Propagation of shocks in global value chains: the coronavirus case

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Before spreading globally, the Covid-19 epidemic was concentrated in the Hubei province. To contain the spread of the virus, the Chinese government has imposed quarantine measures and travel restrictions, entailing the slowdown of economic activity. We study the propagation of this geographically concentrated productivity slowdown to the global economy, through global value chains. Reliance on Chinese inputs has dramatically increased since the early 2000s. As a consequence, most countries are exposed to the Chinese productivity slowdown, both directly through their imports of Chinese inputs and indirectly, through other inputs themselves produced with some Chinese value added. This note aims at quantifying the total exposure of France compared to other countries. First, we compute the share of Chinese value added in French production. Then, we use data at the country and sector levels to quantify the impact of travel restrictions on French GDP.

- Production processes are increasingly spread across borders. Production within "Global Value Chains" allows firms to save on costs but renders value chains vulnerable to local supply shocks.
- The recent outbreak of CV-19 is a dramatic example that we use to measure the impact of a local production drop on the global economy through trade links.
- In France, 3.2% of firms' output pays Chinese inputs, on average. In some sectors like textile or electrical equipment, the proportion is above 10%.
- A 10% drop in Chinese productivity could reduce French GDP by 0.3% through trade links only. Such a shock would be enough to turn the December 2019 INSEE forecast of a 0.2% growth for the first quarter of 2020 into a reduction of economic activity.
- The shock is transmitted to the French economy through few large firms which produce out of foreign inputs.
- Optimal policy responses to supply chain disruptions include providing liquidity to distressed firms in the short-run.
- More data on value chains at firm-level is needed to identify weaknesses in the French productive structure and better target subsidies in case of a future shock.

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Introduction

The outbreak of Covid-19 has triggered a health crisis first limited to the region of origin of the virus, the Hubei province in China, before spreading to the rest of the world. The Chinese government's reaction has been strong, imposing a quarantine on the 11 million inhabitants of Wuhan from January 23rd, then extended to the Hubei region. Mass quarantining has prevented employees from coming back to work after the Chinese New Year holiday. This has caused a number of firms to reduce their production rate, or to actually shutdown production temporarily. Because production processes are increasingly fragmented, with a growing proportion of production steps spread across international borders, such a geographically concentrated supply shock can have consequences far beyond the epicentre of the shock. Whereas the virus itself spreads through people's mobility, the economic shock propagates through trade links. This note exploits detailed data on these trade links to quantify the possible impact of the production slowdown on the global economy.

Global value chains

Since the beginning of the nineties, the world has entered a new phase of globalization. International trade is increasingly triggered by the exchange of intermediate goods,[1] which nowadays represent two thirds of world trade. The growth of trade in intermediates is explained by the development of "Global Value Chains", i.e. production processes that are spread internationally. An extreme example is a Boeing 787 whose parts are sourced from firms located in the US but also in Australia, Canada, Asia and Europe, with these components themselves produced out of inputs that often travel thousands of kilometers before reaching their destination.

These Global Value Chains are extremely concentrated. Each production process is organized among a relatively small number of "superstar" firms spread across a small number of countries. These firms are typically specialized into the production of a single intermediate good. They produce on a "just-in-time" basis and the coordination of different production stages involves sophisticated international logistics chains. A typical example is the value chain of Apple's Iphones, which involves a single producer of memory and application processors (Samsung, in South Korea), a single supplier of phone network components (Infineon in Germany), and a single assembly firm (Foxconn located in Shenzen). Such a fragmentation allows firms to concentrate each production step in one facility. By doing so, they make economies of scale. These generate important efficiency gains which outdo transportation costs. However such organizations show very little resilience to shocks. Any production disruption at one point of the chain mechanically affects the following steps in the production process, something which is sometimes described as a *cascade effect*.

This note studies the lack of resilience of global value chains using the disruption of Chinese production induced by the outbreak of Covid-19 as a natural experiment.[2] We quantify the impact on global GDP of a decrease in Chinese production, representing the quarantine measures and travel restrictions imposed on Chinese workers.

