BIS Working Papers

No 1260

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by Douglas K.G. Araujo, Fernando Linardi and Luis Vissotto

Monetary and Economic Department

April 2025

JEL classification: E32, L14, Q54, R15

Keywords: climate-related physical risks, precipitation anomalies, supply chains, GDP growth

ISSN 1020-0959 (print)
ISSN 1682-7678 (online)

Supply chain transmission of climate-related physical risks*

Douglas K.G. Araujo[1], Fernando Linardi[2], Luis Vissotto[3]

[1]Bank for International Settlements, douglas.araujo@bis.org
[2]Banco Central do Brasil, fernando.linardi@bcb.gov.br
[3]Banco Central do Brasil, luis.vissotto@bcb.gov.br

Abstract

How do climate anomalies affect GDP growth, and how do trade connections help understand this impact? We address these questions exploring local fluctuations in temperature and precipitation coupled with data on supply chain linkages between municipalities in Brazil. GDP growth falls with local anomalous dry spells and to a lower extent, also wet spells. Much of this effect is attributable to moderate levels of climate anomaly. This impact is sufficiently material to transmit across supply chain connections to other municipalities. Focusing on pairs of distant municipalities to avoid common climate shocks, municipalities whose customer firms suffer dry spells have between 1 and 2 percentage points (p.p.) lower GDP growth. This supply chain shock also leads to lower import growth and weaker labour market metrics, suggesting an overall lower level of economic activity. We also examine the major economic sectors separately and find that agricultural activity is more sensitive to supply chain transmission of physical shocks, including moderate ones, than manufacturing (which responds mainly to intense supply chain shocks) or services. This suggests that the local economic mix can be a potentially important driver of effect heterogeneity. Using a counterfactual analysis, we estimate also that supply chain spillovers from climate change varies substantially over the years but can lead to 1 p.p. lower growth on average. Keywords: Climate-related physical risks. Precipitation anomalies. Supply chains. GDP growth. JEL Codes: E32, L14, Q54, R15.

1 Introduction

The macroeconomic impacts of physical shocks and their amplification mechanisms continue to be an important knowledge gap (Battiston, Dafermos, and Monasterolo (2021)). This work documents the importance of supply chains to paint a more complete picture of physical risks from climate change. Our analyses concentrate on the transmission of physical shock across Brazilian

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[*] This work represents the views of the authors and does not necessarily represent those of the Bank for International Settlements or the Banco Central do Brasil. The authors thank Rodrigo Barradas and Alejandro Parada for the research assistance, Tamma Carleton for the many insightful comments and suggestions, Thorsten Beck (discussant), Marshall Burke, Julián Caballero, Ben Cohen, Jon Frost, Deniz Igan, Enisse Kharroubi, Gabriela Nodari, Luiz Pereira, José-Luis Peydró, Kevin Tracol and Goetz van Peter, and participants in the 14th BIS CCA Research Network on 'Macro-financial implications of climate chance and environmental degradation', the II International Conference on the Climate Macro-Finance Interface: 'New Environmental Challenges for Fiscal, Monetary, and Macroprudential Policy' (2CMFI) and at seminars in the Banco Central do Brasil and the Banca D'Italia for many helpful comments that made the paper better.

municipalities directly connected to each other by trade. Using a unique administrative dataset, we explore the economic effects of local climate anomalies of different intensities in aggregate and across sectors. Next, we study how these economic impacts spread through supply chains beyond any local effect. Importantly, our estimates benefit from Brazil's continental size to disentangle the effects of simultaneous shocks occurring locally and in municipalities where supplier or customer firms are located.

Our data and methodology afford multiple dimensions of analyses. For example, the climate anomalies can relate to either wet or dry spells, and have different levels of intensity. In terms of location, the anomalies are measured for each municipality, but in our analyses they can also enter regressions as suppliers and/or customers to each other. Further, each municipality pair is identified as being a (geographically) "distant" link or not, where it is assumed that the distant ones do not share the same physical anomalies because of the distance. Finally, the economic outcome of interest is GDP growth at each municipality, as a whole or divided into agriculture, manufacturing or services sectors.

Using similar measurements of climate anomalies as in the scientific literature, we show that adverse climate anomalies of both moderate and intense magnitude influence local economic outcomes. Due to their sheer frequency and the magnitude of the coefficients, moderate shocks are responsible for the bulk of the effects. These local shocks in fact are so relevant that they spill over via supply chain linkages to impact other regions' economic growth. When customer firms are in municipalities suffering drought, this supply chain link leads to a depressed local labour market and foreign trade import activity, consistent with an increase in slack. Shocks in both customers and suppliers also lead municipalities to diversify more the location of their supply chain connections. But ultimately the effect of local and supply chain-transmitted climate shocks is heterogeneous, depending on the different sectoral mix of economic activity of each municipality: in particular, agriculture is the most sensitive economic sector to both local and moderate supply chain-transmitted shocks; manufacturing on the other hand is more sensitive to intense supplier shocks and services GDP growth is, on average, insulated from these shocks. This might be related to how climate physical shocks negatively impact agricultural yield, which in turn also serves as input to other crops and to animal husbandry - both macroeconomically relevant activities in Brazil.[1]

This work explores in more detail different types and intensity levels of precipitation anomalies across sectors and space. By focusing on Brazilian data instead of cross-country data, our work abstracts from important variations in economic structure and policy and thus a larger share of outcome variation comes from exposure to different local or supply chain climate shocks. Another advantage is that it allows the possibility to use a wealth of consistent datasets at the municipality level. Brazil is a good laboratory for studying the economic impact of climate shocks. Its continental area, geographical diversity, heterogeneous weather patterns as well as its vast biodiversity, result in variations in the exposure to climate-related events (Pörtner et al. (2022)). At the same time, Brazil is a middle-income country with municipalities in different levels of socio-economic development, all of them subjected to the same federal legal and monetary framework that allows for comparability between its regions. Importantly, as documented in Figure 1, most catastrophes

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[1] For example, Ahvo et al. (2023) show how interconnected agricultural supply chains can transmit shocks from lower crop yields within the sector.

in Brazil are related to climate, rather than from geological disasters.

Our findings contribute three main insights to the literature. First, we document economically relevant impacts of physical shocks also for climate anomalies that are not extreme or disastrous. This can raise awareness about the importance of those shocks to climate-related physical risks, as opposed to the focus on extreme events only. In addition, moderate shocks can increase the externally validity of findings compared to those obtained from large disasters, since the latter shed light on important economic questions that in some cases may be applicable only in similarly extreme situations. The second contribution is the strong evidence on how supply chain connections transmit climate economic shocks. Since these effects are measured after controlling for time and municipality, they can be interpreted as occurring above and beyond effects of climate anomalies on prices or other incentives that are not related to the trade linkages. Our third contribution relates to uncovering important aspects that drive heterogeneity in responses to local and remote climate shocks, in this case through the mix of local economic activity between the agricultural, manufacturing and services sectors.

Supply chain are but one form of transmission of local shocks to other localities. Other long-recognised channels include changes in prices (Hayek (1945), Flori, Pammolli, and Spelta (2021)), common banking links (Peek and Rosengren (1997), Fender and McGuire (2010), Cortés and Strahan (2017), Ivanov, Macchiavelli, and Santos (2022)), tourism flows (Anastasia Arabadzhyan and León (2021)), and others. And supply chains of course do not transmit only climate-related shocks: a long literature documents how trade links spread other natural disasters and even ad hoc trade events (Lafrogne-Joussier, Martin, and Mejean (2023)). Still, our findings that supply chain connections transmit economic shocks from different types of climate anomalies and in a heterogenous way, even when shocks are moderate, improves our understanding of the complex economic consequences of climate risks.

The rest of the paper is organized as follows. Section 2 describes the data and offers some background information on changes in average temperature and precipitation experienced by Brazilian municipalities in recent decades and presents the network of linkages among firms located in different municipalities. Section 3 analyse the local impact of climate anomalies, and Section 4 elaborates on those results to document the transmission of shocks through trade linkages. Section 5 breaks down the economic impacts into different broad sectors. A counterfactual exercise in Section 6 demonstrates the relevance of these findings. Then Section 7 connects the dots and concludes.

