus, F., and Miyauchi, Y. (2023). Spatial production networks. Technical report, National Bureau of Economic Research.

Awori, K., Allela, M. A., Nyairo, S., Maina, S. C., and O'Neill, J. (2022). " it's only when somebody says a tool worked for them that i believe it will work for me": Socio-tecture as a lens for digital transformation. *Proceedings of the ACM on Human-Computer Interaction*, 6(CSCW2):1–24.

Barrot, J.-N., Grassi, B., and Sauvagnat, J. (2021). Sectoral effects of social distancing. *AEA Papers and Proceedings*, 111:277–81.

Barrot, J.-N. and Sauvagnat, J. (2016). Input specificity and the propagation of idiosyncratic shocks in production networks. *The Quarterly Journal of Economics*, 131(3):1543–1592.

Bassett, H. R., Lau, J., Giordano, C., Suri, S. K., Advani, S., and Sharan, S. (2021). Preliminary lessons from covid-19 disruptions of small-scale fishery supply chains. *World Development*, 143:105473.

Bergquist, L. F. and Dinerstein, M. (2020). Competition and entry in agricultural markets: Experimental evidence from kenya. *American Economic Review*, 110(12):3705–3747.

Bernard, A. B., Eaton, J., Jensen, J. B., and Kortum, S. (2003). Plants and productivity in international trade. *American economic review*, 93(4):1268–1290.

Bernard, A. B., Grazzi, M., and Tomasi, C. (2015). Intermediaries in international trade: Products and destinations. *Review of Economics and Statistics*, 97(4):916–920.

Bernard, A. B. and Jensen, J. B. (1999). Exceptional exporter performance: cause, effect, or both? *Journal of international economics*, 47(1):1–25.

Bernard, A. B. and Jensen, J. B. (2004). Why some firms export. *Review of economics and Statistics*, 86(2):561–569.

Bernard, A. B., Jensen, J. B., and Lawrence, R. Z. (1995). Exporters, jobs, and wages in us manufacturing: 1976-1987. *Brookings papers on economic activity. Microeconomics*, 1995:67–119.

Bernard, A. B. and Moxnes, A. (2018). Networks and trade. *Annual Review of Economics*, 10:65–85.

Berthou, A. and Stumpner, S. (2022). Trade under lockdown. *Banque de France Working Paper*, No. 867.

Boehm, C. E., Flaaen, A., and Pandalai-Nayar, N. (2019). Input linkages and the transmission of shocks: Firm-level evidence from the 2011 tōhoku earthquake. *Review of Economics and Statistics*, 101(1):60–75.

Boehm, J. and Sonntag, J. (2023). Vertical integration and foreclosure: Evidence from production network data. *Management Science*, 69(1):141–161.

Borusyak, K., Hull, P., and Jaravel, X. (2022). Quasi-experimental shift-share research designs. *The Review of Economic Studies*, 89(1):181–213.

Brooks, W., Donovan, K., Johnson, T. R., and Oluoch-Aridi, J. (2022). Cash transfers as a response to covid-19: Experimental evidence from kenya. *Journal of Development Economics*, 158:102929.

Bunn, P., Altig, D., Anayi, L., Barrero, J. M., Bloom, N., Davis, S. J., Meyer, B., Mihaylov, E., Mizen, P., and Thwaites, G. (2021). Covid-19 uncertainty: A tale of two tails. *University of Chicago, Becker Friedman Institute for Economics Working Paper*, (2021-135).

Carvalho, V. M., Nirei, M., Saito, Y. U., and Tahbaz-Salehi, A. (2021). Supply chain disruptions: Evidence from the great east japan earthquake. *The Quarterly Journal of Economics*, 136(2):1255–1321.

Carvalho, V. M. and Tahbaz-Salehi, A. (2019). Production networks: A primer. *Annual Review of Economics*, 11:635–663.

Chacha, P., Edwards, L., et al. (2018). Imported inputs, government support and performance of manufacturing exporters. *ERSA working paper*, 740.

Chacha, P., Kirui, B., and Wiedemann, V. (2022). Mapping kenya's production network transaction by transaction. *Working Paper available at SSRN 4315810*.

Chacha, P. W. and Edwards, L. (2019). Exporting to fragile states in africa: Firm-level evidence. *Review of Development Economics*, 23(3):1177–1201.

Chacha, P. W., Edwards, L., et al. (2017). The growth dynamics of new export entrants in kenya: a survival analysis. *ERSA working paper*, 712.

Coulibaly, R., Moreno, H., Akiko, S.-E., and Traore, N. (2022). African firms in global value chains: What can we learn from firm-level data in cameroon and côte d'ivoire? *AERC Working Paper*, GVC-009.

Del Prete, D., Giovannetti, G., and Marvasi, E. (2017). Global value chains participation and productivity gains for north african firms. *Review of World Economics*, 153(4):675–701.

Demir, B., Javorcik, B., Michalski, T. K., and Ors, E. (2022). Financial Constraints and Propagation of Shocks in Production Networks. *The Review of Economics and Statistics*, pages 1–46.

Dhyne, E. and Duprez, C. (2015). Has the crisis altered the belgian economy's dna? *Economic Review*, (ii):31–43.

Dhyne, E., Kikkawa, A. K., Mogstad, M., and Tintelnot, F. (2021). Trade and domestic production networks. *The Review of Economic Studies*, 88(2):643–668.

Dix-Carneiro, R., Goldberg, P. K., Meghir, C., and Ulyssea, G. (2021). Trade and informality in the presence of labor market frictions and regulations. Technical report, National Bureau of Economic Research.

Egger, D., Miguel, E., Warren, S. S., Shenoy, A., Collins, E., Karlan, D., Parkerson, D., Mobarak, A. M., Fink, G., Udry, C., et al. (2021). Falling living standards during the covid-19 crisis: Quantitative evidence from nine developing countries. *Science advances*, 7(6):eabe0997.

Foster, C., Graham, M., Mann, L., Waema, T., and Friederici, N. (2018). Digital control in value chains: Challenges of connectivity for east african firms. *Economic Geography*, 94(1):68–86.

Freund, C., Mattoo, A., Mulabdic, A., and Ruta, M. (2022). Natural disasters and the reshaping of global value chains. *IMF Economic Review*, 70(3):590–623.