The coronavirus as a shock to Chinese industrial production

A lock-down was set from January 23rd at the epicenter of the virus in Wuhan, a city home to 11 million people. On January 25th, the quarantine was extended to 16 cities in the Hubei region. Hubei GDP ranks 8th among all Chinese provinces. The region has 59 million inhabitants and is the largest comprehensive transportation hub in central China. On January 20th, there was a declared emergency of Level 1, the highest level on a 4-point scale, in all of the 31 Chinese provinces.[3]

Travel restrictions have a direct consequence on production through the decline in the number of hours worked. They also complicate the synchronization of production involving plants within and outside the Hubei province,

[1] Intermediate goods are used by firms as inputs in their production process.

[2] Previous literature has exploited other natural experiments to estimate the magnitude of the transmission of shocks along value chains. Carvalho et al. (2016) thus study the economic impact of the 2011 Japanese tsunami. The shock was geographically concentrated. It directly affected firms cumulating less than 5% of Japanese output. Downstream propagation, they show, was the main channel through which the shock extended to the rest of the economy. Boehm, Flaaen, and Pandalai-Nayar (2019) further provide evidence of the shock propagating internationally, through trade and multinational firms.

[3] Source: Hofman, Yong, and Yao (2020) and https://knoema.com/atlas/China/Hubei.

including in foreign countries.[4] Quantifying the impact of the shock is impossible until official statistics are published. Available indicators already show a significant decline though. China Purchasing Manager Index thus dropped by almost 30% between January and February, to reach 35.7%, its lowest level since April 2004.[5]

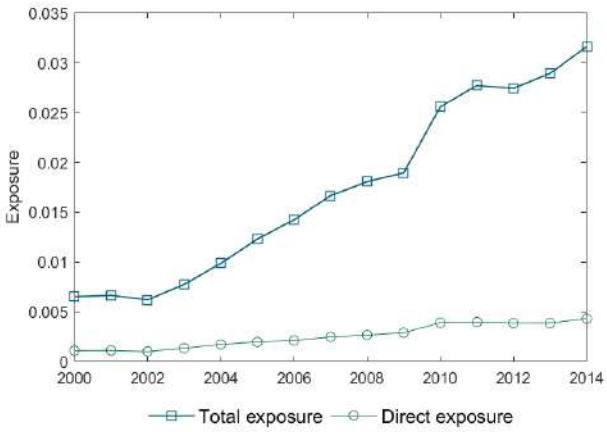
The decline in export sales mechanically affects the volume of shipping. Cargo shipping from Asia to North-America thus decreased by 19.1% in January compared to the same month last year. Data on air freights report a decline of 3.3% in January 2020, mainly driven by the decline on the Asia-Pacific carriers (-5.9%) followed by the European carriers (-3.7%).[6]

All in all, these numbers suggest that travel restrictions have had real consequences from January on. However, it is difficult to evaluate how large the economic impact in China is as it shall vary depending on several unobserved factors. The decline of production at firm-level thus depends on the level of inventories prior to the shock, which strongly varies across firms and sectors. In the simulations later presented, we assume a negative 10% shock on production in China for all sectors. Results can be proportionally adjusted with a different value.

Countries' exposure to the shock through value chains

We start by measuring countries' exposure to the shock using information on world input-output trade flows (see details in Box 1). Exposure is measured at sector level in two different ways. "Direct" exposure is defined as the share of a sector's gross output that pays Chinese suppliers. As explained in Box 1, this indicator underestimates exposure to Chinese shocks, however. The reason is that it neglects Chinese value added content hidden in firms' intermediate purchases that are *not* sourced from China but are themselves produced with some Chinese inputs. We thus define an indicator of "total" exposure to Chinese inputs, which measures the share in a country×sector's output of inputs directly or indirectly sourced from China.

Figure 1: Exposure to Chinese inputs, over time



Source : Authors' calculations based on WIOD data.
Note: This figure shows the evolution over time of France's "exposure" to Chinese inputs. The "Direct exposure" is the average share of intermediates directly sourced from China in each sector's output. "Total exposure" is the share of intermediates sourced from China, either directly or indirectly. Sector-level indices are averaged at country-level using output weights. See details in Box 1.
Interpretation: Between 2000 and 2014, France's exposure to Chinese inputs has increased. Whereas 0.1% of total costs were directly paid to Chinese suppliers in 2000, on average, this number reaches 0.4% in 2014 ("Direct exposure" line). Once indirect exposure to Chinese inputs through the overall value chain is taken into account, France's exposure to Chinese inputs is found to have increased from 0.6 to 3.2% ("Total exposure" line).

