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A bridge over troubled water: flooding shocks and supply chains

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Editorial

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A Bridge over Troubled Water: Flooding Shocks and Supply Chains

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Abstract

This paper estimates how the impact of a natural disaster propagates through the production network. More precisely, we look at the excessive rainfall in the summer of 2021 that caused large areas to be severely flooded in Belgium. We first look at the direct effects on firms active in the flooded areas and find substantial negative effects on sales and employment. Next, we investigate how these shocks propagate through the network, thereby differentiating explicitly between upstream and downstream linkages. Our results show that the floods had a strong negative impact on the performance of firms active in the area. In terms of the supply chain effects, we find negative and persistent effects on sales for firms with upstream exposure.

Keywords: Flooding, climate change, firms, production network.

JEL codes: D57, L25, Q54, R11, L14.

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1 Introduction

One of the consequences of climate change is the increase in frequency and intensity of extreme meteorological weather events such as severe droughts or heavy rainfall (Madakumbura et al., 2021). For example, Fischer and Knutti (2016) find that the number of days with very heavy precipitation over Europe has increased on average by around 45%, comparing the years 1981-2013 to 1951-1980. Bilal and Rossi-Hansberg (2023) document that the probability of storms in coastal counties and heat waves in warm counties in the U.S. has risen fourfold with the 1°C increase in temperature experienced in the last century. Over time, the occurrence of these weather extremes is likely to increase further as climate change unfolds (Field et al., 2012), making the study of their impact even more important.

Extreme weather events are often hard to predict and can have devastating effects locally (Wenz and Willner, 2022), also in terms of the economy. In case of a natural disaster, firms can be directly impacted through the destruction of production facilities and transport infrastructure. Moreover, the workforce also has to cope with the detrimental effects of a disaster, all negatively impacting economic activity. In an economy where production is organized around complex and interlocking supply chains, firms are exposed to natural disasters, not only because of their production taking place in the affected area, but also indirectly due to the exposure of their impacted supply chain partners, both upstream and downstream. As a result, the direct damages in the region hit by a disaster can also lead to disruptions in markets and firms at other places. An assessment of the disaster's economic impact focusing solely on the region of impact does not take into account these ripple effects and will likely underestimate its consequences.

We contribute to our understanding of the effects of disasters by focusing on a large flooding event in Belgium. In July 2021, extreme rainfall caused severe flooding and substantial losses across Western Europe. This included over 200 fatalities and extensive infrastructure damage with an estimated cost of over 10 EUR billion. Within the affected countries, especially Germany and Belgium were hit by this catastrophe, which has been labelled as one of the most devastating in the region over the past decades (Koks et al., 2021). We assess the impact of these floods on the Belgian economy. First, we estimate the direct impact on firms active in the affected area. More precisely, we look at how their sales growth and exit probability changed after the event. Second, we leverage the unique business-to-business data set, holding information on transactions between all Belgian firms. This data set has been used in a number of other recent studies such as Bernard et al. (2022). We estimate how the initial negative shock propagates through the supply chain by looking at how the performance of suppliers and buyers of the firms active in the flooded area changes. In doing so, we explicitly address the heterogeneity of partners in the supply chain and make a distinction between upstream and downstream linkages.

We find that the floods had a strong and negative impact on the performance of the flooded firms and those directly connected with them. Conditioned on survival, we find a 15 percent decrease on sales for firms that were flooded, which lasted for at least three quarters after the shock event. Moreover, we find significant effects also on the probability of exiting the market for those directly affected firms. In terms of the propagation effects, we find that the intensity of the effect depends on whether the firm is positioned upstream or downstream relative to the set of flooded firms.

We find negative and persistent effects on sales for those firms with upstream exposure: one percentage point more upstream exposure decreases sales by almost 0.3 percent. These effects persist for at least four quarters after the shock and are mainly driven by long-term relationships with flooded suppliers. The results related to the downstream exposure to the shock are less conclusive, with no systematic differences observed in terms sales after the shock.

Related Literature: Our work is related to different strands of literature. First, it is connected to the literature on the macroeconomic effects of natural disasters such as earthquakes, volcano eruptions, floods, ... All in all, these events reduce economic activity, especially in the short run and in developing countries. For example, Noy (2009) finds that natural disasters have an observable negative impact on the macro-economy, even more so for small and developing countries. Strobl (2011) and Strobl (2012) estimate the economic effects of hurricanes in Central America and the U.S. respectively. Also the effects of disasters on other more specific outcomes has been the subject of study. For example; Faccia et al. (2021) look at the impact of extreme temperature shocks on inflation and find that hot summers increase food price inflation in the short run, but in the medium run, the effect on prices is either insignificant or negative.

The results on disasters relate as well to the general costs of climate change. Part of these costs are related to the increased frequency of weather shocks such as droughts and high precipitation. Kotz et al. (2024) provide an estimate of the expected costs of climate change. They show that the economic costs of are not only related to the increase in the average temperature but also to temperature variability, number of wet days and extreme daily rainfall.

Second, our paper is related to the quickly evolving literature on production networks and its role in the propagation of shocks. Acemoglu et al. (2012) challenged the idea that aggregate fluctuations cannot originate from microeconomics shocks. It had long been argued that microeconomic shocks wash out on average and therefore don't drive fluctuations in macroeconomic economic performance (Lucas, 1977). If there are n firms in the economy and a firm is hit by an idiosyncratic shock, the impact of the shock on aggregate output is proportional to $1/\sqrt{n}$ and macro fluctuations can only be caused by macro shocks such as war, oil shocks, monetary policy, ... This is the so-called diversification argument. Related, Hulten (1978) stated that the impact on aggregate TFP of a microeconomic TFP shock equals the shocked producer's sales as a share of GDP times the micro shock. These sales shares are typically small, so again, granular fluctuations are unlikely to drive aggregate changes.

However, economists, policy makers and business people have long argued that micro shocks can have important macroeconomic consequences. Take the electricity sector as a case in point. The sector accounts on average for 2%-3% of total GDP in developed economies. Following the above reasoning, the effect of a strong negative shock in the sector cannot be larger than 3% of total GDP. Most people would however agree that the impact can be much larger as electricity is a crucial input for many other sectors and firms. More general, the production of goods and services in the present economy is organized around complex supply chains, spanning various regions and sectors and disruptions to these are increasingly recognized as a source of aggregate risk.

Acemoglu et al. (2012) build a mathematical model and show that because of interconnections between firms, idiosyncratic shocks can propagate throughout the economy, thereby affecting the production of other sectors and generate sizable aggregate effects.[1] In subsequent work, different papers such as Acemoglu et al. (2017) and Baqaee and Farhi (2019) have established conditions under which input-output linkages lead to the propagation of microeconomic shocks into sizable aggregate shocks. Carvalho and Tahbaz-Salehi (2019) provide an overview of the literature on production networks.