Fujiy, B. C., Ghose, D., and Khanna, G. (2022). Production networks and firm-level elasticities of substitution. *STEG Working Paper Series*, WP027.

Gabaix, X. (2011). The granular origins of aggregate fluctuations. *Econometrica*, 79(3):733–772.

Gereffi, G., Humphrey, J., and Sturgeon, T. (2005). The governance of global value chains. *Review of international political economy*, 12(1):78–104.

Granér, M. and Isaksson, A. (2009). Firm efficiency and the destination of exports: evidence from kenyan plant-level data. *The Developing Economies*, 47(3):279–306.

Grant, M. and Startz, M. (2022). Cutting out the middleman: The structure of chains of intermediation. Technical report, National Bureau of Economic Research.

Greenaway, D. and Kneller, R. (2007). Firm heterogeneity, exporting and foreign direct investment. *The Economic Journal*, 117(517):F134–F161.

Hansen, U. E., Nygaard, I., Morris, M., and Robbins, G. (2022). Servicification of manufacturing in global value chains: Upgrading of local suppliers of embedded services in the south african market for wind turbines. *The Journal of Development Studies*, 58(4):787–808.

Hummels, D., Jørgensen, R., Munch, J., and Xiang, C. (2014). The wage effects of offshoring: Evidence from danish matched worker-firm data. *American Economic Review*, 104(6):1597–1629.

Huneeus, F. (2018). Production network dynamics and the propagation of shocks. *Job Market Paper*.

Kaberia, S. K. and Muathe, S. (2021). Effect of covid-19 pandemic on performance of women owned micro, small and medium enterprises in kenya. *Int'l J. Soc. Sci. Stud.*, 9:7.

Kansiime, M. K., Tambo, J. A., Mugambi, I., Bundi, M., Kara, A., and Owuor, C. (2021). Covid-19 implications on household income and food security in kenya and uganda: Findings from a rapid assessment. *World development*, 137:105199.

Kashiwagi, Y., Todo, Y., and Matous, P. (2021). Propagation of economic shocks through global supply chains—evidence from hurricane sandy. *Review of International Economics*, 29(5):1186–1220.

Kinyanjui, G., Rubatsimbira, D., and Wiedemann, V. (2023). Changing mobility patterns and food price dynamics during the covid-19 pandemic in kenya and uganda. *Working Paper*.

Korovkin, V. and Makarin, A. (2022). Production networks and war: Evidence from ukraine. *Available at SSRN 3969161*.

Kremer, M. (1993). The o-ring theory of economic development. *The Quarterly Journal of Economics*, 108(3):551–575.

Lafrogne-Joussier, R., Martin, J., and Mejean, I. (2023). Supply shocks in supply chains: Evidence from the early lockdown in china. *IMF economic review*, 71(1):170–215.

Lee, H. L., Padmanabhan, V., and Whang, S. (1997). Information distortion in a supply chain: The bullwhip effect. *Management science*, 43(4):546–558.

Macchiavello, R. and Morjaria, A. (2015). The value of relationships: evidence from a supply shock to kenyan rose exports. *The American Economic Review*, 105(9):2911–2945.

Majune, S. K. (2020). The effect of lockdown policies on international trade flows from developing countries: Event study evidence from kenya.

Majune, S. K., Moyi, E., and Gathiaka, K. (2020). Explaining export duration in kenya. *South African Journal of Economics*, 88(2):204–224.

Melitz, M. J. (2003). The impact of trade on intra-industry reallocations and aggregate industry productivity. *econometrica*, 71(6):1695–1725.

Metters, R. (1997). Quantifying the bullwhip effect in supply chains. *Journal of operations management*, 15(2):89–100.

Minten, B., Vandeplas, A., and Swinnen, J. (2012). Regulations, brokers, and interlinkages: The institutional organization of wholesale markets in india. *Journal of Development Studies*, 48(7):864–886.

Navas-Alemán, L. (2011). The impact of operating in multiple value chains for upgrading: the case of the brazilian furniture and footwear industries. *World development*, 39(8):1386–1397.

Ndubuisi, G. and Owusu, S. (2022). Wage effects of global value chains participation and position: An industry-level analysis1. *The Journal of International Trade & Economic Development*, 31(7):1086–1107.

Newman, M. (2018). *Networks*. Oxford university press.

Nordhagen, S., Igbeka, U., Rowlands, H., Shine, R. S., Heneghan, E., and Tench, J. (2021). Covid-19 and small enterprises in the food supply chain: Early impacts and implications for longer-term food system resilience in low-and middle-income countries. *World Development*, 141:105405.

Pape, U. J., Delius, A., Khandelwal, R., and Gupta, R. (2020). Socio-economic impacts of covid-19 in kenya : Results update. Technical report, World Bank Group, Washington, D.C.

Pavcnik, N. (2002). Trade liberalization, exit, and productivity improvements: Evidence from chilean plants. *The Review of economic studies*, 69(1):245–276.

Rankin, N., Söderbom, M., and Teal, F. (2006). Exporting from manufacturing firms in sub-saharan africa. *Journal of African Economies*, 15(4):671–687.

Reardon, T., Liverpool-Tasie, L. S. O., and Minten, B. (2021). Quiet revolution by smes in the midstream of value chains in developing regions: wholesale markets, wholesalers, logistics, and processing. *Food Security*, 13:1577–1594.

Sargent, T. J. and Stachurski, J. (2022). Economic networks: Theory and computation. *arXiv preprint arXiv:2203.11972*.

Sheffi, Y. (2015). *The power of resilience: How the best companies manage the unexpected*. mit Press.

Sheffi, Y. and Rice Jr, J. B. (2005). A supply chain view of the resilient enterprise. *MIT Sloan management review*.

Shupler, M., Mwitari, J., Gohole, A., Cuevas, R. A. d., Puzzolo, E., Čukić, I., Nix, E., and Pope, D. (2020). Covid-19 lockdown in a kenyan informal settlement: Impacts on household energy and food security. *medRxiv*.

Startz, M. (2021). The value of face-to-face: Search and contracting problems in nigerian trade. *Working Paper*.

Türkcan, K., Majune Kraido, S., and Moyi, E. (2022). Export margins and survival: A firm-level analysis using kenyan data. *South African Journal of Economics*, 90(2):149–174.

Wagner, J. (2007). Exports and productivity: A survey of the evidence from firm-level data. *World Economy*, 30(1):60–82.