1.1 Literature

A long literature explores the economic effects of physical risks; with some insights learned also from the broader set of natural disasters that includes geological events. Some studies focus on the effect of temperature levels or deviations from long-term averages on economic growth (Dell, Jones, and Olken (2012); Burke, Hsiang, and Miguel (2015); Henseler and Schumacher (2019); Maximilian Kotz et al. (2021); Kalkuhl and Wenz (2020)). Other studies examine the effect of variability of temperature and precipitation on economic growth or GDP per capita (Felix et al. (2018); Damania, Desbureaux, and Zaveri (2020); Letta and Tol (2019); Kahn et al. (2021); M. Kotz, Levermann, and Wenz (2022)). S. Acevedo et al. (2020) documents a relationship between temperature shocks and reduced investment, depressed labour productivity, poorer human health, and lower agricultural and industrial output. Deryugina (2017) documents the fiscal effects of hurricanes, and the insurance provided by social safety nets. Hornbeck (2012) shows the short- and long-run adjustments in counties affected by the 1930s American Dust Bowl environmental catastrophe.

In a study of the 1950s drought in the US, Rajan and Ramcharan (2023) show that ex ante credit availability had a sizeable impact on the long-run effects of the drought through changing the ability of affected towns to adapt to the circumstances through investment and innovation. Kim, Matthes, and Phan (2022) use a smooth transition vector autoregression (pioneered by Auerbach and Gorodnichenko (2012)) applied to US data, finding substantial effects of climate-related physical risks on industrial production, consumption, unemployment and inflation. Parker (2018) also finds that climate disasters impact inflation, with a more pronounced effect in developing countries. The work by Gonzalez, Ornelas, and Silva (2023) illustrate the multi-sectoral impact of physical risks. They show that the 2015 Mariana environmental disaster caused affected farms to receive broadly half less payments (a proxy for revenue) from non-affected customers, and credit card and consumer finance balances to fall by 8%.

Another strand in the literature examines how economic losses propagate beyond local shocks. This is consistent with the argument made by Acemoglu et al. (2012) that sectoral shocks and their second-order effect can explain aggregate outcomes, and by Elliott, Golub, and Leduc (2022) about the possibility that supply chains can transmit even relative small shocks. Acemoglu, Akcigit, and Kerr (2016) show how the propagation of macroeconomic shocks through input-output and geographic networks can be a powerful driver of macroeconomic fluctuations. Wenz and Willner (2022) overview approaches to assess extreme weather events along global supply chains. Giroud and Mueller (2019) document how local shocks propagate across US regions through firms' internal networks of establishments, while Cravino and Levchenko (2017) investigate how multinational firms contribute to the transmission of shocks across countries. Additionally, studies have examined the propagation of natural disasters such as the 2011 Japan earthquake (Carvalho et al. (2020); Boehm, Flaaen, and Pandalai-Nayar (2019)) and Hurricane Sandy in the US (Kashiwagi, Todo, and Matous (2021)).

Using firm-level data, the papers show how shocks propagate through supply chains to areas not directly hit by disasters. Barrot and Sauvagnat (2016) use natural disasters in the US to document large effects on customer firms when their suppliers are disrupted, in a way that is consistent with specificity of their input to the production chain. Das et al. (2022) show that supply and demand shocks propagate upstream and downstream in the production and distribution network, both domestically and abroad. Feng, Li, and Wang (2023) show that international trade connections explain cross-border spillovers of climate shocks. Zappalà (2023) use a global sectoral production data to investigate the propagation of weather shocks to agriculture in a multi-region, multi-sector production network model. His paper explores linkages across sectors and space, showing that these linkages contribute significantly to loss estimates compared to estimates from aggregate projections of GDP on climate shocks.

2 Data

We combine multiple publicly-available climate and economic data at the municipal level with confidential Banco Central do Brasil (BCB) payments data. The primary features of these data are the richness of data at an disaggregated geographical level information, and the use of multiple complementary measures of weather anomalies that do not depend on individually identified large scale disasters. The research period spans from 2000 (local shocks) or 2012 (with supply chain data) to end-2019, a sufficiently long period that encompasses different economic policies and business cycle dynamics but avoids the turbulent Covid-19 pandemic period.

2.1 Climate data

Similar to the scientific literature on climate anomalies, our measure of climate anomalies comes from divergences in precipitation in a given location from its historical distribution. In particular, we use municipality-level precipitation and temperature readings since 1961 to calculate the *Standardized Precipitation Evapotranspiration Index* (SPEI) (Vicente-Serrano, Beguería, and López-Moreno 2010). This indicator measures the divergence between actual and expected temperature-adjusted precipitation in a given location for a given window of time. For example, the one-year adjusted precipitation values of a municipality are compared to its historical averages. The SPEI values are measured in standard deviations (s.d.) of the historical values for each location, and are thus comparable across locations and time. Positive readings indicate wetter climates than the historical average for a location, and conversely negative readings point to occurrences of droughts. This indicator is the basis for the physical shocks in this study due to the prevalence of this type of precipitation-related climate anomaly across Brazil (Figure 1).[2]

The SPEI measured at each time window reflects different physical implications of climate anomalies. For example, one-year SPEI is more informative about the effect of drought on soil humidity and river volumes, while five-year SPEI levels indicate more structural implications, such as on underground water reserve levels. Our preferred measure of physical shock is the one-year SPEI. A year-long deviation can be sufficiently material to overwhelm short-term resilience measures (such as input stocks in manufacturing firms) while not long-term enough to reshape how supply chains are structured. For example, abnormally high one-year SPEIs could indicate cases of excessive rain that leads to urban flooding, causing both loss of life and wealth (often also affecting poorer households' goods) as well as logistic obstacles to commerce.[3] In addition, a one-year shock horizon maps well with the annual frequency of the municipal GDP data.[4]

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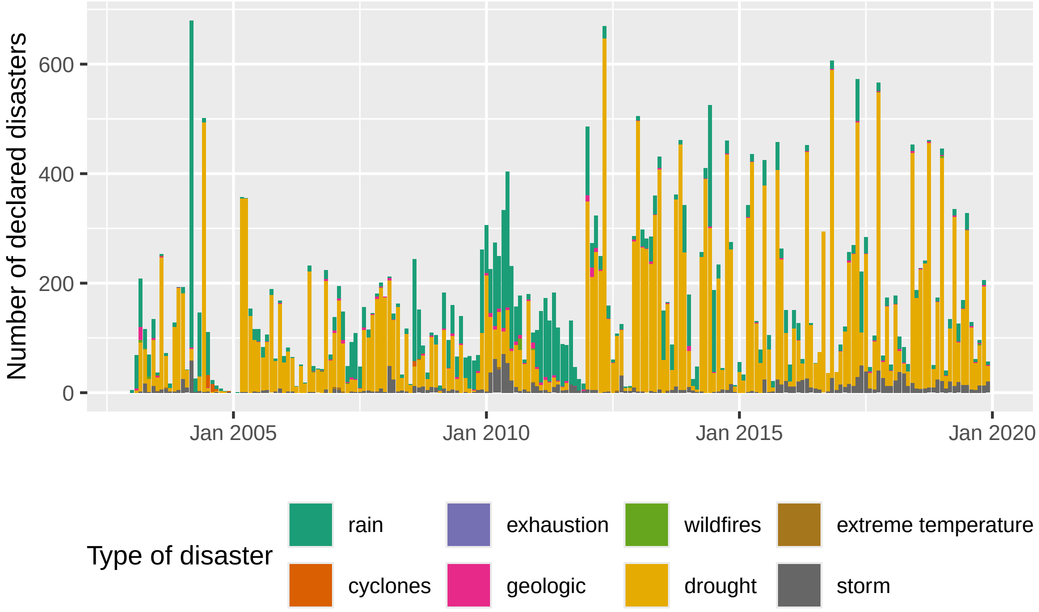
[2] Other widely-used indicators of precipitation anomaly include the Standardized Precipitation Index (SPI), closely related to the SPEI, and the Palmer Drought Severity Index (PDSI). The SPI follows a similar calculation as the SPEI but without any adjustment for temperature, which bias the anomaly estimations especially for more arid regions. The PSDI, on the other hand, is a fairly complex indicator that adjusts for temperature but also soil characteristics. For this reason, it is more directly associated with the soil-level damage of droughts. The SPEI can be interpreted as a balance between the simplicity of SPI with the usefulness of the nuances provided by the PDSI (Liu et al. (2024)).