There exists a limited number of papers, most closely related to our work, that combine the literature on production networks with the literature on the effects of natural disasters. On the one hand, this allows researchers to give a more complete assessment of the effects of disasters. On the other hand, these disasters are as well exogenous shocks that help identify the propagation effects of input disruptions. One of the earliest examples is Barrot and Sauvagnat (2016). Leveraging on data from natural disasters in the US, the authors find that affected suppliers impose substantial output losses on their customers, especially when they produce specific inputs. These output losses translate into significant market value losses, and they spill over to other suppliers.

Boehm et al. (2019) look at the 2011 Tōhoku earthquake in Japan and its cross-country transmission. They find that for US affiliates of Japanese firms, output falls roughly one-for-one with declines in imports, in line with a relationship between imported and domestic inputs being close to Leontief. Carvalho et al. (2021) exploit as well the 2011 earthquake in Japan to study the role of input-output linkages in the amplification of shocks. They find that the disaster resulted in a 3.1% point and 3.8% point decline in the sales growth rates of respectively customers and suppliers of disaster-hit firms. Moreover, not only the direct trading partners of disrupted firms are affected, but also their customers' customers, their suppliers' suppliers, and so on. Next, the authors build a general equilibrium model and combine it with the firm level data to find that the disaster resulted in a 0.47 % point decline in Japan's real GDP growth in the year following the disaster.

In a recent paper, Balboni et al. (2024) complement the literature and investigate how firms adapt to floods in Pakistan. They document that flood-affected firms are more likely to relocate to safer ground, and switch to suppliers who are active in areas with lower risks of flooding disruptions. They quantify the aggregate impact of the floods using a model of endogenous production network formation and find that the damages from floods can be mitigated through these adaptation strategies.

Our paper contributes to the academic literature in various ways. First, although there is a rich literature on the macroeconomic impact of natural disasters, only a limited number of papers have explicitly shown how these shocks affect the whole supply chain. When this aspect is neglected and the focus is only on the affected region, the aggregate impact is likely to be underestimated as suppliers and buyers outside the region will also be hit. Second, the few studies that also focus on supply chains, rely on a limited data set of mainly large firms and from the manufacturing sector. Business-to-business (B2B) transaction data allows us to observe all buyers and suppliers

[1] Gabaix (2011) shows as well how idiosyncratic shocks lead to aggregate fluctuations. Instead of focusing on input-output linkages, the channel goes through the firm size distribution. If this distribution is sufficiently fat-tailed, firm level shocks can have important aggregate effects.

along the value chain together with the transaction values between them, which will result in a more complete assessment of the economic impact. Third, the data set allows to explore important sources of firm heterogeneity, such as the length and intensity of the relationship between buyers and suppliers.

The rest of the paper proceeds as follows. Section 2 provides more information on the flooding event. Section 3.1 describes the data sets and the identification of the firms being flooded. The empirical model is introduced in section 4. Section 5 shows the results and finally, Section 6 concludes.

2 Empirical Setting: The 2021 mid-July Western Europe floods

In July 2021, extreme rainfall caused severe flooding in Germany, Belgium and the Netherlands. In Belgium the flooding was concentrated in Wallonia, the southern part of Belgium. The phenomenon led to substantial infrastructure impairment and human casualties. Estimates for the economic damages exceed 10 billion EUR, positing the event as one of the gravest natural disasters to affect the region in recent history (Koks et al., 2021). Extreme precipitation levels were recorded in the Liège region, surpassing 250 mm over a 48-hour period. This magnitude of rainfall typically has a recurrence interval of 100 years, highlighting the exceptional nature of the event. The Reconstruction Committee, an entity created by the Walloon committee to supervise the rebuilding of the affected areas, estimated that $100,000$ people were affected, $48,000$ buildings damaged (of which $3,000$ firms) and 559 bridges destroyed, among other damages (de Goër de Herve and Pot, 2024). The spatial distribution of the flood impact, as documented by the Walloon regional government, is illustrated in Figure 1, which delineates the affected areas.

The impact of the 2021 floods in Wallonia was not uniform across the region, with some areas experiencing far more severe consequences than others. In response to this varied impact, the Walloon Government implemented a classification system to categorize the affected communes. This system divided the communes into three distinct categories based on the severity of the flooding's impact: Categories 1 (most affected), 2 (mildly affected) and 3 (least affected). Of particular note are the 10 communes classified under Category 1, which bore the brunt of the flooding. These communes,[2] experienced catastrophic damage to infrastructure, homes, and businesses. The geographical distribution of these categories is visually represented in Figure 2. This map clearly illustrates the spatial pattern of the flood's impact across the Walloon region. The Vesdre valley,[3] between Eupen and Liège, in particular, was one of the hardest-hit areas, with some locations seeing water levels rise by several meters in a matter of hours. In the most affected areas, many businesses were forced to temporarily cease operations, leading to significant economic disruption.

Our empirical analysis will primarily focus on firms located in the 10 Category 1 communes, as well as their buyers and suppliers. This focus allows us to examine the most pronounced effects of the flooding on business operations, supply chains, and economic recovery. By studying these

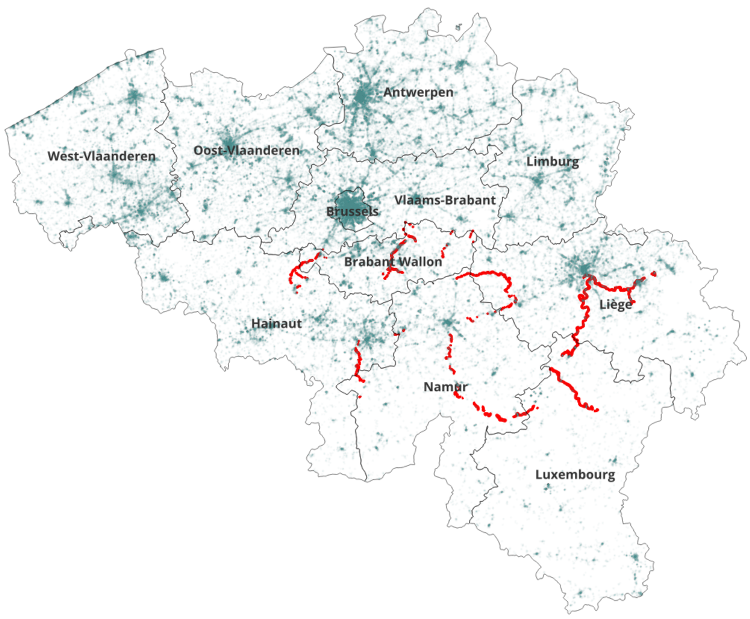
[2] The 10 communes classified as Category 1 are Chaudfontaine, Esneux, Eupen, Liège, Limbourg, Pepinster, Rochefort, Theux, Trooz and Verviers.
[3] The river Vesdre flows from Eupen via Verviers to Liège where it ends in the river Ourthe.

severely impacted areas, we aim to gain insights into the resilience of local economies in the face of extreme weather events and the effectiveness of subsequent recovery efforts.