Yao, Y., Duan, Y., and Huo, J. (2021). On empirically estimating bullwhip effects: measurement, aggregation, and impact. *Journal of Operations Management*, 67(1):5–30.

Appendices

Appendix A Additional material for Section 2 - data and context

A.1 Additional descriptive statistics

Table A1: Sector-level breakdown of total sales (2019)

Sectors	%
Wholesale & Retail	22.88
Manufacturing	21.44
Electricity & Gas	16.37
Information & Communication	8.20
Transportation & Storage	8.00
Construction	7.07
Hospitality	2.93
Administrative & Support Services	2.32
Agriculture, Forestry, & Fishing	2.20
Professional, Scientific & Technical	1.95
Total	93.37

This table shows the share of aggregate sales for the ten biggest sectors by their total domestic sales volume.

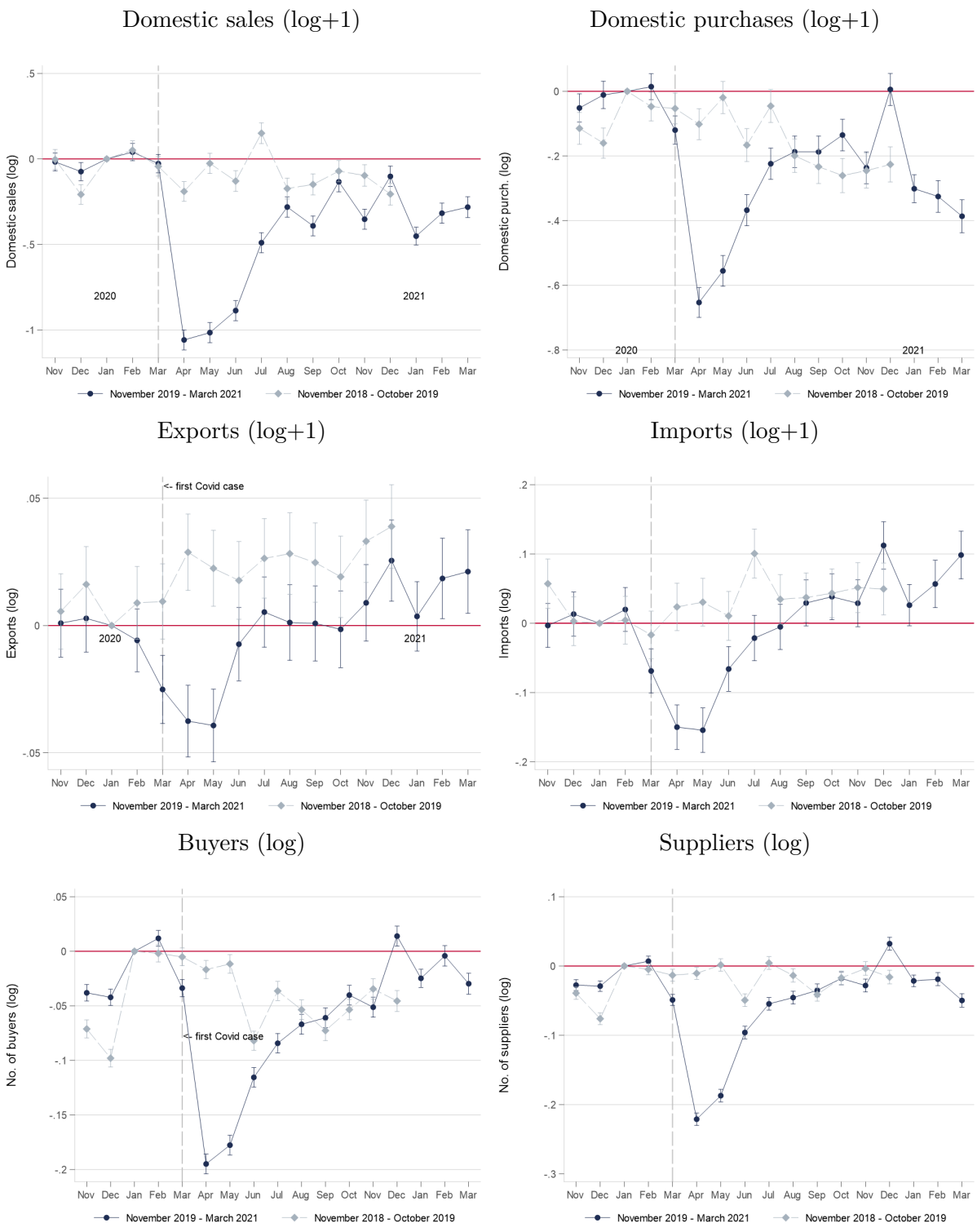
Table A2: Summary statistics on inter-firm relationships between 2015 and 2020

Year	Firms	Total sales (in bn. KES)	Relationships	Firm-to-firm sales (in % of total sales)
2015	31,684	4,857.5	886,940	49.3
2016	36,920	5,881.1	1,134,159	49.5
2017	40,677	6,218.8	1,204,754	50.6
2018	44,997	6,594.0	1,332,150	49.0
2019	48,697	6,828.3	1,528,410	56.3
2020	49,955	6,651.1	1,528,109	60.0

This table shows the number of firms in the production network, firm-to-firm relationships, the aggregate sales volume, as well as the share of aggregate domestic sales that is linked to transactions between registered entities.