[3] One of various examples from local news is about the damages to trucks hauling goods to and from a São Paulo warehouse, at (in Portuguese): https://valor.globo.com/agronegocios/noticia/2020/02/10/chuva-em-sp-leva-ceagesp-a-paralisar-atividades.ghtml.

[4] Throughout the paper, the main results are estimated with SPEI. But quantitative analyses with the related indicator *Standardized Precipitation Index* (SPI) (McKee et al. (1993), Edwards and McKee (1997), Guttman (1999))

Figure 1: Declared environmental disasters in Brazil



The historical weather data for the SPEI are taken from the widely-used Climatic Research Unit gridded Time Series (CRU TS) monthly dataset, version 4 (Harris et al. (2020)). This is a climate dataset on a grid with a resolution of 0.5° x 0.5° in latitude and longitude that consists of weather variables such as precipitation, temperature, diurnal temperature range, cloud cover, wind speed, and others. We use monthly precipitation and average daily mean temperature to calculate the SPEI at the municipality level using the SPEI R package (Beguería et al. 2014), with the gamma distribution calibrated with a rectangular kernel, ie all past observations in the one-year horizon have the same weight.

An interesting empirical feature that Brazil offers for the study of physical risks comes from the wide fluctuations in temperature and precipitation conditions observed during the research period. This is best seen in Figure 2, which portrays the 12-month rolling averages of the national unweighed mean of municipal temperature and precipitation values. Temperature levels have remained broadly below 24°C up until 2015, but have been consistently above that level since. And the precipitation level has swung widely to a peak in 2010, then gradually falling to reach levels that were not seen in the two decades before.

Our definition of “physical shock” is statistical: the positive and negative SPEI values of more

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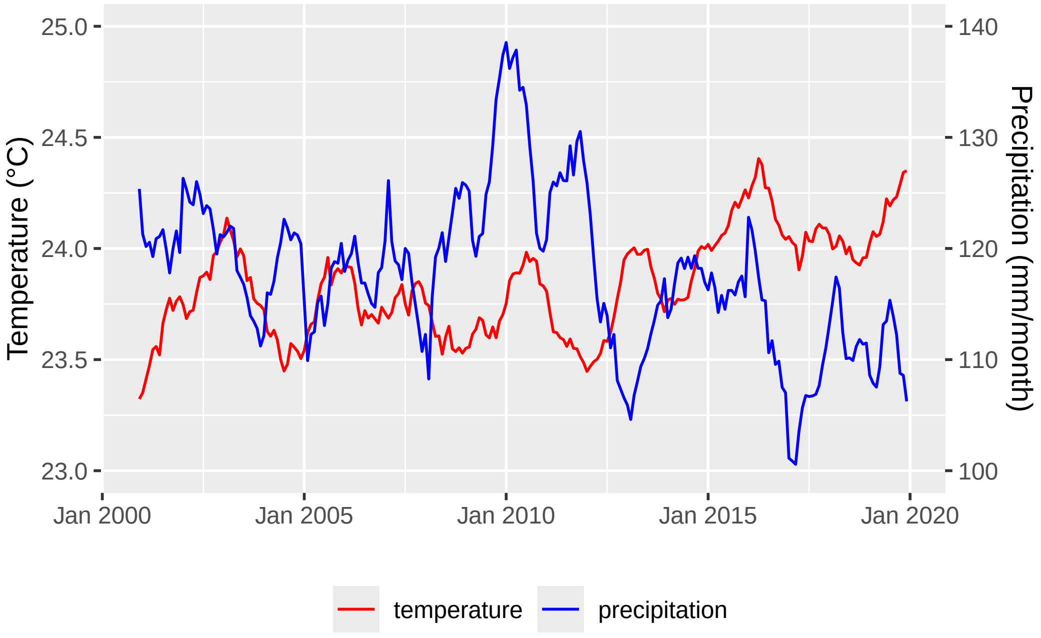
yield similar results, so are not reported. Conceptually, both the SPEI and SPI are different ways of calculating the deviations of precipitation from the long-term average for that same location and time period in the year, with these differences standardised according to the same distribution. The main difference between the SPEI and SPI is that the former relates only to precipitation, while the latter also corrects for changes in the temperature of a given location to better reflect the phenomenon of evapotranspiration, which is important for many physical phenomena such as water absorption by the soil or its use by plants. These sets of results are broadly the same.

Figure 2: Average 12-month temperature and precipitation levels in Brazil



than one s.d. (less than minus one) identify the "anomalous" episodes. Positive SPEI anomalies are also referred to as "wet spells" throughout; conversely, negative SPEI anomalies are "dry spells". This definition benefits from an intuitive understanding that anomalies are events tending towards the tails of distributions, and allows a natural quantitative comparison of the shocks. To explore variation in intensity of the anomalies, we consider all anomalies of more than two s.d. (or less than negative two s.d.) to be "intense", while the ones between one and two s.d. are called "moderate"; this notation is presented more formally in the empirical sections below.

Figure 3 shows the evolution of the climate anomalies identified this way. Note the virtual absence of intense positive shocks. For this reason, the empirical specifications below do not include this particular type of anomalies.

2.2 Supply chain data

The supply chain network is based on confidential BCB data on electronic funds transfers between firms' bank accounts at different banks.[5] This payment modality has no upper ceiling and settles on the same day, reasons for which it is widely used for interfirm payment. Correspondingly, these payments represent 42% of all transaction values according to BCB data,[6] the largest value share in the payments system within our period of analysis. Notably, this share remained stable even with the advent of the popular instant payments system Pix (Duarte et al. 2022).[7] This

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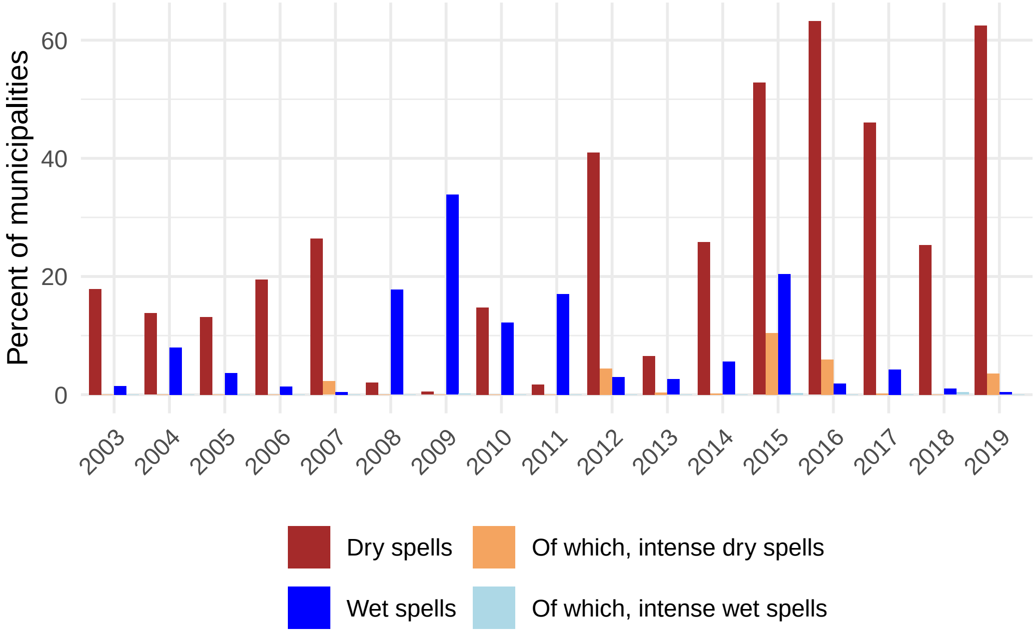
[5] Transfers between bank accounts in the same bank are settled internally in the bank's systems ("book transfer") and therefore do not go through the BCB payments system.

[6] Available at https://www.bcb.gov.br/estatisticas/spbadendos/.