It is worth noting that the impacts extended beyond immediate physical damage. The floods also led to disruptions in transportation networks, energy supply, and telecommunications, which had ripple effects on businesses even in less directly affected areas. This underscores the interconnected nature of modern economies and the potential for localized disasters to have wider regional impacts.

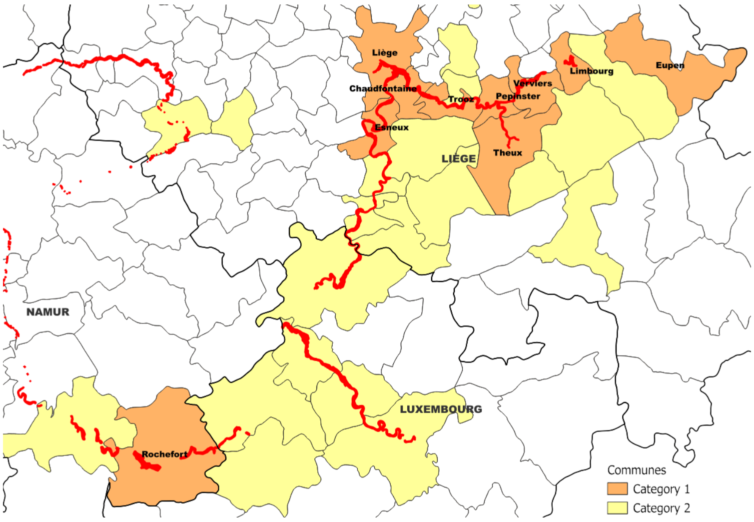
The Walloon government's response included not only the categorization of affected areas but also the implementation of various support measures. These included emergency financial aid, tax relief for affected businesses, and long-term reconstruction plans. The effectiveness of these measures in supporting economic recovery, particularly in the Category 1 communes, will be an important aspect of our analysis.

Figure 1: Flooded Areas in Belgium



The red sections denote the flooded zones as retrieved from satellite images by the Walloon Government. The green dots represent firm density.

Figure 2: Belgian Communes in Categories 1 and 2



The red sections denote the flooded zones as retrieved by satellite images. Category 1 communes shown in orange. Category 2 communes in yellow.

3 Data

3.1 Data sources

For the empirical analysis, we make use of six administrative micro-level data sources on Belgian firms provided by the National Bank of Belgium: (i) VAT declarations, (ii) social security data, (iii) Business-to-Business (B2B) transactions, (iv) Crossroads Bank of Enterprises (CBE), (v) Central Balance Sheet Office (CBSO), and (vi) firm level trade data. These data sources can be linked by a unique firm-level identifier and cover the period 2017 - 2023.

VAT declarations: VAT liable firms in Belgium are obliged to report total sales, investment and intermediate inputs to the VAT administration. These variables can in principle also be retrieved from the annal accounts. The VAT declarations however, have two main advantages: (1) these declarations are also available for small firms while sales are only reported for large firms in the annual accounts and (2) sales and inputs are observed on a quarterly basis instead of on a yearly basis in the annual accounts.

Social Security data: Quarterly data on employment (FTE, heads) and wage bill as reported to the National Social Security Office.

Business-to-Business (B2B) data: Our data on business-to-business transactions is based on the VAT customer listings. All VAT liable firms have to submit these at the end of each calendar year. An observation reports the yearly sales value of all firms i selling to firms j (provided this value exceeds 250 euros), based on the invoices of firms i to j. This allows us to observe the domestic buyer-supplier linkages of all Belgian firms together with their transaction value. Pecuniary sanctions in case of erroneous or late reporting ensure a very high quality of the data (Bernard et al., 2022). For more details on the construction of the data set, we refer to Dhyne et al. (2023). The data set is an update of the data that has been used in a number of recent papers such as Bernard et al. (2022) and Baqaee et al. (2023) among others. This data set allows us to construct the supply chain of firms affected by the floods.

Crossroad Bank for Enterprises: This source contains the basic data concerning firms and their establishments, such as address and year of incorporation. The data allows us to control for the presence of multi-establishment firms, holding one or more establishments within or outside the affected area.

Annual Accounts: We observe the annual accounts of all incorporated firms of the non-financial sector in Belgium. These accounts provide detailed information including the typical data from the balance sheet (assets, liabilities) and profit and loss statement (revenues, input costs, labour cost) as well as 5-digit (NACE) industry codes. Typically only large firms report revenues and input costs. If this data is missing, we use turnover and intermediate inputs from their VAT declarations.

Trade Data : We have data on all firm level imports and exports of goods coming from the Belgian customs records and the intra-EU trade declarations. We observe for each firm the value of its imports and exports at the product-country level, where products are defined according to the Combined Nomenclature (C8) classification.

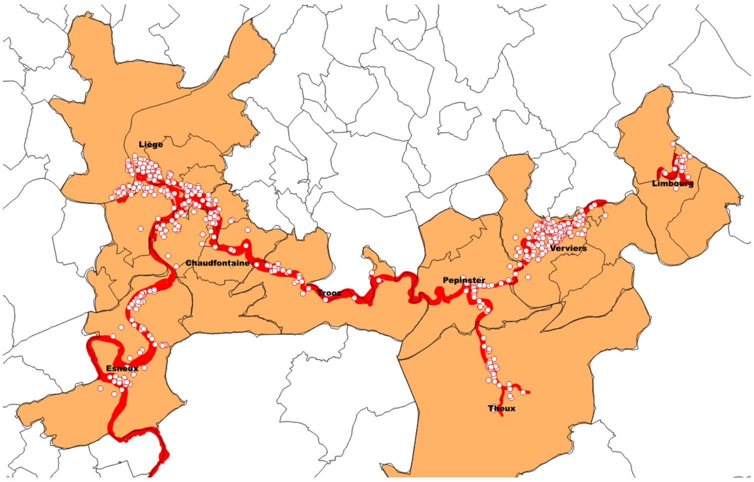
The above data sources are complemented with **flooding data**. This includes the set of geo-referenced flooded polygons in Belgium, as shown in Figure 1. The gathering method was mainly through satellite and helicopter imaging, and it was carried out by the Wallonian Regional Government. The data was provided by the Public Service of Wallonia (SPW).