A.2 Comparison of firm dynamics during the COVID-19 crisis with 2019 trends

Figure A1: Major firm-level outcomes during the COVID-19 crisis vs 2019 trends

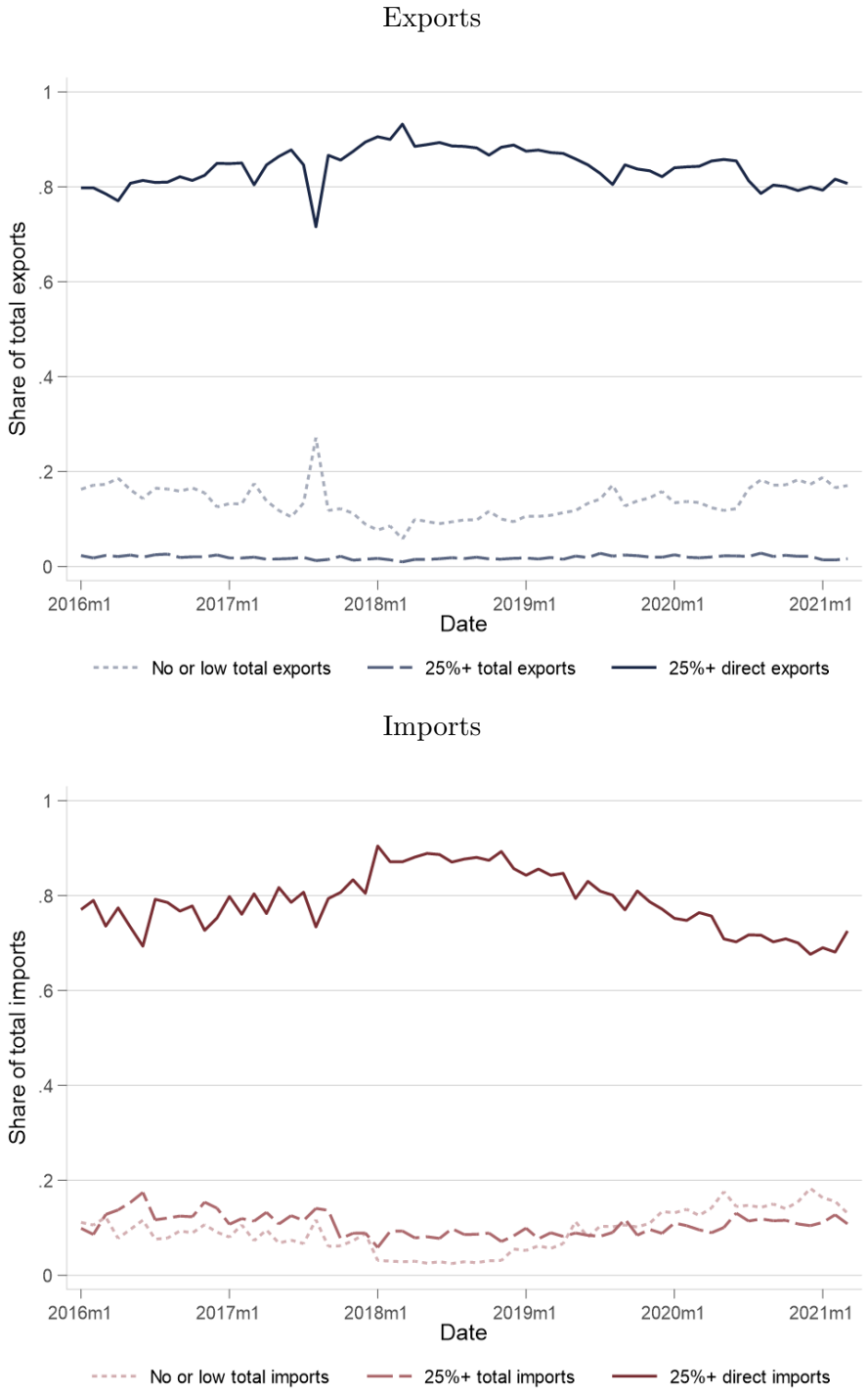


In the above graphs we regressed firm-level outcomes on a series of monthly time dummies. We further included firm- and month-fixed effects and normalised the coefficient for January 2020 to zero. Standard errors are clustered at the firm level, and the error bars show the 95-percent confidence intervals. The regressions include data from April 2015 to March 2021.

Appendix B Additional material for Section 3 - Links to international supply chains

B.1 Firm-level exposure to international markets and contribution to aggregate imports and exports

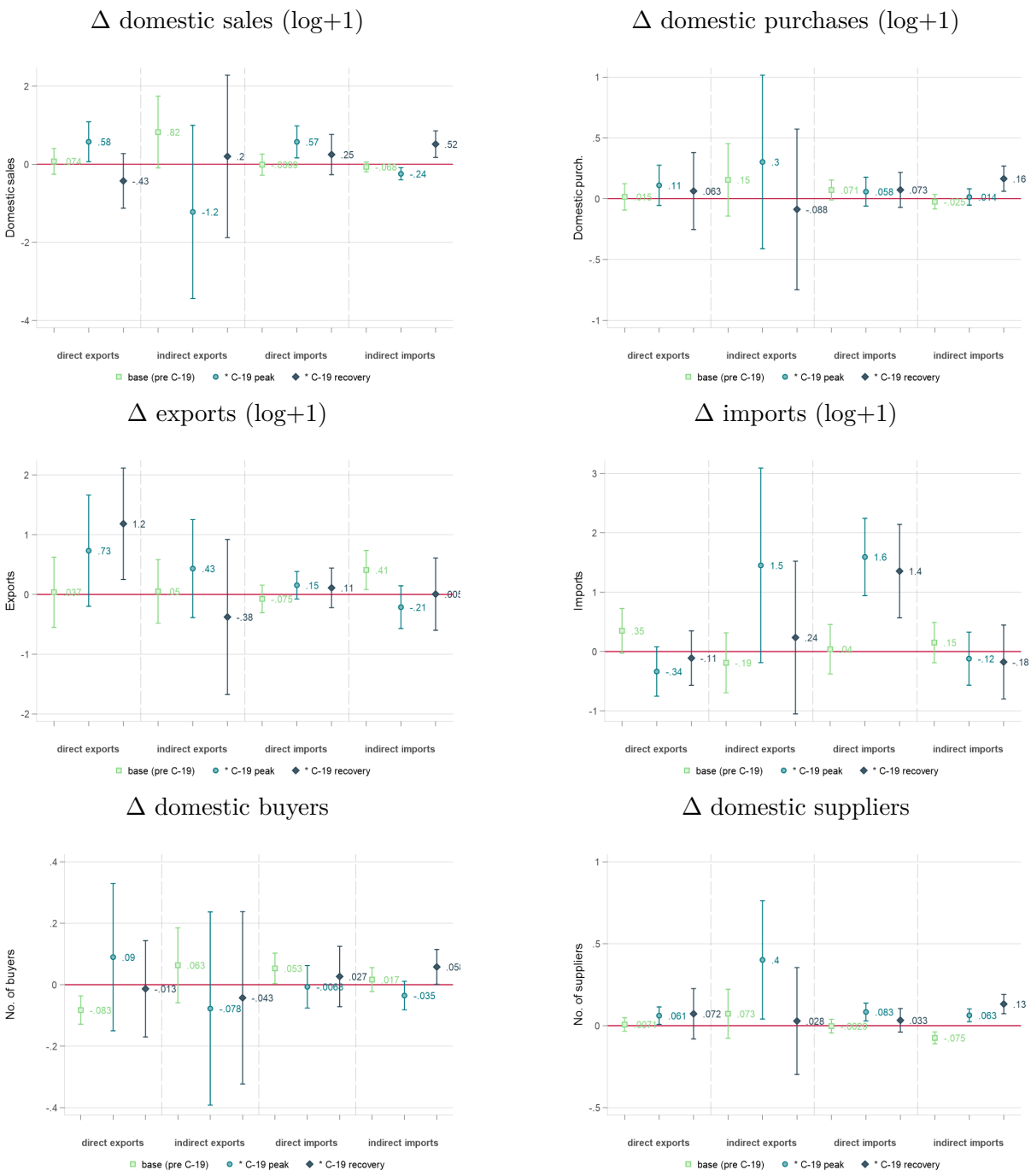
Figure B1: Share of total exports and imports attributed to firms with varying exposure to international markets