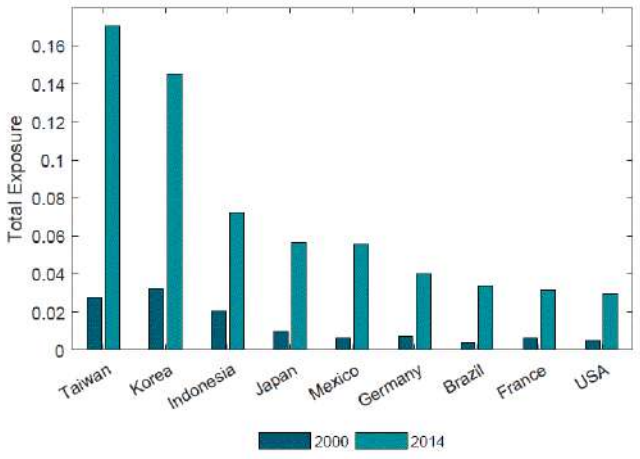
Figure 1 shows the evolution of French exposure, aggregated across sectors over 2000-2014. Both indicators display a positive trend, which is consistent with the view that China's export growth following its entry into the World Trade Organization has increased firms' reliance on Chinese inputs. Over the period of observation, direct exposure to Chinese intermediates has increased from 0.1 to 0.4% of firms' output, on average. But the rise in firms' overall exposure to Chinese intermediates is strikingly stronger. Between 2000 and 2014, the total exposure index has indeed increased from 0.6 to 3.2%, on average. The steep trend is a direct consequence of value chains becoming more globally fragmented, with all production stages increasing their reliance on Chinese products. In such complex value chains, idiosyncratic shocks to China propagate through all components of the input-output network.

[4] Anecdotal evidence based on the Apple case are reported in *The Economist* (Feb 15th, 2020). The firm "typically shuttles some 50 of its executives between California and China each day." Carriers have suspended flights to and from China, thus complicating the organization of production processes.

[5] Source: Moody's analytics. The Purchasing Managers Index is an index calculated from a monthly survey of enterprises' purchasing managers and takes into account various indicators such as new orders, output, employment, suppliers' delivery times and stocks of items purchased. A value below 50% reflects a contraction of manufacturing activity.

[6] Source: The Northwest Seaport Alliance and International Air Transport Association (IATA). Data for ships are based on data from Seattle and Tacoma ports.

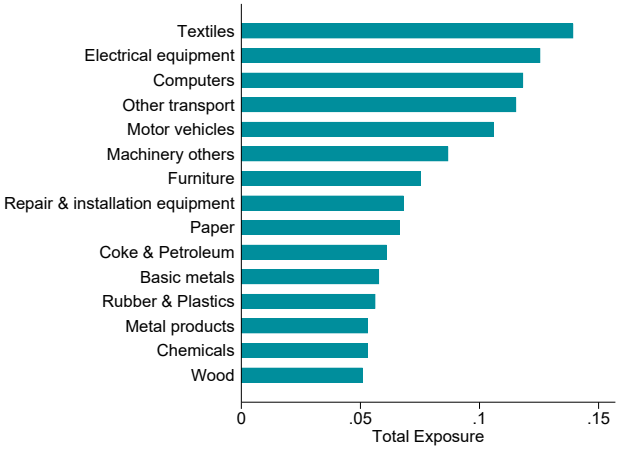
Figure 2: Exposure to Chinese inputs, across countries



Source : Authors' calculations based on WIOD data.
Note: This figure shows the share of intermediates (directly or indirectly) sourced from China for various countries, in 2000 and 2014.
Interpretation: Taiwan's total exposure to Chinese inputs has increased from less than 3% to more than 16% between 2000 and 2014.

While all countries' exposure to Chinese inputs has increased over the period of analysis, the tendency is somewhat heterogeneous across countries, as illustrated in Figure 2. Emerging Asian countries are the most strongly exposed to Chinese shocks, due to the importance of regional value chains. In Taiwan and Korea, overall exposure to Chinese inputs is thus above 14%. In comparison, the exposure of rich countries in North America or Europe is small, around 4%.