3.2 Identifying the flooded firms

In order to identify the set of flooded firms, we proceed as follows: First, we filter out all those firms that were not operating in the most severely affected communes (i.e. *Category 1*) in order to isolate the firms with the highest probability of being effectively treated. Second, we geolocate the remaining firms and calculate the distance with respect the closest flooded polygon in the map (see red areas in Figure 3). Finally, we designate as *flooded* to all those firms operating in a Category 1 commune and that were on a radius of 500 meters to a flooded area[4]. For those firms with multiple establishments (in addition to the headquarters's location), we consider them as *flooded* if at least half of the establishments were located on a flooded area. The final sample includes 1,249 unique *flooded* firms that are present in the database at least 4 quarters before and after the period of the shock (i.e. 2021Q3). Figure 3 displays the distribution of *flooded* firms across the Category 1 communes.

[4] As a benchmark, we choose a conservative one that provides some flexibility in case the geolocation algorithm does not yield fully precise coordinates; nonetheless, in most scenarios 500m should capture most of the treatment variability. Different treatment radius are tested for the empirical section.

Figure 3: Geographic distribution of flooded firms



The red sections denote the flooded zones as retrieved through satellite imaging by the Walloon Government. The white dots represent the firms identified as flooded - with less than 500m away from a flooded polygon. The orange filling indicates that the area is part of a Commune in the Category 1 .

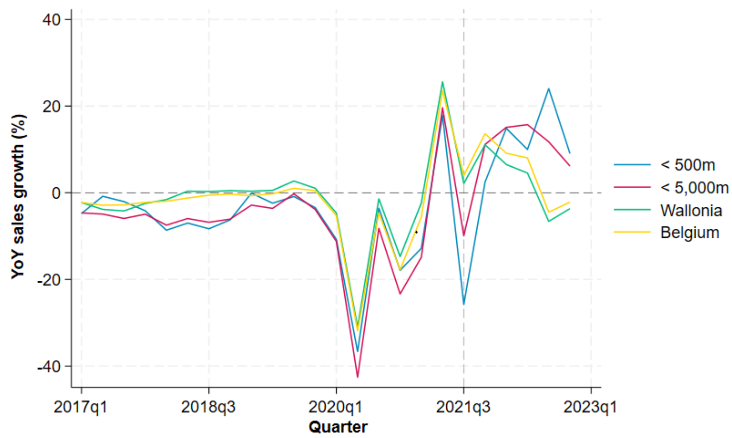
Table 1 shows the pre-flood characteristics of the firms we identify as flooded and non-flooded. A general comparison does not show systematic differences in terms of size, longevity or industry composition. This idea is reinforced when we plot each of these groups' sales growth trajectory over time in Figure 4. It seems clear that their evolution follows closely until the quarter of the disaster, where sales growth drops considerably among the flooded firms in comparison to the control group. This is reassuring of the exogenous and localized nature of the shock we are studying.

Table 1: Summary statistics of flooded and non-flooded firms

	Flooded		Non-flooded	
	< 500m	< 5,000m	Rest of Wallonia	Rest of Belgium
Log Sales	11.29	11.13	11.21	11.22
	(1.37)	(1.41)	(1.45)	(1.56)
Log No. Employees	1.07	1.05	1.11	1.19
	(1.02)	(1.03)	(1.11)	(1.20)
Firm's age	18.76	17.92	17.50	18.02
	(14.88)	(15.22)	(14.04)	(14.32)
# Establishments	0.25	0.29	0.24	0.29
	(0.42)	(0.52)	(0.84)	(4.73)
Manufacturing	0.10	0.08	0.08	0.07
	(0.30)	(0.27)	(0.27)	(0.25)
Services	0.11	0.11	0.08	0.09
	(0.31)	(0.31)	(0.27)	(0.28)
Retail	0.11	0.13	0.10	0.10
	(0.31)	(0.33)	(0.30)	(0.30)
# Unique firms	1,249	5,757	44,982	231,669

The table reports the mean of a set of pre-flood characteristics of firms inside and outside the affected areas. The Wallonia and Belgium groups exclude all the treated firms; those with a distance below 5,000m to a flooded area. The number of establishments refer to the number of offices on top of the headquarters. The considered firms are all that provide non-missing values for the variables reported. Values taken for 2019. Standard deviations in parenthesis.

Figure 4: Sales growth trajectory



The Wallonia and Belgium groups exclude all the *potentially* treated firms (those with a distance below 5,000m to a flooded area). We consider only firms with non-missing values for the variables reported in Table 1.

4 Empirical Strategy

4.1 Direct Effects

Exploiting the exogenous nature of the shock, we use a difference-in-difference design to identify the effects of the flooding event. First, we tackle the identification of the effects on the firms directly exposed to the floods. The following specification illustrates our empirical strategy:

$$y_{ist} = \alpha_i + \alpha_{st} + \sum_{\tau \neq 0} \left(\beta_\tau \times \text{Flooded}_i \times \text{quarter}_\tau\right) + \sum_{\tau \neq 0} \left(\delta_\tau \times \boldsymbol{X}_{i0} \times \text{quarter}_\tau\right) + \varepsilon_{ist} \qquad (1)$$

Where y_{ist} represents the logarithm of sales in t of firm i that operates in sector s, Flooded_i is a binary indicator variable for whether firm i was flooded, quarter_τ denotes the time distance (in quarters) from the flooding event and $\boldsymbol{X}_{i0}$ comprises the pre-flood observable characteristics of i (number of full-time employees, number of establishments, age of the firm). As usual, α_i and α_{st} are firm and sector-quarter fixed effects. To assess the direct effects, we are interested in the set of coefficient β_τ with $\tau \in \{-4, ..., -1, 1, ..., 4\}$. In this stage, we remove from the estimation sample those firms with the highest supply-chain exposure. This intends to capture effects that are less underestimated in case of high pass-through effects.