The above graph plots the share of aggregate imports and exports that can be attributed to (i) firms with no or low exposure to international import/export markets, (ii) firms with high indirect exposure to international markets, and lastly (iii) firms with high levels of direct exports and imports specified in Section 3.2.

B.2 Firm response to international shocks

Figure B2: Major firm-level outcomes during the COVID-19 crisis vs 2019 trends



The results present the estimation of Equation 1 regressing the respective shock measures on the change in logged firm-level outcomes relative to the same month in the previous year as well as firm- and sector-date-fixed effects. Here we further interact the shock measures with dummies that are equal to one for the dates April to June 2020 (C-19 peak) and July 2020 to March 2021 (C-19 recovery). The coefficients for the interaction terms thus need to be interpreted relative to the respective coefficients estimated for the pre-COVID period. Standard errors are clustered at the firm level. We further control for the sum of shares and firm age (log) weighted by the sum of shares. The regressions include data from April 2018 to March 2021.

B.3 Properties of world demand and supply shocks and country-product exposure shares ω_{cp}

To estimate the pass-through of international shocks to world demand and supply we rely on variation at the country-product-level. Firms in our sample export close to 1,000 products to 128 different countries and import close to 1,200 products from 130 countries. The asymptotic properties of the shift-share estimator hinge on a large enough sample size (Borusyak et al., 2022), which in a shift-share world implies (i) sufficient variation in world demand and supply shocks, and (ii) sufficiently dispersed exposure shares. Table B1 summarises key properties of the empirical variation we observe for the shocks and shares during our sample period. The reported average, median and maximum shares ω_{pct} are averages across all firms within a country-product-month cell. We do not observe a high concentration in the exposure shares, which pins down our effective sample size (Borusyak et al., 2022). Unsurprisingly, the observed concentration is, however, much higher for exports than for imports with an effective sample size of 11,098 relative to 58,074. Turning to the shocks to world demand and supply, we find sufficient variation in the shock sizes. Import and export shocks are on average negative, which is driven by the large negative shocks we observe during the COVID-19 period. A concern is that these shocks are highly correlated due to the aggregate nature of pandemic-related shocks. Following Borusyak et al. (2022) we compute the intra-class correlation coefficient using a hierarchical decomposition of the within-month variation. We are primarily concerned about a high degree of within-country correlation of shocks and therefore follow a country to country-product hierarchy for the decomposition. The estimates of the model further yield the random effect for a time-invariant country-product component. We find low levels of clustering of the shock residuals at the country level.[41]

[41] As a robustness check we also look at 2020 only, but find only a moderate increase in clustering. The clustering for the time-invariant component doubles but is still sufficiently small.

Table B1: Shocks and shares summary statistics

	Exports	Imports
Countries	128	130
Products	996	1,197
Country x products	12,244	29,815
Effective sample size (1/HHI of ω_{cpt})	11,098	58,074
Avg. ω_{cpt}	5.00e-06	1.51e-06
Median ω_{cpt}	1.65e-07	1.54e-07
Max ω_{cpt}	.000384	.0000975
Avg. Δ log world demand/supply	-.0205	-.0292
Standard deviation Δ log world demand/supply	1.07	.877
Interquartile range Δ log world demand/supply	.56	.448
Intra-country correlation	.0000533	.0000126
Intra-country-product correlation	.0626	.037

Appendix C Additional material for Section 4 - Robustness checks and extensions looking at the firm's network position and resilience

C.1 The role of inventory levels

Similarly to diversification of a firm's supplier portfolio, inventory levels can serve as a buffer stock for firms to cope with supply chain shortages in the short-run. For a subgroup of firms, we are able to look at the relevance of pre-crisis levels and compare its relevance to the diversification of upstream supply chains.

Measurement

We distinguish between firms with a high inventory to sales ratio in the previous year vs firms with lower inventory levels. Information on inventory is not captured in the VAT data. We therefore merge the data with corporate income tax (CIT) files, which detail the value of the stock of inventory at the end of the firm's fiscal year. We classify firms as high inventory holders if their inventory to sales ratio falls into the top quarter within their 4-digit sector.[42] We exclude any 4-digit sector where inventory holdings of firms in the top quartile is zero. Moreover, only a subset of VAT-paying businesses, those which are also corporate entities, file CIT returns.[43] Our sample size for this section therefore drops from over 48,000 firms to just over 30,000 firms. This subset of firms accounts for 60 percent of the annual VAT sales in 2018. Within the top quartile, the value of inventory held by the median firm is equivalent to 60 days of their average daily sales volume (in non-COVID years).[44]

Results

Firms with high levels of inventory at the end of the previous fiscal year recover more strongly from the shock. During the recovery period their monthly sales are on average 8.6 percentage points higher than for firms with lower levels of inventory in the same sector.[45] The event-study plot in Figure C3 (bottom graph) suggests that this effect can primarily be attributed to a better performance of high-inventory firms in the third quarter of 2020, just after the initial downturn. However, high-inventory firms do not seem to start performing worse once their pre-crisis stock is potentially depleted, which is to be expected a few months into the crisis. A

[42] In an alternative specification we use the median as a cutoff. Here we do not find any difference in the recovery of firms with above-median inventory levels relative to those with lower levels of inventory. We attribute this to the fact that inventory levels of firms that sit just above the median are not very different from firms in the lowest two quartiles for most sectors. Only those in the top quartile differ notably. Our cut-off choice is in line with Lafrogne-Joussier et al. (2023), who classify firms in the top quintile as high-inventory firms.