Figure 3: French exposure to Chinese inputs, across sectors



Source : Authors' calculations based on WIOD data.
Note: This figure shows the share of intermediates (directly or indirectly) sourced from China for various French sectors, in 2014.
Interpretation: Among the 15 most exposed sectors in France, the Textile industry has the highest exposure to Chinese inputs, at 14%.

Finally, Figure 3 illustrates how exposure to the Chinese shock varies in France across sectors. Naturally, the production of more complex goods such as electrical equipment or motor vehicles tends to be more internationally

Box 1: Measuring shocks propagation in production networks

Measuring the propagation of shocks in production networks is a complicated task for conceptual and statistical reasons. Conceptually, the difficulty comes from the fact that exposure to a given country's or sector's inputs is both direct and indirect. For example, a French producer of cars is directly exposed to Chinese shocks whenever it purchases intermediates (such as airbags) to Chinese firms. But this "direct" exposure is small in comparison with its overall exposure, induced by other intermediates also displaying some Chinese value added content. For example, the electronics system, if outsourced to a Spanish or Korean supplier, might use Chinese chips among the inputs. Any intermediate product sourced by the car producer, whether it is purchased domestically or abroad, has some Chinese value added content as long as at least one production stage upward in the value chain is located in China. Measuring the firm's exposure to Chinese shocks thus requires to recover information on both direct and indirect intermediate consumptions.

The second difficulty is statistical as information on international input-output flows is scarce. In particular, firms do not provide much statistics on the organization of their value chain. Even at the more aggregated sectoral level, information is limited. In this note, we use the "World Input-Output Database" (WIOD, 2016 version), which provides information up to 2014 (see Timmer et al. (2015)). This dataset combines information on country-specific input-output tables together with detailed trade data to measure the flow of inputs flying from one particular sector in a given country to any other country-sector pair. Input-output matrices are available annually between 2000 and 2014 which allows to study changes in the aggregate structure of global value chains, over time.

Based on the WIOD dataset, we first measure the share of a particular sector in a particular country as a source in the gross output of a particular sector of a given country. Summing across all inputs sourced from China gives a measure of the "direct" exposure mentioned above, i.e. how much of a sector's output is paid to Chinese suppliers. In order to account for propagation through intermediate goods containing Chinese inputs, one uses a Leontief inverse matrix with allows to measure how the gross output of each sector from each country is exposed to shocks affecting China, both directly and indirectly. This is what we use as an indicator of each country's "total" exposure to Chinese inputs.

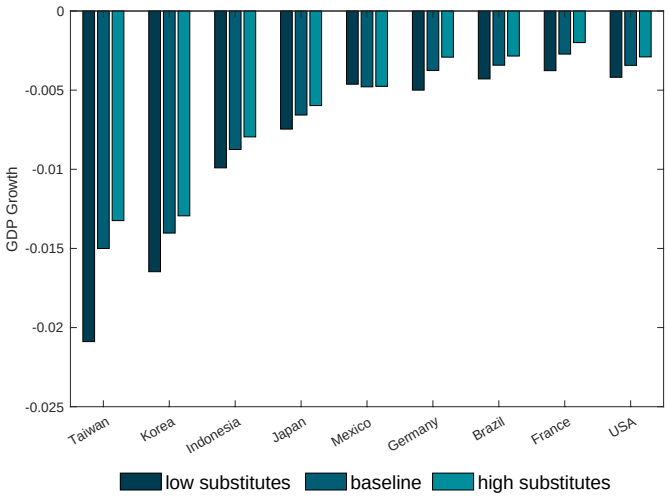
fragmented, and thus more exposed to foreign shocks. Exposure to Chinese shocks also varies with the country's relative share in world production, across sectors. Exposure is naturally higher in sectors where the country concentrates a very large share of the world production, textile or toys for instance.[7] In France, the most strongly exposed sectors are Textiles, Electrical equipment, Computers and Transport equipment.