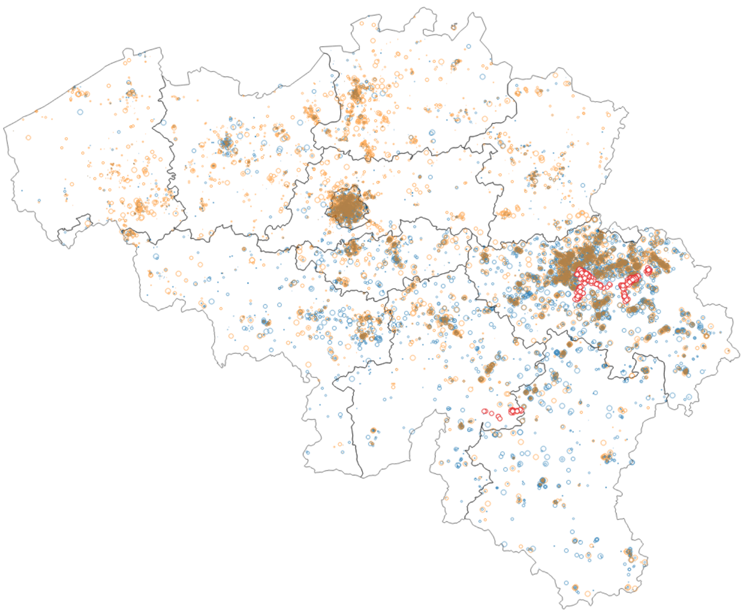
4.2 Propagation Effects

To assess the propagation effects, we consider a continuous measure of exposure for each of the firms that directly traded with any of the flooded firms at the moment of the shock. We refer to this set of firms as *first-order connected* firms. As detailed in Section 3.1, we rely on the B2B dataset to identify these first-order connected buyers and suppliers, and compute their upstream and downstream exposure in the following way:

$$\text{Upstream}_i^{(1)} = \frac{\sum_{j\in\mathcal{S}_i}(\text{Purchases}_{ij,\tau_0} * \text{Flooded}_j)}{\sum_{j\in\mathcal{S}_i}(\text{Purchases}_{ij,\tau_0})} \; ; \; \text{Downstream}_i^{(1)} = \frac{\sum_{j\in\mathcal{B}_i}(\text{Sales}_{ij,\tau_0} * \text{Flooded}_j)}{\sum_{j\in\mathcal{B}_i}(\text{Sales}_{ij,\tau_0})} \quad (2)$$

Where $\text{Purchases}_{ij,\tau_0}$ refer to the purchases from i to $j \in \mathcal{S}_i$ in $\tau = 0$, Sales_{ij,τ_0} refer to the sales from i to $j \in \mathcal{B}_i$ in $\tau = 0$, and the variable Flooded_j is a dummy that takes the value of 1 if the firm j was flooded. Ideally, we would like to observe both exposures *just* before the floods occurred. However, this is not possible since we only dispose from annual transaction data. In order to avoid capturing relationships that formed or evolved as a response of the shock in 2021, we construct the exposure using data from the two prior years. This implies that, for example, $\text{Purchases}_{ij,\tau_0}$ will account for the sum of purchases that buyer i made from supplier j in 2019 and 2020, given that there exist at least one buying transaction from i to j in 2021. We apply the exact same logic for the construction of the downstream exposure. Figure 5 shows the geographic distribution of the first-order connected buyers and suppliers across Belgium. Even though the shock was of a localized nature, it had a long reach through the production linkages with the rest of the economy.

Figure 5: Connected buyers and suppliers



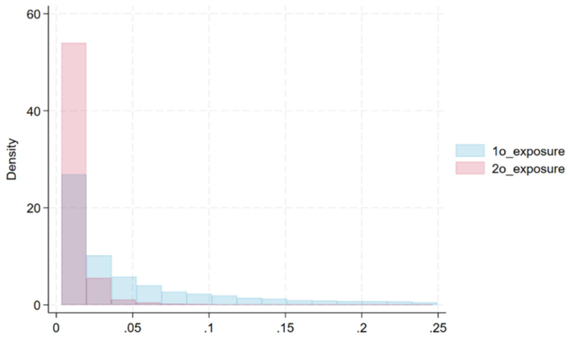
The red dots represent the flooded firms as described in Section 2.1. The blue dots represent the connected buyers of this set. The orange dots represent the connected suppliers. The size of the dots is weighted according to their level of trade exposure.

Under a similar procedure we can compute the k-order exposure to the shock for any firm i. We can define $\text{Upstream}_i^{(k+1)}$ and $\text{Downstream}_i^{(k+1)}$ for $k \in \{1, 2, ..., K\}$ by using the expressions derived in Eq. 2:

$$\text{Upstream}_i^{(k+1)} = \sum_{j \in \mathcal{S}_i} (\phi_{ij,\tau_0} * \text{Upstream}_j^{(k)}) \;;\; \text{Downstream}_i^{(k+1)} = \sum_{j \in \mathcal{B}_i} (s_{ij,\tau_0} * \text{Downstream}_j^{(k)}) \quad (3)$$

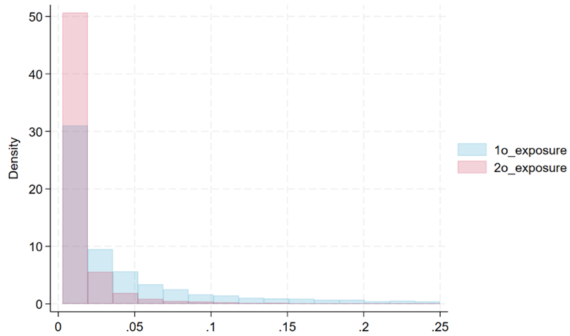
Where ϕ_{ij,τ_0} represents the share of j in the total purchases of firm i in $\tau = 0$, and s_{ij,τ_0} is the share of j in the total sales of firm i in $\tau = 0$. Intuitively, these variables measure the weighted exposure of a firm through their buyers and suppliers' exposure. To provide a more comprehensive picture of the linkages' strength, Figures 5 and 6 show the distribution of first and second order exposures across the economy. Naturally, the higher the exposure in the $k-$order chain, the higher the fading rate and the density of exposures around the lower end of the distribution.

Figure 6: Upstream Exposure



Note: We constructed the exposure as represented by Eq. 2 and 3. The measure is calculated for the period 2019-2020. The figure shows the density uniquely of values strictly different to 0. We censor the right end of the distribution for exposition purposes; the shown distribution includes more than 99 percent of observed values.

Figure 7: Downstream Exposure



Note: The measure is calculated for the period 2019-2020. The figure shows the density uniquely of values strictly different to 0. We censor the right end of the distribution for exposition purposes; the shown distribution includes more than 99 percent of observed values.