[7] Available at https://www.bcb.gov.br/estabilidadefinanceira/estatisticaspix/.

Figure 3: Evolution of climate anomalies



underscores its relevance as a payment method for firms.

Importantly in our case, these electronic fund transfers help differentiate trade-related payments: other business-to-business payments such as expenditures with utilities companies are often settled via payment stubs, which use a different payments rail and are not captured in this data. The same firm-to-firm payments data have been used in other studies as a proxy for the supply chain network (eg Martins, Schiozer, and Linardi (2023), Gonzalez, Ornelas, and Silva (2023)) and also by the BCB in its oversight activities (Banco Central do Brasil (2015)).

Other works in the literature identify trade linkages with invoices (eg, P. Acevedo et al. (2023)) or regulatory filings by publicly-traded companies (eg, Qiu, Shin, and Zhang (2023)). Using payments data to proxy for supply chains, as done in this paper, has advantages and disadvantages. Payments identify exactly firms that are customers and suppliers to each other, even when these trade relationships are informal and thus are not documented in invoices. Payments also expand the universe of firms for which there is supply chain data beyond the typically large firms that are in some cases required to disclose public information. Another advantage is that the actual amounts are, by definition, observed.[8]

However, there are important limitations in how much the payments data we use can identify supply chain relationships. First, we cannot measure the whole supply chain network: as mentioned above, these payments only consider electronic transfers between accounts in different banks, since

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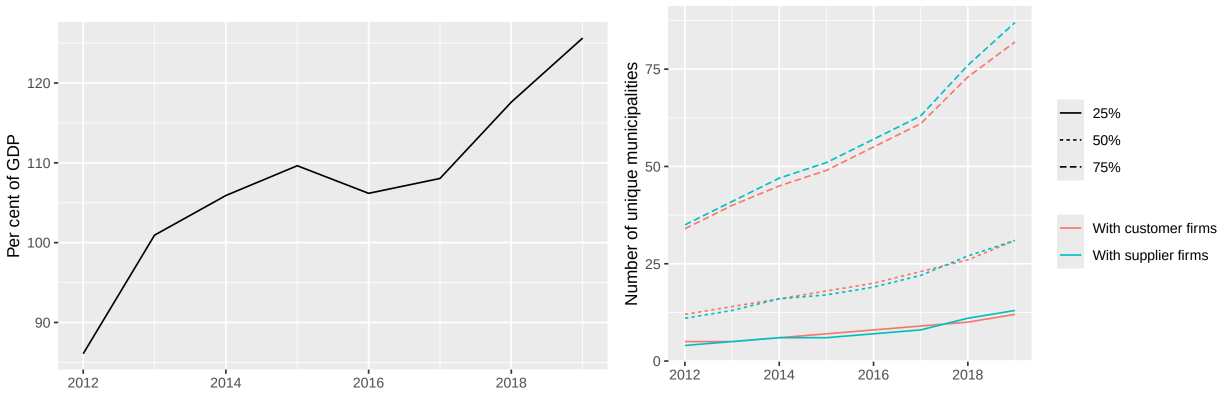
[8] Other papers that use the same dataset include Silva, Amancio, and Tabak (2022), Gonzalez, Ornelas, and Silva (2023), among others. Silva, Amancio, and Tabak (2022) discusses the dataset in more detail, including the evolution of network centrality measures over a similar time period to that of our analysis.

intrabank transfers are settled internally by the bank via book transfer. Cash or credit card payments are also not included, although typically those would relate to very small firms or mundane low-ticket purchases instead of actual production inputs. Transactions settled outside of Brazil, such as foreign trade, are also not considered. This means that supply chain identification might be suboptimal, especially in smaller municipalities where only one or two banks have active presence (generally the large, government-owned banks).[9] Another potential limitation is conceptual: electronic funds transfers correspond to the actual payment, not the sales process. In other words, links where the customer firm renege on their trade debts are not reflected in our data, even if the original purchase of goods or services created economic demand along its supply chain. Finally, the sample is constructed by clipping lower-value payments to constraint the dataset size and facilitate analyses. Only those payments with a minimum bilateral interfirm relationship of R$ 10,000 each quarter (around $2,300 as of November 2023) are present in the data.

The supply chain data we use have aggregate relevance for the Brazilian economy. In the left panel of Figure 4, the total amounts of firm-to-firm payments divided by Brazilian GDP shows that these payments amount to broadly the same magnitude as GDP. The right panel shows the distribution of number of connections over time; these numbers are broadly consistent with the detailed work of Silva, Amancio, and Tabak (2022).

Figure 4: Network metrics


(a) Electronic payment transfers between firms in Brazil

(b) Evolution of network connections

The network serves to identify cases where climate shocks occur throughout the supply chain. Table 1 presents the data on these connections, measured as the share of municipalities directly connected by trade. Each of dry and wet spells are measured separately, once for customers and once for suppliers. Two notable features are the time-variation of the series, consistent with Figure 3, and the differences between types of climatic shocks.

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[9] In addition, firms in the same sector tend to converge to the same bank (Paravisini, Rappoport, and Schnabl (2023)).

Table 1: Supply chain networks in Brazil

	Customer dry spells		Customer wet spells		Supplier dry spells		Supplier wet spells	
Year	Mean	SD	Mean	SD	Mean	SD	Mean	SD
2012	0.031	0.090	0.080	0.151	0.035	0.108	0.033	0.084
2013	0.005	0.033	0.002	0.020	0.007	0.046	0.002	0.017
2014	0.054	0.106	0.001	0.009	0.053	0.126	0.001	0.007
2015	0.059	0.110	0.098	0.156	0.045	0.102	0.041	0.085
2016	0.162	0.186	0.004	0.030	0.119	0.175	0.004	0.028
2017	0.147	0.177	0.007	0.032	0.109	0.163	0.004	0.025
2018	0.104	0.150	0.004	0.023	0.061	0.106	0.003	0.018
2019	0.156	0.175	0.002	0.018	0.124	0.153	0.002	0.019

The climate shocks are not collinear, but shocks of a similar type are somewhat correlated. Table 2 shows that the correlation between the percentage of in- and out-flows (ie, flows from customers and to suppliers) to firms suffering the same type physical shocks (wet or dry spells) have a sizeable but still contained correlation of circa one third. In contrast, there is little correlation between exposures to municipalities suffering different types of climate shocks, as expected.

Table 2: Correlation between remote supply chain climate shocks

	Customer wet spell	Customer dry spell	Supplier wet spell	Supplier dry spell
Customer wet spell	1			
Customer dry spell	-0.082	1		
Supplier wet spell	0.329	-0.037	1	
Supplier dry spell	-0.044	0.369	-0.051	1

2.3 Economic and geographic variables

The municipality-level economic and geographic variables come from the Brazilian statistical institute (IBGE). We obtain annual municipal GDP (in total and divided by broad economic sectors), as well as latitude and longitude coordinates of each municipality. The municipal GDP growth numbers are summarised in Table 3.

Table 3: Municipal GDP growth in Brazil

	GDP		GDP agriculture		GDP manufacturing		GDP services	
Year	Mean	SD	Mean	SD	Mean	SD	Mean	SD
2003	0.176	0.149	0.259	0.301	0.048	0.344	0.155	0.148
2004	0.095	0.137	0.054	0.278	0.182	0.325	0.111	0.135
2005	0.068	0.146	-0.056	0.284	0.044	0.330	0.102	0.135
2006	0.112	0.132	0.072	0.273	0.186	0.381	0.122	0.124
2007	0.122	0.137	0.092	0.277	0.065	0.339	0.119	0.131
2008	0.149	0.128	0.173	0.292	0.100	0.350	0.132	0.126
2009	0.079	0.128	0.056	0.244	0.151	0.364	0.104	0.127
2010	0.129	0.146	0.059	0.277	0.247	0.413	0.120	0.147
2011	0.138	0.127	0.161	0.281	0.158	0.326	0.143	0.127
2012	0.092	0.147	-0.041	0.326	0.094	0.331	0.144	0.131
2013	0.136	0.157	0.191	0.326	0.049	0.359	0.136	0.125
2014	0.092	0.138	0.069	0.259	0.112	0.346	0.124	0.142
2015	0.065	0.137	0.031	0.234	0.053	0.356	0.070	0.118
2016	0.082	0.144	0.144	0.275	0.036	0.350	0.081	0.130
2017	0.051	0.131	-0.025	0.322	0.038	0.300	0.065	0.124
2018	0.044	0.125	-0.021	0.236	0.044	0.316	0.060	0.118
2019	0.051	0.107	0.017	0.230	0.068	0.274	0.058	0.107

Foreign trade data comes from Base dos Dados (Dahis et al. (2022)), who clean the original data from the Brazilian Economics Ministry. The data is aggregated to a municipality level. An overview of this data is provided in Table 4. However, not all municipalities engage in foreign trade: only 1884 municipalities out of 5570 have either export or import data at any given year after 2012 (when the network data begins).