Impact of the shock on GDP growth

Indicators recovered from input-output matrices give a good first-order approximation of how a shock in China spreads to the rest of the world. But they do not allow to take into account *general equilibrium effects*. The negative productivity shock[8] in China has a feedback impact on foreign firms through demand. On the one hand, foreign firms gain market shares over their Chinese competitors. On the other hand, Chinese GDP shrinks which reduces foreign exporters' sales in China. On top of these effects, relative prices adjust across countries, in a way that directly depends on the structure of value chains.

Taking into account such general equilibrium effects requires building a multi-country, multi-sector model fed with calibrated productivity shocks and solving it in general equilibrium. Such an exercise relies on many assumptions that are detailed in the reference study and results should thus be taken with caution. In particular, running such simulations implies making assumptions regarding the way firms all around the world will adjust by switching to inputs that are not produced in China. In the baseline simulation, such a key parameter called the *elasticity of substitution* is assumed to be unitary, i.e. any increase in the price of Chinese inputs is proportionally compensated through substitution towards non-Chinese inputs.[9] Because the level of this elasticity is uncertain, we also provide results based on alternative values.

Figure 4: Impact of a 10% productivity shock in China on foreign countries' real GDP



Source : Authors' calculations based on WIOD data.
Note: The histogram shows the simulated impact of a 10% uniform productivity decrease in China on various countries' real GDP. Results are expressed in percentage change from the level of GDP that would have prevailed, in the absence of a shock. The figure compares the impact in the baseline calibration with scenarios assuming inputs to be complementary ("low substitutes" bars which assumes an elasticity of substitution of 0.1) or more substitutable ("high substitutes" bars that corresponds to an elasticity of 1.5). Substitutability in the baseline scenario is equal to 1.
Interpretation: In the baseline scenario, a 10% productivity drop in China reduces French GDP by 0.27%. When it is assumed that firms cannot easily substitute away from Chinese inputs, the estimated impact is larger, at 0.38% ("low substitutes" scenario).

Results recovered from these simulations are summarized in Figure 4, for the same nine countries shown in Figure 2. The assumption is a 10% productivity drop in all sectors in China. Results are expressed in growth rates using as benchmark the level of GDP that would have been achieved, in the absence of the shock. In the baseline scenario, the impact is substantial for countries most exposed to Chinese inputs, reaching -1.5% in Taiwan. The impact on French GDP is found equal to -0.27%. This is substantial. Given the 0.2% growth forecast from the French statistical institute for the first quarter of 2020, such a shock could lead to a contraction of French GDP.

Figure 4 shows how results vary depending on the assumed ability to substitute inputs from other countries to inputs sourced from China. As expected, the contraction of real GDP caused by the productivity shock in China is

[7] There is another source of cross-sector heterogeneity that we cannot take into account due to insufficient data. Namely, the production shock is concentrated in mainland China, in particular the Hubei province. This implies that the strength of the shock at sector level is correlated with regional specialization in production. The Hubei province is the heart of China's "optics valley", hosting a number of firms making components for telecoms networks such as optical-fibre cables or advanced chips. According to *The Economist* (February 15th, 2020), "Analysts worry that the epidemic in Hubei could reduce global shipments of smartphones by as much as 10% this year."

[8] In the stylized model used in this paragraph, the shock induced by the slowdown of production in China is represented by a 10% productivity drop. Reduced worked hours or difficulties synchronizing production processes lead to a drop in output, at constant factor costs. In economists' language, that corresponds to a drop in total factor productivity.

[9] At the firm-level, this is arguably a heroic assumption. Anecdotal evidence indeed suggests that value chains are extremely sticky and firms may not be able to substitute at all. In such case, a disruption in the value chain causes downward firms to stop producing. Not all firms are directly exposed to the shock though. Many do not source any input from China and even if they do, their suppliers may still be able to serve them. When aggregating across firms to match with the sectoral data, the impact of the shock on various firms averages out and assuming some substitutability is more reasonable.

amplified when inputs are assumed low substitutes. In such scenario, foreign firms confronted with difficulties to source intermediates in China cannot easily switch to suppliers in other countries. As a consequence, the productivity drop induced by the quarantines has a stronger impact on downstream firms. In this scenario, the contraction in French GDP reaches -0.38%. It is interesting to note that the same model calibrated on trade data from 2003 delivers results that are ten times smaller, a direct consequence of the rise of trade with China over the decade 2003-2014.