To estimate the propagation effects on the connected firms, we rely on a similar difference-in-difference strategy than the used in Eq. 1. We setup the following specification:

$$\begin{aligned} y_{ist} = &\sum_k \sum_{\tau \neq 0} \left(\beta_\tau^{U(k)} \times \text{Upstream}_i^{(k)} \times \text{quarter}_\tau \right) + \\ &\sum_k \sum_{\tau \neq 0} \left(\beta_\tau^{D(k)} \times \text{Downstream}_i^{(k)} \times \text{quarter}_\tau \right) + \sum_{\tau \neq 0} \left(\delta_\tau \times \mathbf{X}_{i0} \times \text{quarter}_\tau \right) + \alpha_i + \alpha_{st} + \varepsilon_{ist} \end{aligned} \quad (4)$$

In this case, we rule out from the estimation sample those firms that were directly affected by the floods in order to isolate the effects from the supply-chain exposure. As before, we control for pre-flood characteristics, industry-time fixed effects and individual fixed effects. The coefficients of interest are $\beta_\tau^{U(k)}$ and $\beta_\tau^{D(k)}$, which capture the dynamic effects of the upstream and downstream exposure on y, respectively. In this specification, $\text{Upstream}_i^{(k)}$ and $\text{Downstream}_i^{(k)}$ are constructed as detailed in Eq. 2 and 3.

Finally, we are also interested in which observed characteristics make a firm more (or less) resilient to a supply-chain shock - for a given exposure level. For this matter, we follow the recent work by Khanna et al. (2022) and setup a triple difference-in-difference specification of the following form:

$$
\begin{aligned}
y_{ist} = & \sum_k \beta^{U(k)} \left[\mathbb{1}\left(t > 2021\text{Q2}\right) \times \text{Upstream}_i^{(k)} \times Z_{i0} \right] + \sum_k \beta^{D(k)} \left[\mathbb{1}\left(t > 2021\text{Q2}\right) \times \text{Downstream}_i^{(k)} \times \mathbf{Z}_{i0} \right] \\
& + \sum_k \delta^{U(k)} \left[\mathbb{1}\left(t > 2021\text{Q2}\right) \times \text{Upstream}_i^{(k)} \right] + \sum_k \delta^{D(k)} \left[\mathbb{1}\left(t > 2021\text{Q2}\right) \times \text{Downstream}_i^{(k)} \right] \\
& + \gamma \left[\mathbb{1}\left(t > 2021\text{Q2}\right) \times \mathbf{Z}_{i0} \right] + \alpha_i + \alpha_{st} + \varepsilon_{ist}
\end{aligned}
\tag{5}
$$

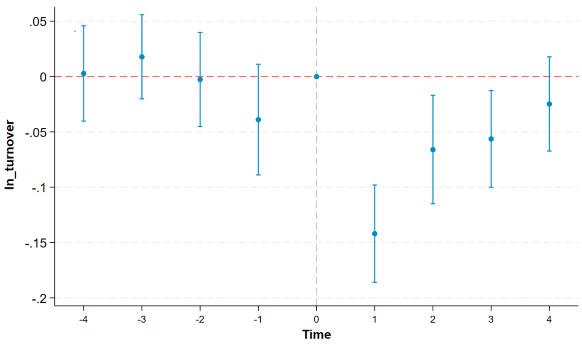
Here, the coefficients $\beta^{U(k)}$ $\left(\beta^{D(k)}\right)$ capture the differential resilience for firms with one percentage point higher upstream (downstream) exposure and also with one unit higher of the characteristic of interest $\mathbf{Z}_0$. For comparability purposes, we standardize the variables in the vector $\mathbf{Z}_0$. The set of coefficients δ and γ account for the average differential of the exposures and the characteristic $\mathbf{Z}_0$, respectively.

5 Results

5.1 Effect on flooded firms

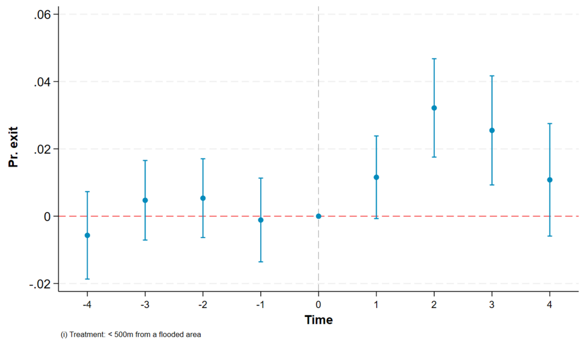
Our results indicate a strong effect on the performance of the flooded firms. Compared to their non-flooded counterparts, they experienced a decrease of 15 percent on their sales in the following quarter. The negative effect lasts for two more quarters and finally recovers to pre-shock levels on the fourth one. Figure 8 displays these results. An important remark is that this first set of results is conditioned on the treated firms surviving the floods. Therefore, its aggregate effect might be underestimated if we only analyse the sample of remaining firms. For this purpose, we analyze as well the effects on the exit probability[5] of the flooded firms. The results are shown in Figure 9, where it is possible to observe a significant increase after two quarters with respect to the control group.

Figure 8: Log Sales



Note: We plot the estimated β_τ coefficients from Eq. 1 and their 95% intervals. The dependent variable is the natural logarithm of sales. The omitted quarter is the 2021Q2.

Figure 9: Exit Probability



Note: We plot the estimated β_τ coefficients from Eq. 1 and their 95% intervals. The dependent variable indicates whether the firm has left the market. The omitted quarter is the 2021Q2.

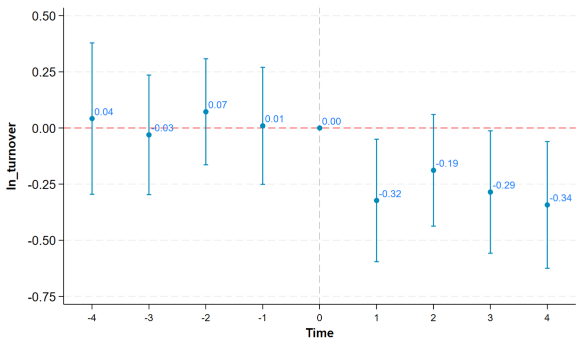
[5] We consider that the firms have left the market if: (i) they show sales equal to 0 on the database or (ii) they do not appear anymore in the registered list of firms in the VAT returns.

5.2 Propagation Effects

5.2.1 Effects on sales

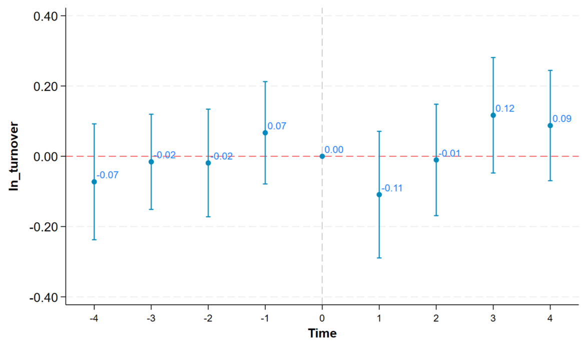
Our results suggest that the intensity of the effect depends on whether the connected firm is positioned upstream or downstream to the group of flooded firms. Our baseline specification focus on the first-order links ($k = \{1\}$) and narrows the exposure construction to those buyer-supplier relationships that started at least two years before the shock. Based on this specification, we find a negative and long-lived effect from upstream exposure on sales. As shown in Figure 10, these results indicate that an increase of 1 percentage point (pp.) in first-order upstream exposure reduced sales in almost 0.3 percent the following quarter which after three more quarters. The absence of significant pre-trends is reassuring of the exogenous nature of the exposure (conditioned on observables) before the shock. For the firms with downstream exposure, the effects on sales is less conclusive. There seems to be a small decrease in sales the period that comes immediately after the shock, which is followed by a fast recovery on the sales level. Nonetheless, under the conventional significance levels, we can not draw systematic differences with respect the control group. Figure 11 displays the coefficients for this group.