[43] VAT-paying businesses that do not file CIT are mainly sole proprietors or export processing zones.

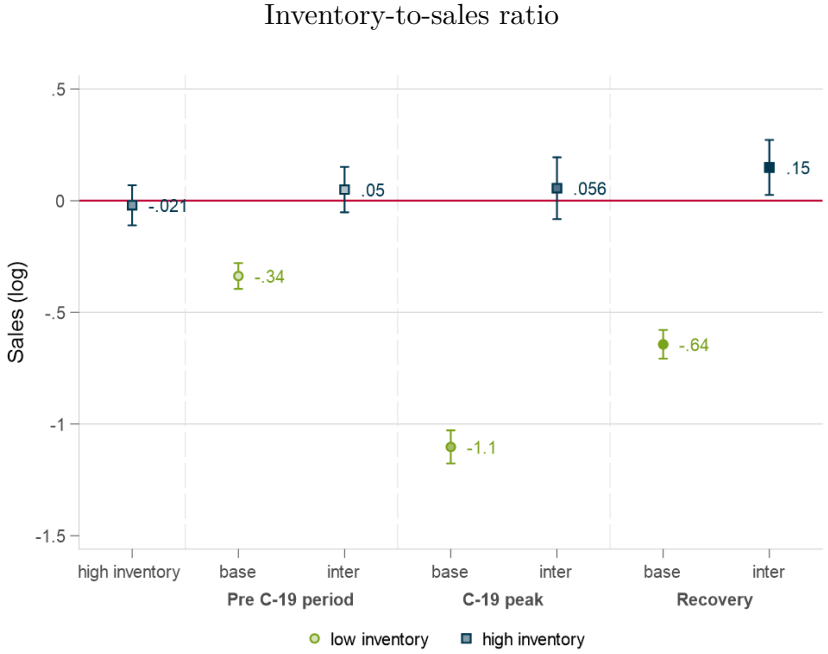
[44] Our findings are robust to ignoring sector heterogeneity in inventory levels and simply using 60 days (=2 months) as a general cut-off for all firms.

[45] Note the log scale of the coefficients in Figure C1.

possible interpretation is that high end-of-year inventory levels not only represent a snapshot in time, but also correlate with the availability of medium- to long-term storage facilities that allow for the holding of buffer stocks. Further, we only look at firm sales as a well-measured outcome rather than productivity or measures that are able to capture potential downsides of inefficiently high inventory levels (Yao et al., 2021). Our estimated difference in trajectories for high-inventory firms is similar to the findings in Lafrogne-Joussier et al. (2023) for French exporters. We closely follow their approach in classifying high and low inventory firms. Lafrogne-Joussier et al. (2023) find that French exporters with high levels of end-of-year inventory export 5.2 percentage points more in the aftermath of the early lockdown period in 2020 in China. Returning to our own setting, the estimate for high-inventory firms is also comparable to the difference observed for firms with a diversified supplier base relative to firms with lower levels of diversification.[46] The last row of Table C3 shows that high inventory firms are also more likely to feature in the group of highly diversified firms. However, there is no 1:1 overlap. While 25 percent of the high-inventory firms are also highly diversified firms, as many as 22 percent of the firms with low diversification also have high inventory levels. In Figure C2, we look at whether firms that feature in both groups drive the overall results. We do not find this to be the case. Inventory levels and diversification of the upstream supply chain seem to operate as independent channels. For the subgroup of firms for which we can look at both indicators at the same time, the effects are limited to the recovery period. This finding is again in line with our interpretation of the initial COVID-19 downturn primarily as an uncertainty and demand shock, while upstream supply chain bottlenecks become more binding during the recovery.

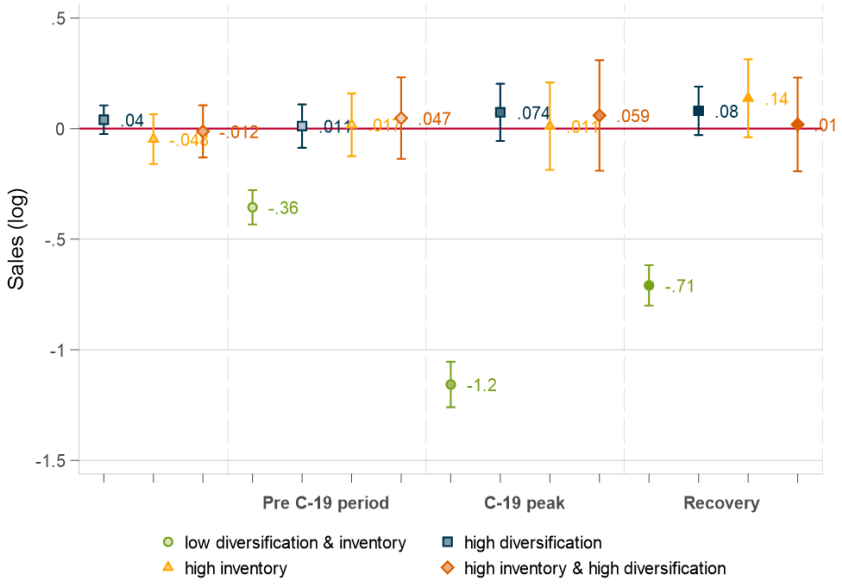
[46] The effect is slightly less for diversification due to higher levels of average sales among the group of firms with lower levels of diversification.

Figure C1: Pre-crisis inventory levels and firm sales during the crisis and recovery phase



The above graphs present the results from estimating Equation 2. We control for firm age, share of sales to final domestic demand, share of high-inventory firms in the firm's own 4-digit sector, and import and export status. The pre-COVID-19 (C-19) phase corresponds to November 2019 to March 2020, the COVID-19 peak is April to June 2020, and the recovery July 2020 to March 2021.