Table 4: Evoution of municipal foreign trade in Brazil

	Exports (log USD)		Export growth		Imports (log USD)		Import growth	
Year	Mean	SD	Mean	SD	Mean	SD	Mean	SD
2012	15.802	3.128	-0.014	1.261	15.071	3.267	0.023	1.244
2013	15.655	3.213	0.025	1.235	15.060	3.257	0.126	1.306
2014	15.735	3.116	0.114	1.231	15.068	3.232	0.051	1.330
2015	15.668	3.114	-0.087	1.261	14.833	3.285	-0.318	1.389
2016	15.540	3.166	0.045	1.365	14.631	3.235	-0.180	1.351
2017	15.638	3.179	0.101	1.224	14.645	3.317	0.080	1.334
2018	15.676	3.181	0.054	1.362	14.776	3.312	0.148	1.291
2019	15.523	3.243	0.064	1.411	14.681	3.318	0.052	1.380

3 Effect on local economic activity

In this section, we lay out our basic empirical strategy for the analysis of physical shocks and their effects on GDP growth. These local impacts act as a natural benchmark for the subsequent results. We begin by estimating the effects of temperature and precipitation anomalies as captured by SPEI on aggregated outcomes at the municipality-year level. Then, a similar regression using different intensities of the local physical shock breaks down the headline effect.

Our core model used to estimate the effects from local climate anomalies is Equation 1:

$$y_{i,t} = \theta y_{i,t-1} + \alpha_i + \gamma_t + \iota \kappa_{i,t-1} + \sum_k \beta^k_{\text{Local}} \eta^k_{i,t} + \epsilon_{i,t}, \tag{1}$$

where $y_{i,t}$ is the yearly GDP growth of the municipality i in year t, α_i denotes municipality fixed effects to absorb municipality-specific time-invariant characteristics, and γ_t denotes year fixed effects to control for year-specific characteristics/shocks common to all locations. $\kappa_{i,t-1}$ is the vector of existing climatic conditions (temperature and precipitation) at municipality i in the previous year; and ι is the adaptation coefficient, which we assume is constant throughout the sample period.[10] $\eta^k_{i,t}$ are dummies that represent the occurrence of climate anomalies in municipality i, with type of climate anomaly $k \in \{\text{wet}, \text{dry}\}$ representing whether the shock is a wet spells or a dry period. Specifically, $\eta^k_{i,t}$ are defined in this paper as 1 if the one-year SPEI is higher or lower than ± 1 s.d. (depending on k), and zero otherwise. $\epsilon_{i,t}$ is the error term, with a covariance matrix clustered at the mesoregion level (see Figure 5).[11]

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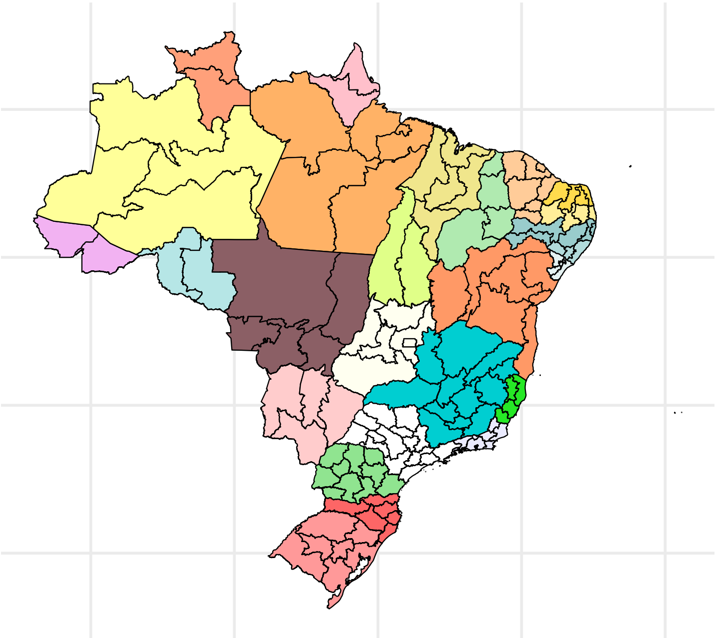
[10] See Carleton et al. (forthcoming) for an in-depth discussion about the economics of climate adaptation.

[11] The Federal District mesoregion only has one municipality, Brasília. We merge it into the East Goiás mesoregion, avoiding a single-municipality cluster.

Figure 5: Brazil mesoregions, coloured by Brazilian State



The coefficients of interest are β^k_{Local}, which measure the effect of the different weather anomalies on local economy. Equation 1 can be interpreted as a simple stochastic growth model (Brock and Mirman (1972)), similar to von Peter, von Dahlen, and Saxena (2024),[12] and the physical risks are shocks to the system.

Local climate shocks lead to lower economic growth contemporaneously (Table 5). There is a statistically and economically significant effect of lower precipitation on contemporaneous economic growth. This result is consistent with other studies (Mohaddes et al. 2023). Wet spells are also associated with lower economic growth, albeit less strongly than dry spells and with a lower magnitude. Wet spells are associated with circa half a percentage point lower growth, while negative precipitation shocks contemporaneously lower annual GDP growth by more than 1 percentage point on average with more statistical significance. These results are on top of constant municipality or year effects, as well as municipality-specific lagged climate conditions.

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[12] von Peter, von Dahlen, and Saxena (2024) use the stochastic growth model to estimate the long-term macroeconomic costs of natural disasters. Their model, which counts with more lags to better estimate the growth dynamics, allows a direct estimate of long-term effects as $\frac{\beta^k_{\text{Local}}}{1-\sum_\ell \theta_\ell}\eta_{i,t}$, with ℓ being the lag in their model. Given the relatively brief time series, in this paper we focus on the short-term, contemporaneous effect.

Table 5: Influence of local abnormal precipitation on GDP

Dependent Variable:	GDP growth	
Model:	(1)	(2)
Variables		
Wet spell	-0.0051*	-0.0059*
	(0.0030)	(0.0030)
Dry spell	-0.0173***	-0.0137***
	(0.0028)	(0.0026)
Avg. prec. (t-1)		0.0003*
		(0.0002)
Avg. temp. (t-1)		0.0287**
		(0.0120)
GDP growth (t-1)	-0.1859***	-0.1841***
	(0.0146)	(0.0142)
Fixed-effects		
Municipality	Yes	Yes
Year	Yes	Yes
Fit statistics		
Observations	88,931	88,931
R^2	0.11958	0.12165
Within R^2	0.03779	0.04005

Clustered (Region) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Breaking down physical shocks by their intensity highlights the importance of moderate shocks to economic outcomes. In these analyses, physical shocks are broken down into $\eta^k_{i,t} = \underline{\eta}^k_{i,t} + \bar{\eta}^k_{i,t}$, where 1 s.d. $\leq \underline{\eta}^k_{i,t} < 2$ for $k =$ wet spells and -1 s.d. $\geq \underline{\eta}^k_{i,t} > -2$ for $k =$ dry spells. Correspondingly, $\bar{\eta}^k_{i,t} \geq 2$ s.d. for wet spells and the opposite for dry spells. Equation 1 becomes:

$$y_{i,t} = \theta y_{i,t-1} + \alpha_i + \gamma_t + \iota \kappa_{i,t-1} + \sum_k \beta^k_{\text{Local moderate}} \underline{\eta}^k_{i,t} + \sum_k \beta^k_{\text{Local intense}} \bar{\eta}^k_{i,t} + \epsilon_{i,t},$$

although in practice, given the lack of intense wet shocks, the empirical estimates do not include $\widehat{\beta}^{\text{Wet}}_{\text{Local intense}}$.