Figure 10: 1o-upstream exposure effects



Note: We plot the estimated $\beta_{\tau}^{U(1)}$ coefficients from Eq. 4 and their 95% intervals, with standard errors clustered at a firm-level. The labels indicate the point estimate. The dependent variable is the natural logarithm of sales. The omitted quarter is 2021Q2.

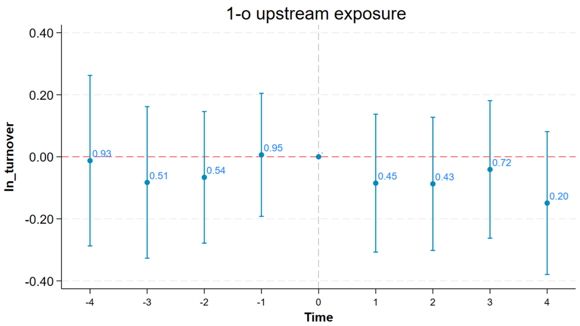
Figure 11: 1o-downstream exposure effects



Note: We plot the estimated $\beta_{\tau}^{D(1)}$ coefficients from Eq. 4 and their 95% intervals, with standard errors clustered at a firm-level. The labels indicate the point estimate. The dependent variable is the natural logarithm of sales. The omitted quarter is 2021Q2.

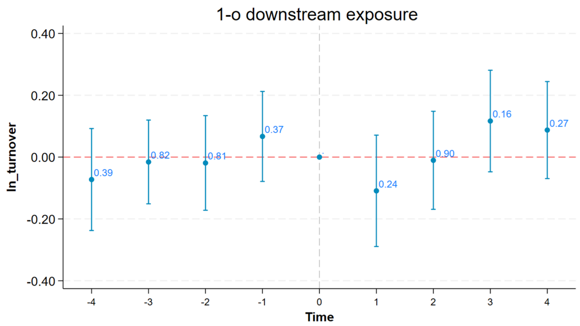
Interestingly, we show that the effects observed in Figure 10 are driven mainly by the enduring relationships with flooded suppliers. In Figure 12 we show that the effects diminish considerably once we allow the exposure variable to account also for transactions that were created only one year prior the flooding shock. This hints that disruptions in enduring input-relationships might be the most critical for the operation of downstream firms, which is in line with the input-specificity effects documented by Barrot and Sauvagnat (2016). On the contrary, the effects from downstream exposure do not seem to be particularly susceptible to these reformulation (see Figure 13).

Figure 12: Upstream effects inc. short-term



Note: We plot the estimated $\beta_{\tau}^{U(1)}$ coefficients from Eq. 4 and their 95% intervals, with standard errors clustered at a firm-level. The labels indicate the point estimate. The dependent variable is the natural logarithm of sales. The omitted quarter is 2021Q2.

Figure 13: Downstream effects inc. short-term

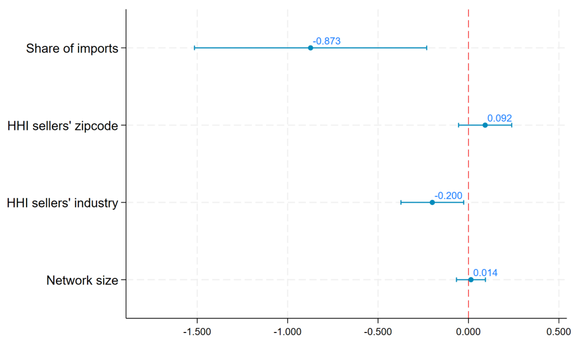


Note: We plot the estimated $\beta_{\tau}^{D(1)}$ coefficients from Eq. 4 and their 95% intervals, with standard errors clustered at a firm-level. The labels indicate the point estimate. The dependent variable is the natural logarithm of sales. The omitted quarter is 2021Q2.

5.2.2 Heterogeneous Effects

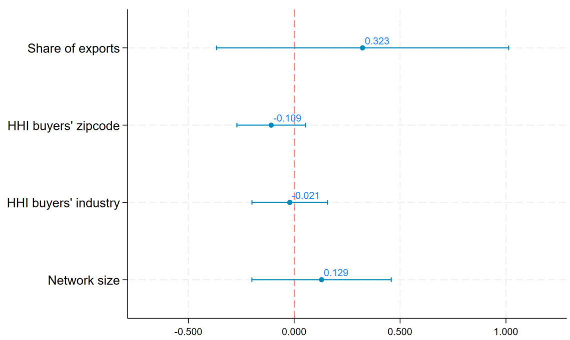
Next, we investigate which firm characteristics are associated with a higher resilience to shocks. We focus on three specific factors: network diversity, network size, and the weight of their international flows. These are the three variables that comprise $\mathbf{Z}_0$ in Eq. 5. For network diversity, we construct the Herfindahl-Hirschman Index (HHI) for the concentration of sales and purchases among (i) 2-digit NACE categories and (ii) operation zipcodes. These two should capture the industry and geographic diversification, both up and downstream. Next, for network size, we consider the total number and buyers of suppliers in the first layer of their production network. Finally, for the weight of the international inflows and outflows, we compute the proportion that imports and exports represented from their total sales. All these variables are computed in the year (or quarter, if data allows) before the flooding shock and then standardized for ease of interpretation and comparability.

Figure 14: Upstream het. effects



Note: We plot the estimated $\beta^{U(1)}$ coefficients from Eq. 5 and their 95% intervals, with standard errors clustered at a firm-level. The labels indicate the point estimate. The dependent variable is the natural logarithm of sales.