It has to be noted that the simulations are recovered from a static model and that we cannot say anything about the dynamics of the shock transmission and of the later recovery. Implicitly here, the production slowdown in China immediately affects growth in the rest of the world. In practice, the first consequences of the shock cannot be expected to materialize before at least three weeks, which is the time it takes to ship Chinese inputs to Europe. Then the effects can be delayed by the existence of stocks.[10] Moreover, the diffusion through all input-output linkages further delays the propagation. Whereas our simulations suggest that the impact on French GDP can be substantial, the effect is likely to hit French firms progressively, potentially over several months.

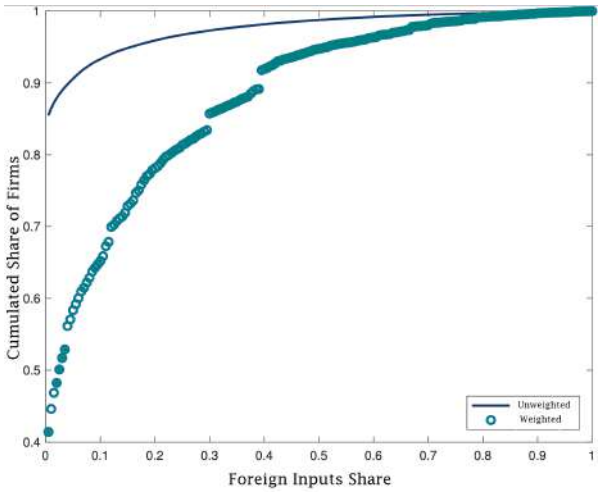
Finally, let us emphasize that the numbers discussed here are recovered from a model that assumes the productivity slowdown is limited to China. The Covid-19 epidemic will have an impact far beyond what is discussed here. Many countries have now adopted mobility restrictions, which will further affect supply chains. Investment might slow down because of blurred prospects about the timing of the recovery (see IPP Policy Brief N°48 by Martin, Martinez, and Mejean, 2019, for a discussion of the impact of uncertainty on trade and investment). And sectors directly affected by mobility restrictions, such as transport, restaurants and tourism, will contract.

[10]Information on the level of inventories at firm-level is scarce, although it is key to quantify the possible impact of the shock. According to the CEO of Llamasoft, a US firm that does supply chain analytics, "Most industries carry buffer inventory and you can measure that in days of supply. So for example, in the pharmaceutical industry, [...] most companies carry anywhere from three to six months of buffer inventory." In the high-tech industry, buffering inventories would be closer to three to 12 weeks against "just anywhere between two and 10 weeks of inventory" in the automotive industry.

Firms' individual exposure to the shock

Until now, the quantification of the propagation of the production disruption induced by the Covid-19 crisis has been discussed using sector-level data. But there is ample evidence that heterogeneity across firms is substantial, including within a sector. In particular, firms have strongly heterogeneous production functions. Their sourcing decisions make them unequally exposed to foreign shocks.

Figure 5: Cumulated distribution of firms according to the share of foreign inputs in intermediate consumption



Source : di Giovanni, Levchenko, and Mejean (2020) using French customs and INSEE-Ficus data for 2005.
Note: The solid line represents the cumulated share of firms that display a proportion of foreign inputs in overall intermediate consumption below a given level. The blue circles display the weighted cumulated distribution where the weights are based on firms' value added.
Interpretation: In the overall population of French firms, more than 86% source all of their inputs from France ("Unweighted" line). They represent 40% of aggregate value added ("Weighted" line). At the other side of the distribution, 2% of firms purchase more than 40% of their inputs abroad but they represent 10% of aggregate value added.

This heterogeneity is illustrated in Figure 5. The figure shows the cumulated distribution of French firms according to their exposure to foreign inputs. Here, exposure is defined as the share of foreign inputs in overall intermediate consumption.[11] The solid line shows that very few firms, roughly 15%, import some of their inputs from abroad. Even in that sub-sample, most firms are little exposed to foreign inputs. Only a third of importing firms source more than 20% of their inputs from abroad. Finally, firms exposed to foreign inputs are not representative of the overall population but are instead larger than the average. The 15% of firms that source some of their inputs from abroad thus represent 60% of aggregate value added (blue circles in Figure 5). The correlation explains the large

[11]Taking into account indirect exposure through other inputs is not possible with existing individual data.

overall exposure of France to foreign shocks, despite the small number of directly exposed firms. The few firms involved in input-output relationships with foreign suppliers represent a large share of France's aggregate GDP, directly and through their own relationships with French partners, that they "contaminate" with foreign shocks (di Giovanni, Levchenko, and Mejean, 2020).