As seen in Table 6, the effects observed in Table 5 can be attributed mostly to the moderate portion of the shocks. The coefficient on moderate dry spells has a similar magnitude to the overall effect: $\widehat{\beta}^{\text{Wet}}_{\text{Local moderate}} \approx \widehat{\beta}^{\text{Wet}}_{\text{Local}}, \widehat{\beta}^{\text{Dry}}_{\text{Local moderate}} \approx \widehat{\beta}^{\text{Dry}}_{\text{Local}}$. And in any case the more intense shocks are, by definition, less frequent. Moderate dry spells lower GDP growth by more than one percentage point. And while more intense shocks have a statistically significant impact that is larger in magnitude than that of moderate shocks, this effect dilutes somewhat when climatic conditions are considered. Intense shocks capture headlines and are also the identifying assumption in part of the physical risks literature, but these results point to the relevance of moderate shocks for understanding the economic impact of climate anomalies.

Table 6: Influence of local moderate and intense abnormal precipitation on GDP

Dependent Variable:	GDP growth	
Model:	(1)	(2)
Variables		
Mod. wet spell	-0.0053*	-0.0060**
	(0.0030)	(0.0030)
Mod. dry spell	-0.0171***	-0.0137***
	(0.0028)	(0.0025)
Int. dry spell	-0.0220***	-0.0142**
	(0.0064)	(0.0070)
Local prec. lag		Yes
Local temp. lag		Yes
Local GDP lag	Yes	Yes
Fixed-effects		
Municipality	Yes	Yes
Year	Yes	Yes
Fit statistics		
Observations	88,931	88,931
R^2	0.11960	0.12165
Within R^2	0.03781	0.04005

Clustered (Region) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

4 Supply chain transmission of climate shocks

The significance of local physical shocks for economic growth raises the question of potential spillovers to other regions connected by trade. In this section, we study the transmission of physical shocks over the supply chain network. Compared to the previous section, we now combine the municipality climate and GDP data with the network of municipalities connected by payments between firms. We estimate the impact of the weather shocks beyond the impact on municipalities directly exposed to the shock by taking these propagation effects into account. The regressions from this section onward have less data points because the supply chain network dataset starts in 2012.

We extend Equation 1 to include shocks from other municipalities where supplier and customer firms are located, as in Equation 2 below:

$$\begin{aligned} y_{i,t} = \theta y_{i,t-1} + \alpha_i + \gamma_t + \iota \kappa_{i,t-1} + \sum_k \beta^k_{\text{Local}} \eta^k_{i,t} + \\ \sum_k \beta^k_{\text{Customers}} \sum_j \omega_{i,j,t} \eta^k_{j,t} + \sum_k \beta^k_{\text{Suppliers}} \sum_h \rho_{i,h,t} \eta^k_{h,t} + \epsilon_{i,t}, \end{aligned} \tag{2}$$

with

$$\omega_{i,j,t} \geq 0, \sum_j \omega_{i,j,t} \leq 1 \text{ and } \rho_{i,j,t} \geq 0, \sum_j \rho_{i,j,t} \leq 1,$$

where $\omega_{i,j,t}$ and $\rho_{i,j,t}$ are the shares that municipality j represent on i's total customers and suppliers in year t, respectively. These numbers include the firms that buy and sell to other firms in the same municipality i. Hence, these weights don't necessarily sum up to unit. The coefficients of interest are $\beta^k_{\text{Customers}}$ and $\beta^k_{\text{Suppliers}}$.

Estimating these effects requires a clean measure of supply chain climate shocks, which is not always straightforward. For example, municipality pairs might experience the same climate anomalies if they are geographically close. To mitigate concerns about shared climate shocks, the regressions that include supply chain connections only include connected municipalities that are more distant than the median distance between all connected municipalities, approximately 572.9 km.[13] Municipalities far apart for more than 572.9 km are likely to not share the same climate (or weather) occurrences, assuaging concerns about commonality of climate anomalies being the main driver of the results. While the subset of remote municipalities comprises a smaller share of sales than the whole population of municipalities, regressions run with the broader population of trade counterparty municipalities without filtering by distance (not reported) have broadly the same R^2 as the reported results, which consider only the remote trade counterparties.

First, we regress local GDP growth on climate shocks suffered by connected municipalities. The first column of Table 7 considers only wet spell shocks affecting customer firms ($\beta^{\text{Wet}}_{\text{Customers}}$), followed by an analysis of the dry spells from customers ($\beta^{\text{Dry}}_{\text{Customers}}$); the third column estimates both of these coefficients together. The fourth and the fifth column look at $\beta^{\text{Wet}}_{\text{Supplier}}$ and $\beta^{\text{Dry}}_{\text{Supplier}}$, with the sixth column combining both. Finally, the last column estimates all these forms of climate shock jointly, ie the full specification in Equation 2.

---

[13] This is comparable to the distance between Basel and Amsterdam, San Francisco and Los Angeles, Luanda and Kinshasa or Tokyo and Aomori as the crow flies.

Table 7: Influence of local and remote supply chain climate shocks on GDP

Dependent Variable:	GDP growth						
Model:	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Variables							
Wet spell	-0.0187***	-0.0190***	-0.0188***	-0.0197***	-0.0198***	-0.0197***	-0.0180***
	(0.0052)	(0.0052)	(0.0052)	(0.0057)	(0.0057)	(0.0057)	(0.0053)
Dry spell	-0.0106***	-0.0106***	-0.0107***	-0.0100***	-0.0100***	-0.0101***	-0.0103***
	(0.0037)	(0.0037)	(0.0037)	(0.0038)	(0.0038)	(0.0038)	(0.0037)
Customer wet spell	0.0152		0.0095				0.0026
	(0.0123)		(0.0130)				(0.0159)
Customer dry spell		-0.0196**	-0.0183*				-0.0161
		(0.0094)	(0.0098)				(0.0114)
Supplier wet spell				0.0143		0.0110	0.0124
				(0.0255)		(0.0257)	(0.0289)
Supplier dry spell					-0.0138	-0.0133	-0.0049
					(0.0087)	(0.0088)	(0.0106)
Local prec. lag	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Local temp. lag	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Local GDP lag	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fixed-effects							
Municipality	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Fit statistics							
Observations	38,233	38,233	38,233	37,108	37,108	37,108	34,547
R^2	0.17987	0.18004	0.18006	0.18036	0.18044	0.18045	0.19075
Within R^2	0.05721	0.05740	0.05742	0.05910	0.05919	0.05920	0.05946
Wald (supply chain)	0.21407	0.03777	0.06306	0.57648	0.11511	0.26187	0.57020

Clustered (Region) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Consistent with Table 6, there is evidence that dry spells in municipalities with customer firms lower GDP growth, even after local climate anomalies and other conditions are considered. This effect is economically large: if all customer municipalities suffered an anomalous dry spell, GDP growth would be on average close to 2 p.p. smaller. However, jointly estimating $\widehat{\beta}^{\text{Dry}}_{\text{Customer}}$ along with the other supply chain coefficients increases the uncertainty around it, even as the point estimates reduces only slightly. As shown below in Table 10, when accounting for how supply chain shocks themselves might be correlated, the effect of $\widehat{\beta}^{\text{Dry}}_{\text{Customer}}$ is visible. Further, a sectoral breakdown of the effect of supply chain climate shocks (shown in Table 14) reveals that this particular shock impacts primarily agricultural economic activity, which helps explain why the aggregate GDP growth effects are not significant.