Figure C2: Supply chain diversification and pre-crisis inventory levels



The above graphs present the results from estimating Equation 2. We control for firm age, share of sales to final domestic demand, share of high inventory and highly diversified firms in the firm's own 4-digit sector, and import and export status. The pre-COVID-19 (C-19) phase corresponds to November 2019 to March 2020, the COVID-19 peak is April to June 2020, and the recovery July 2020 to March 2021.

C.2 Balance tables for firms by network characteristic group

Table C1: Firm-level characteristics and 2018 outcomes by upstream diversification

	(1) low diversification		(2) high diversification		T-test Difference
Variable	N	Mean/SE	N	Mean/SE	(1)-(2)
Firm age	16828	11.745	10787	12.582	-0.837***
		(0.072)		(0.093)	
Nairobi or Mombasa based	16828	0.777	10787	0.786	-0.009*
		(0.003)		(0.004)	
Direct exporter	16828	0.042	10787	0.057	-0.015***
		(0.002)		(0.002)	
Direct importer	16828	0.141	10787	0.240	-0.099***
		(0.003)		(0.004)	
Share of dom. sales out. network	16828	0.288	10787	0.191	0.096***
		(0.003)		(0.003)	
Sales (log)	16828	16.355	10787	17.032	-0.677***
		(0.019)		(0.022)	
Purchases (log)	16828	14.977	10787	16.128	-1.150***
		(0.030)		(0.030)	
No. employees	16828	20.891	10787	37.054	-16.163***
		(1.371)		(2.474)	
Value added (log)	14208	15.837	9294	16.224	-0.386***
		(0.016)		(0.021)	
Value added per employee (log)	8579	14.578	7156	14.383	0.194***
		(0.018)		(0.017)	

Notes: The value displayed for t-tests are the differences in the means across the groups. ***, **, and * indicate significance at the 1, 5, and 10 percent critical level.

Table C2: Firm-level characteristics and 2018 outcomes by downstream diversification

Variable	(1) low diversification N	(1) low diversification Mean/SE	(2) high diversification N	(2) high diversification Mean/SE	T-test Difference (1)-(2)
Firm age	17683	11.455	13905	11.764	-0.309***
		(0.070)		(0.078)	
Nairobi or Mombasa based	17683	0.773	13905	0.740	0.033***
		(0.003)		(0.004)	
Direct exporter	17683	0.037	13905	0.055	-0.017***
		(0.001)		(0.002)	
Direct importer	17683	0.167	13905	0.174	-0.007*
		(0.003)		(0.003)	
Share of dom. sales out. network	17683	0.325	13905	0.378	-0.053***
		(0.003)		(0.004)	
Sales (log)	17683	16.224	13905	16.851	-0.627***
		(0.019)		(0.020)	
Purchases (log)	17683	14.974	13905	16.187	-1.213***
		(0.027)		(0.022)	
No. employees	17683	13.565	13905	40.056	-26.490***
		(0.612)		(2.531)	
Value added (log)	14638	15.746	11720	16.124	-0.378***
		(0.016)		(0.019)	
Value added per employee (log)	8497	14.593	8600	14.403	0.190***
		(0.018)		(0.016)	

Notes: The value displayed for t-tests are the differences in the means across the groups. ***, **, and * indicate significance at the 1, 5, and 10 percent critical level.

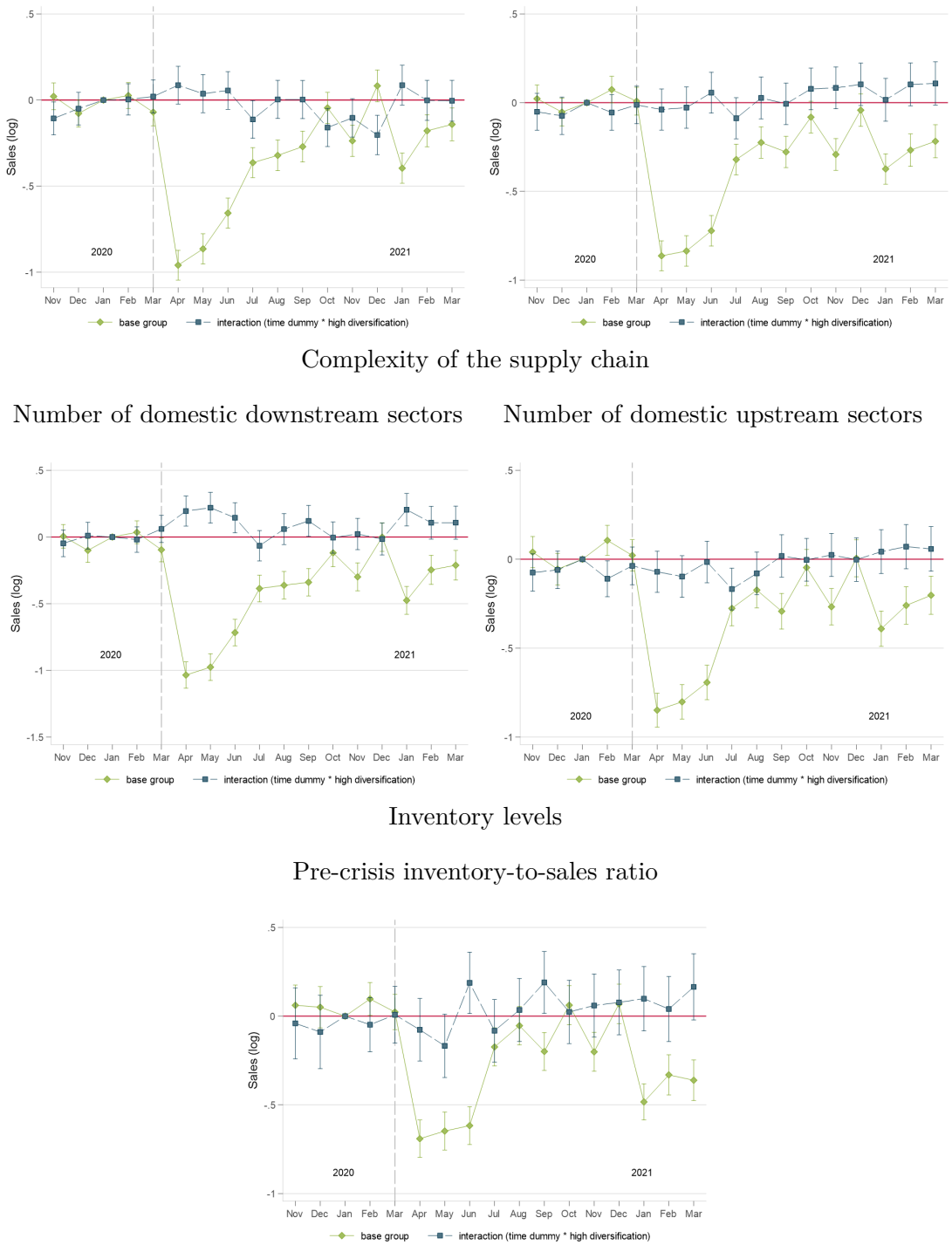
Table C3: Firm-level characteristics and 2018 outcomes by inventory levels