The effects we estimate thus hide substantial heterogeneity between a majority of firms that are not directly exposed to the shock, and a few firms that are heavily exposed through imported inputs. In such circumstances, there is a risk of cascade following some exposed firms' bankruptcy. While the model does not take this possibility into account, bankruptcy is a risk for firms that are short in intrants and thus cannot keep on producing. Bankruptcies have additional costs as they induce a permanent loss for the economy.

Conclusion

The fragmentation of production processes, both domestically and internationally, allows firms to produce more efficiently, at a larger scale. This mode of production has helped firms benefit from additional efficiency gains through specialization. But this organization of production into concentrated value chains has external effects due to their lack of resilience to shocks. When any extreme event hits value chains, consequences are large and global.

The optimistic view is that such events help firms measure the vulnerability of their supply chain. They may want to adjust by diversifying their production process. But such a scenario is probably too optimistic. The Covid-19 crisis comes after several shocks to global value chains, including the 2011 Japanese earthquake and the recent China-US trade war. Despite of such events, there is not much evidence that firms have started diversifying their supply chain. And it is not clear that they will have incentives to do so once having recovered from the Covid-19 crisis given strong competitive pressures in international markets that force them to seek further efficiency gains.

The interdependence of firms through input-output networks creates *externalities*. Decisions made by one firm, such as choosing a unique supplier, make them more likely to be disrupted and then to propagate the shock downstream to their clients. A parallel can be drawn with the risk of bankruptcy in the financial sector: the 2008 crisis has revealed how interdependence of banks dramatically extended any local risk to a system-wide threat. Policy responses can take inspiration from what has been done since in the financial sector.

A first policy response in the short-run implies providing cash to firms that suffer from production disruptions through their value chain and may be at risk of a bankruptcy. The targeted firms could equally be some of the few firms directly exposed to the shock or firms only indirectly affected. This is actually what the French government has already done, while providing firms with the possibility to delay the payment of employers' contributions, by helping them to switch to partial unemployment schemes and by offering small firms collateral for liquidity loans. The benefit of such liquidity provision is to avoid cascade effects in which firms not directly under risk become vulnerable to the shock. The Covid-19 crisis is a temporary shock. Firms will recover once the travel restrictions will be eased. It is important that the temporary shock does not mutate into a permanent contraction in real output. It has to be noted though that such "bailout" entails some form of moral hazard. Firms hit by the idiosyncratic shock in China will not have an incentive to improve the diversification of their value chain if they foresee the possibility of a bailout in case of a shock.

Exactly as stress tests have started being implemented after the 2008 crisis, measuring the fragility of value chains could require collecting more data on individual firms' vulnerabilities. In practice, that means asking firms to provide information on their most important suppliers and clients, which represents extremely sensitive data.[12] But that information would not even be sufficient since firms' direct exposure to shocks can be substantially smaller than their overall exposure. As explained in this note, measuring a firm's overall exposure to some shock requires to reconstitute the whole value chain of the firm and all its suppliers. Achieving that level of data collection for worldwide value chains would be extremely difficult. However, the bulk of trade in intermediates takes place at the regional level. In practice, French firms mostly organize their production process within the European Union. Having a European-level dataset of firm-level input-output linkages would be a first path towards better identifying supply chain fragilities. Building such statistics is necessary to

[12] Note that such information, although incomplete, exists for US firms and is exploited in Barrot and Sauvagnat (2016) to measure the propagation of extreme weather shocks into production networks. Under regulation SFAS No. 131, publicly listed firms have to disclose information on their major customers. Based on this, it is possible to reconstitute some pieces of value chains within the US.

provide targeted aid for firms in response to future shocks on value chains. Moreover, identifying such vulnerabilities will open the door to policies forcing firms to internalize the consequences of the lack of resilience of their value chain on the French economy.

Reference study

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