Focusing now on the intensity of customer and supplier shocks, we estimate the following extension of Equation 2:

$$
\begin{aligned}
& y_{i,t} = \theta y_{i,t-1} + \alpha_i + \gamma_t + \iota \kappa_{i,t-1} + \sum_k \beta^k_{\text{Local}} \eta^k_{i,t} + \\
& \sum_k \beta^k_{\text{Customers moderate}} \sum_j \omega_{i,j,t} \underline{\eta}^k_{j,t} + \sum_k \beta^k_{\text{Customers intense}} \sum_j \omega_{i,j,t} \bar{\eta}^k_{j,t} + \\
& \sum_k \beta^k_{\text{Suppliers moderate}} \sum_h \rho_{i,h,t} \underline{\eta}^k_{h,t} + \sum_k \beta^k_{\text{Suppliers intense}} \sum_h \rho_{i,h,t} \bar{\eta}^k_{h,t} + \epsilon_{i,t}.
\end{aligned}
\tag{3}
$$

Moderate dry spells in customer municipalities can also impact growth. The columns of Table 8 break down transmissions of shocks from remote customers (first column) and suppliers (second column) into moderate and intense shocks. The third column focuses only on intense shocks, and the fourth column examines the breakdown along the supply chain jointly.

Both moderate and intense dry spells in remote customer municipalities depress GDP growth, helping to explain the results in Table 7. But the similarity in the point estimate of $\widehat{\beta}^{\text{Dry}}_{\text{Customers moderate}}$ with $\widehat{\beta}^{\text{Dry}}_{\text{Customers}}$ in Table 7, along with the more frequent occurrence of moderate shocks compared to more intense shocks (by virtue of how they are defined) indicates that moderate shocks are responsible for the bulk of the supply chain transmission. Further evidence that the main effect is attributable to moderate shocks comes from the Wald test of the nullity of the coefficients on $\bar{\eta}^k_{j,t}$: while it seems to provide some new information when only customer shocks are considered (first column, significance around the 10% mark), this is rejected for the other specifications.

Table 8: Influence of local and remote supply chain climate shocks on GDP by intensity

Dependent Variable:	GDP growth			
Model:	(1)	(2)	(3)	(4)
Variables				
Mod. customer wet spell	0.0090			0.0017
	(0.0130)			(0.0159)
Mod. customer dry spell	-0.0170*			-0.0150
	(0.0098)			(0.0115)
Int. customer dry spell	-0.0483*		-0.0356	-0.0397
	(0.0279)		(0.0316)	(0.0323)
Mod. supplier wet spell		0.0116		0.0140
		(0.0257)		(0.0291)
Mod. supplier dry spell		-0.0123		-0.0034
		(0.0088)		(0.0109)
Int. supplier dry spell		-0.0369	-0.0330	-0.0318
		(0.0302)	(0.0317)	(0.0320)
Local anomaly	Yes	Yes	Yes	Yes
Local prec. lag	Yes	Yes	Yes	Yes
Local temp. lag	Yes	Yes	Yes	Yes
Local GDP lag	Yes	Yes	Yes	Yes
Fixed-effects				
Municipality	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Fit statistics				
Observations	38,233	37,108	34,547	34,547
R^2	0.18009	0.18046	0.19064	0.19079
Within R^2	0.05746	0.05922	0.05933	0.05951
Wald (intense)	0.10019	0.31750	0.30764	0.66107

Clustered (Region) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

What is the nature of the impact from customer dry spell shocks on local economic activity? The regressions in Table 9 shed some light to this question. Each column is a regression of a different economic variable, also at the municipal level, on $\sum_j \omega_{i,j,t}\eta_{j,t}^{\text{Dry}}$ and standard controls. The first two columns look at foreign trade, namely at municipalities' export and import growth. The remaining three columns look at the labour market: total payroll growth and its decomposition into the average wage and jobs growth. These columns control for contemporaneous export and import growth to capture the final effect of the climate shock on employment variables, after considering any endogenous adjustment through foreign trade channels.

Building on findings connecting domestic and international supply chains (eg, Inoue and Todo (2023)), we find visible effects on import growth and on labour market dynamics when controlling for contemporaneous developments in foreign trade. In other words, these results already account for potential re-directing of activity towards other clients after Brazilian customers suffer a dry spell shock. Growth of imports (in US dollar) falls markedly, even when considering the potential to export products;[14] consistent with lower demand from domestic customers slowing import activity. This is also visible in labour market data: total payroll falls markedly, driven mainly by a reduction in the number of jobs but also, to some extent, by lower average wages.[15]

Table 9: Influence of remote customer dry spell on economic variables

Dependent Variables:	Export growth	Import growth	Payroll growth	Avg wage growth	Jobs growth
Model:	(1)	(2)	(3)	(4)	(5)
Variables					
Customer dry spell	0.1025	-0.3944*	-0.0703***	-0.0191*	-0.0521**
	(0.1853)	(0.2277)	(0.0262)	(0.0102)	(0.0220)
Lagged dep. variable	Yes	Yes	Yes	Yes	Yes
Contemp. export growth		Yes	Yes	Yes	Yes
Contemp. import growth	Yes		Yes	Yes	Yes
Contemp. payroll growth	Yes	Yes			
Local anomaly	Yes	Yes	Yes	Yes	Yes
Local prec. lag	Yes	Yes	Yes	Yes	Yes
Local temp. lag	Yes	Yes	Yes	Yes	Yes
Fixed-effects					
Municipality	Yes	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes	Yes
Fit statistics					
Observations	9,691	9,691	10,742	10,742	10,742
R^2	0.30800	0.32709	0.27109	0.40938	0.26025
Within R^2	0.18590	0.21437	0.04695	0.04978	0.05245

Clustered (Region) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

In short, dry spells in municipalities with customer firms spill over to local economic consequences, even after considering the local climatic situation (which continues to be meaningful). The supply chain-transmitted effect is due, in part, to moderate shocks, even in remote municipalities. And there is evidence that its effects depresses the local job market, even after accounting for any potential adjustment to foreign trade. Moreover, this lower economic activity leads to what is possibly lower demand for imported products.

Supply chains are not the only way that two economic locations can be connected. Multiple other channels can contribute to transmitting economic shocks. For example, financial integration through banks contributes to synchronising business cycles (eg, Kalemli-Ozcan, Papaioannou, and Perri (2013)), tourism flows are associated with economic integration (Khalid, Okafor, and Burzynska (2022)) and reliance on the same commodities for economic activity (Camacho and Perez-Quiros (2014)). To be clear, in this paper we do not explicitly model these other transmis-

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[14] Note that the point estimate for export growth is economically meaningful even if statistically not different from zero. The magnitude of the coefficients hint at some possible offsetting increase in foreign sales.

[15] Similar regressions but without controlling for contemporaneous export and import growth yield negative coefficients but with a higher parameter uncertainty that render them statistically insignificant at the 10% level.

sion channels. Instead, they are absorbed in year and municipality fixed effects.[16]

4.1 Joint supply chain shocks

The relevant transmission of dry spell shocks from customers, along with the non-trivial correlation seen in Table 2 between exposures to the same type of climate shock, warrants a closer examination of the potential interaction between shocks on both sides of the supply chain. In this section, we explore specifications of Equation 2 with both customer and supplier shocks.

The regression in Table 10 interacts $\sum_j \omega_{i,j,t}\eta^k_{j,t} \times \sum_h \rho_{i,h,t}\eta^k_{h,t} \forall k$. The interaction occurs for the same k due to the relatively high correlation, eg to account for the fact that customers and supplier firms might be in the same or close municipalities.

Table 10: Influence of remote customer and supplier abnormal precipitation on GDP

Dependent Variable:	GDP growth
Model:	(1)
Variables	
Wet spell	-0.0177***
	(0.0053)
Dry spell	-0.0105***
	(0.0037)
Customer wet spell	0.0127
	(0.0179)
Supplier wet spell	0.0384
	(0.0349)
Customer dry spell	-0.0215*
	(0.0123)
Supplier dry spell	-0.0115
	(0.0111)
Customer wet spell × Supplier wet spell	-0.1460*
	(0.0814)
Customer dry spell × Supplier dry spell	0.0319
	(0.0297)
Local prec. lag	Yes
Local temp. lag	Yes
Local GDP lag	Yes
Fixed-effects	
Municipality	Yes
Year	Yes
Fit statistics	
Observations	34,547
R^2	0.19088
Within R^2	0.05961

Clustered (Region) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

---

[16] For example, year fixed effects control for all the different commodities prices.