Variable	(1) low inventories N	(1) low inventories Mean/SE	(2) high inventories N	(2) high inventories Mean/SE	T-test Difference (1)-(2)
Firm age	13221	10.300	4046	12.455	-2.155***
		(0.072)		(0.149)	
Nairobi or Mombasa based	13222	0.744	4046	0.728	0.016**
		(0.004)		(0.007)	
Direct exporter	13222	0.044	4046	0.045	-0.001
		(0.002)		(0.003)	
Direct importer	13222	0.184	4046	0.277	-0.093***
		(0.003)		(0.007)	
Share of dom. sales out. network	13222	0.378	4046	0.357	0.022***
		(0.004)		(0.007)	
Sales (log)	13222	16.585	4046	16.619	-0.034
		(0.022)		(0.034)	
Purchases (log)	13222	15.506	4046	15.995	-0.489***
		(0.032)		(0.045)	
No. employees	13222	19.305	4046	24.310	-5.005**
		(0.852)		(2.250)	
Value added (log)	11196	15.895	3146	15.813	0.082**
		(0.019)		(0.036)	
Value added per employee (log)	6991	14.577	2362	14.237	0.340***
		(0.019)		(0.030)	
High upstream diversification	10854	0.376	3453	0.481	-0.105***
		(0.005)		(0.009)	
High downstream diversification	12518	0.447	3915	0.499	-0.052***
		(0.004)		(0.008)	

Notes: The value displayed for t-tests are the differences in the means across the groups. ***, **, and * indicate significance at the 1, 5, and 10 percent critical level.

C.3 Firm-level outcomes relative to January 2020 by firm network characteristics

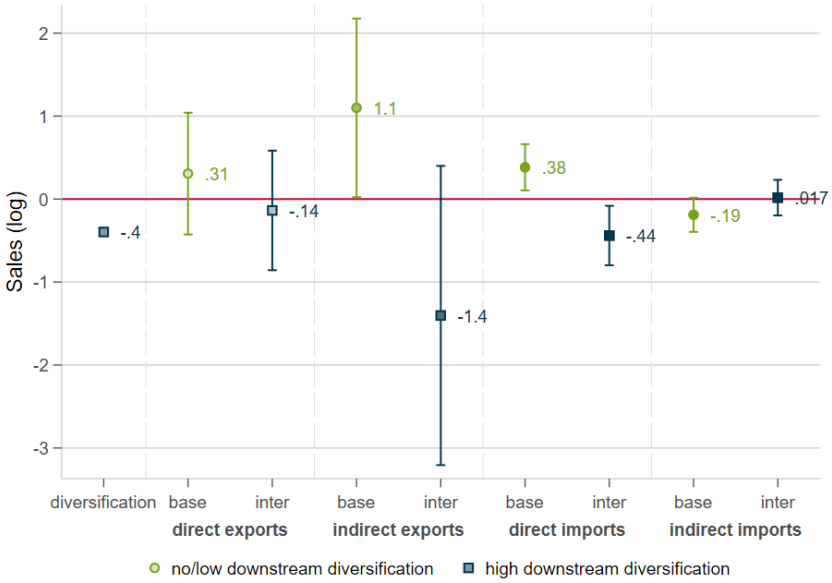
Figure C3: Domestic network position and firm sales during the crisis and recovery phase



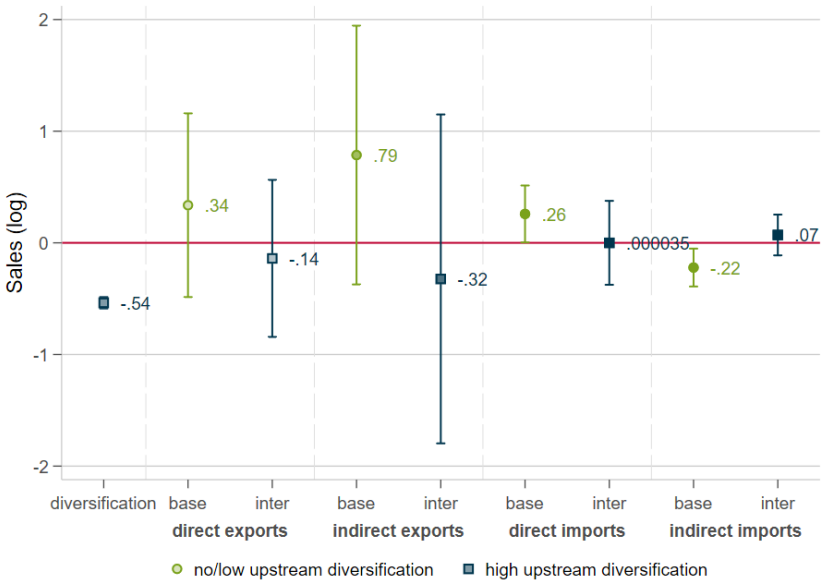
In the above graphs we regressed firm-level outcomes on a series of monthly time dummies (solid green line). We further interacted the time dummies with the respective measure for the firm's network position or inventory levels (dashed blue line). We included firm and month fixed effects and normalised the coefficient for January 2020 to zero. Standard errors are clustered at the firm level and the error bars show the 95-percent confidence intervals. The regressions included data from April 2015 to March 2021.

Figure C4: Supply chain diversification and the response of firm sales to international shocks

Downstream (number of domestic buyers)



Upstream (number of domestic suppliers)



The above graphs present the results from estimating Equation 1 while interacting the shock measures with dummies for above-median diversification of the up- and downstream supply chain. The coefficients for control variables are not included.