Figure 15: Downstream het. effects



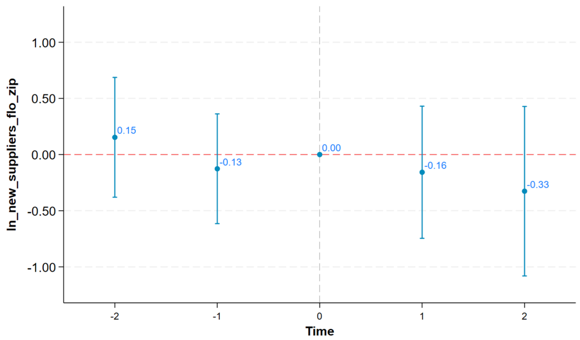
Note: We plot the estimated $\beta^{D(1)}$ coefficients from Eq. 5 and their 95% intervals, with standard errors clustered at a firm-level. The labels indicate the point estimate. The dependent variable is the natural logarithm of sales.

Figure 14 shows that, for a given a level of upstream exposure, firms with higher imports-to-sales proportions experienced an even stronger decline in sales following the floods. This could suggest that, for those connected firms, international and domestic inputs behave as productive complements rather than substitutes, making disruptions in the domestic supply-chain even harder to mitigate. In this vein, previous work by Boehm et al. (2019) has highlighted the low degree of substitution capacity between imported and domestic inputs, and its importance in the context of supply-chain disruptions. Considering that these results focus on long-enduring domestic relationships, this reading could be even more likely. We also find that firms with a higher upstream industry concentration suffer from a higher penalty when confronted by a supply-chain shock. We do not find significant differences when observing at geographic concentration (controlling by the concentration of their purchases to flooded firms) nor the size of the network. Finally, in Figure 15 we show the heterogeneity for the downstream exposure effects. In the line with general effects of this propagation channel, it becomes harder to draw significant conclusions also in terms of potential heterogeneity.

5.2.3 Network Composition Effects

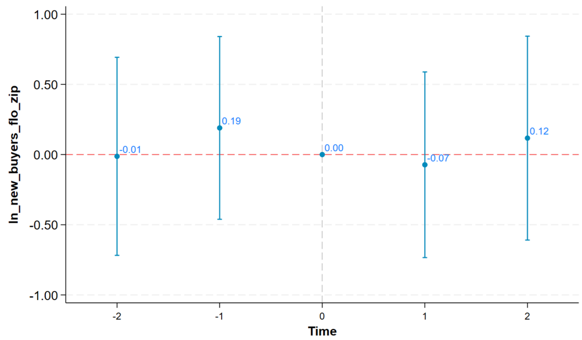
Finally, we study if firms with a higher supply-chain exposure are more prone to restructure the composition of their production networks in the light of a flooding shock. We leverage on the same specification as in Eq. 3, with the sole difference that supply-chain outcomes are only available on an annual basis. As response variables, we focus specifically on the formation of new buyer-supplier relationships with firms that operate in the areas that were flooded in 2021. This measure should reflect, at least partially, those intentions from firms to moderate their future exposure. Figure 16 shows the effect of a upstream exposure on the formation of new suppliers from flooded areas. In this case, we do not observe significant differences based on the ex-ante upstream exposure. This could mean that, in the light of the shock, firms readjust the their network composition regardless if they were highly affected or not. Alternatively, this might reflect that firms do not deem as likely the occurrence of a similar event in the short term, seconding the necessity to readjust their networks. Similar results are found for downstream exposure and the formation of production relationships with buyers from flooded areas (see Figure 17). These results remain consistent whether we analyze the exposure of long or short-lived buyer-supplier relationships.

Figure 16: New suppliers - upstream effects



Note: We plot the estimated β_τ coefficients from Eq. 3 and their 95% intervals, with standard errors clustered at a firm-level. The labels indicate the point estimate. The dependent variable is the natural logarithm of the new suppliers from flooded areas. The omitted quarter is the 2021Q2.

Figure 17: New buyers - downstream effects



Note: We plot the estimated β_τ coefficients from Eq. 3 and their 95% intervals, with standard errors clustered at a firm-level. The labels indicate the point estimate. The dependent variable is the natural logarithm of the new buyers from flooded areas. The omitted quarter is the 2021Q2.

6 Conclusions

Because of climate change, extreme weather events are increasingly likely to happen. It is crucial to know what the precise impact is of these events. In a modern economy, specialized firms are interconnected through the supply chain and any disruption in the production of goods or services is likely to also impact suppliers and buyers connected to the disrupted firms. Therefore, natural disasters will not only have an impact in the affected region itself. Estimates of the economic impact should therefore take into account the propagation and amplification of shocks throughout the whole economy.

This paper provides evidence on the economic impact of the July 2021 floods in Belgium. Leveraging the unique and highly detailed Belgian business-to-business database, we make an explicit distinction between direct effects on firms located in the flooded area and indirect effects through the supply chain. We find strong and significant direct effects of the floods. Firms active in the affected area have a significantly higher probability of exit. Moreover, conditional on survival, sales decrease on average by 15% and this negative effect lasted for at least three quarters after the floods. In terms of the supply chain effects, we find that it matters whether the firm is positioned upstream or downstream relative to the flooded firms. We find that one percentage point more upstream exposure decreases sales by almost 0.3%. These effects persist for at least four quarters after the shock and are mainly driven by long-term relations with flooded suppliers. The results related to downstream exposure to the shock are inconclusive.

In future updates of the paper, we will further explore the heterogeneity in the results and build a theoretical production network model to explain these results.

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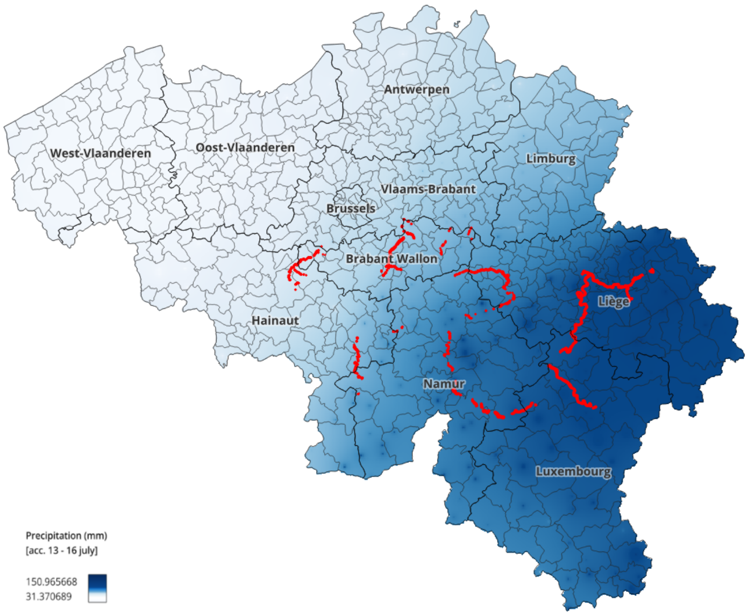
Appendix

Figure 18: Flood intensity



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