The customer dry spell effects confirm when they are also estimated jointly, as seen on Table 10. The magnitudes are broadly similar to the effects found for the customer dry spell shocks. Interestingly, when a wet spell hits municipalities that include customer and supplier firms (for example, in the same area or even the same municipality), then economic growth falls markedly, at 14.6 p.p. if all counterparty municipalities were under this condition. Due to the considerable correlation between shocks of the same time occurring both down- and upstream in a supply chain, this effect could be an important driver of supply chain transmission of economic shocks.

4.2 Foreign trade

Since domestic supply chain shocks appear to have implications for foreign trade, as seen on Table 9, in this subsection we explore whether controlling for foreign trade interaction with local shocks meaningfully changes previous results. This would signal the presence of meaningful adjustment or amplifications mechanisms between domestic and international trade. For example, if there are no trade frictions and customers are perfectly substitutable, then shocks to the customer drought shocks in one municipality would be compensated by increased trade with other customers - include outside the country. Through this mechanism, foreign trade could be one way by which municipalities can cope with climate physical shocks along their trade chain.

Table 11: Influence of domestic and foreign trade on GDP

Dependent Variable:	GDP growth		
Model:	(1)	(2)	(3)
Variables			
Customer wet spell	0.0412	0.0414	0.0442
	(0.0419)	(0.0423)	(0.0409)
Customer dry spell	-0.0597**	-0.0611**	-0.0611**
	(0.0270)	(0.0270)	(0.0270)
Supplier wet spell	0.0382	0.0349	0.0335
	(0.0582)	(0.0576)	(0.0595)
Supplier dry spell	0.0029	0.0012	0.0023
	(0.0367)	(0.0362)	(0.0369)
Export growth × Customer wet spell		0.0061	
		(0.0210)	
Export growth × Customer dry spell		0.0161	
		(0.0128)	
Export growth × Supplier wet spell			0.0355
			(0.0424)
Export growth × Supplier dry spell			0.0105
			(0.0173)
Import growth × Supplier wet spell		-0.0256	
		(0.0376)	
Import growth × Supplier dry spell		-0.0247	
		(0.0202)	
Import growth × Customer wet spell			0.0234
			(0.0175)
Import growth × Customer dry spell			-0.0111
			(0.0107)
Local anomaly	Yes	Yes	Yes
Local foreign trade	Yes	Yes	Yes
Local prec. lag	Yes	Yes	Yes
Local temp. lag	Yes	Yes	Yes
Local GDP lag	Yes	Yes	Yes
Fixed-effects			
Municipality	Yes	Yes	Yes
Year	Yes	Yes	Yes
Fit statistics			
Observations	10,696	10,696	10,696
R^2	0.22711	0.22757	0.22763
Within R^2	0.04389	0.04446	0.04454

Clustered (Region) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

In fact, our findings suggest that foreign trade does not change the capacity of municipalities to adjust to supply chain-transmitted climate shocks: customer dry spells continue driving significant reduction in local economic activity, as evidenced in Table 11. The first regression only controls for export and import growth, providing baseline results. Also here, the effect from dry spell at municipalities with customer firms is relevant.

While foreign trade could be a natural offsetting mechanism in case of economic shock from domestic supply chains, this does not seem to be the case. The regression in the second column of Table 11 assesses whether foreign trade can replace affected domestic supply chains. More specifically, if municipalities with affected clients can attenuate any economic transmission as their exports grow more, the coefficient on the interaction would offset the direct impact from the climate shock from the customer. Similarly, municipalities with affected suppliers can replace disruptions if imports growth by more; also in this case, the coefficient on the interaction would offset the effect of any direct shocks from disrupted suppliers. It turns out, the data do not support this hypothesis.

An alternative way that foreign and domestic trade could interact is to amplificy economic losses from supply chain shocks, but that does not seem to be the case. The third column of Table 11 tests the possibility that local economies might be particularly prone to disruptions during periods of higher levels of foreign demand (interactions with exports) or foreign supply (interactions with imports). For example, supplier disruptions during a period of higher export growth could force firms in affected municipalities to procure more expensive alternatives or to push back on deliveries. Also in this case, there is no empirical evidence for a direct amplification mechanism between domestic supply chain disruptions and foreign trade.

Summing up, foreign trade does not seem to serve as an adjustment channel that offsets domestically-transmitted supply chain shocks, nor as an operational amplifier of domestically-received shocks. Rather, as shown in Table 9, foreign trade appears to be *impacted* by domestic climate shocks transmitted through supply chain.

4.3 Effects on diversification

While the effects of supply chain-transmitted climate shocks on foreign trade are muted, firms might still diversify their supply chain to other municipalities in Brazil as a response. In fact, it is plausible to assume that given enough time, the networks connections are endogenous (Acemoglu and Azar (2020)). For example, Kopytov et al. (2024) discuss how more volatile suppliers are passed over in favour of more stable suppliers, even when this leads to higher prices, as firms reorient towards more reliable partners. And as shown above, climate-related physical risks can be plausibly considered as an important downside risk to firm productivity across supply chains.

We use our data to verify the extent to which firms respond to remote climate shocks, and to which ones. To do this, we run the same regressions as in column (7) of Table 7, but where the dependent variables are the (municipality-wise) HHI on customer municipalities and the same metric for supplier municipalities. All of these regressions also include lagged values of both HHIs. These regressions include contemporaneous local shocks, like the others. This is important to approximate a causal interpretation of the coefficient on the remote shocks, since firms in remote municipalities are likely to themselves also reassess the value of maintaining relationships with the local firms after a local shock.

Table 12: Influence of remote supply chain climate shocks on customer municipality concentration

Dependent Variables: Model:	HHI Customers (1)	HHI Suppliers (2)
Variables		
Customer wet spell	-0.0947***	-0.0841***
	(0.0169)	(0.0166)
Customer dry spell	-0.1414***	-0.0822***
	(0.0124)	(0.0115)
Supplier wet spell	-0.0168	-0.3008***
	(0.0314)	(0.0348)
Supplier dry spell	-0.0324***	-0.1948***
	(0.0086)	(0.0171)
HHI Cust and Suppl lag	Yes	Yes
Local anomaly	Yes	Yes
Local prec. lag	Yes	Yes
Local temp. lag	Yes	Yes
Local GDP lag	Yes	Yes
Fixed-effects		
Municipality	Yes	Yes
Year	Yes	Yes
Fit statistics		
Observations	30,839	30,839
R^2	0.76675	0.71248
Within R^2	0.13531	0.13458
Wald (supply chain)	3.6×10^{-33}	7.23×10^{-46}

Clustered (Region) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

As seen in Table 12, firms do diversify the location of their customers and suppliers in response to a broad variety of supply chain climate shocks. The customer base tends to diversify more strongly when the climate anomaly occurs in customer municipalities, although especially for supplier dry shocks there is also an noticeable increase in customer diversification. Similarly, municipalities tend to diversify quite strongly the location of suppliers when the climate anomaly occurs in municipalities with suppliers. A significant but smaller effect observed when the it is municipalities with customers that observe the climatic shock.

5 Sectoral impacts from local and supply chain shocks

Physical shocks span a wide variety of potential threats to economic activity, with damages to both physical and human capital affecting different sectors in specific ways. Impacts of local climate anomalies on agriculture appear to be the most intuitive given the strong relationship between crop or husbandry yields and climate variables. However, other activities such as manufacturing or services may also be impacted due to physical damages to structures or to heat-induced lower productivity, for example, or to supply chain disruptions. On top of that, disruptions and damages might lead to price movements or to compensations that (partially or totally) offset losses in quantities, leading to more sector-specific adjustment mechanisms (eg, Deschênes and Greenstone (2007)).

In this section, we investigate the extent to which local and supply chain-transmitted weather shocks impact economic sectors differently. To understand heterogeneity of responses to local shocks, we first report in Table 13 below a comparison of sectoral responses to local shocks. Then, we repeat the analyses that focusing on sectoral GDP growth, namely, related to agriculture, manufacturing and services and how they respond to shocks of different intensities.

Table 13: Sectoral GDP response to local climate physical shocks

Dependent Variables: Model:	Agr. GDP growth (1)	Man. GDP growth (2)	Ser. GDP growth (3)
Variables			
Wet spell	-0.0084	-0.0107	-0.0076**
	(0.0095)	(0.0078)	(0.0031)
Dry spell	-0.0383***	-0.0203***	-0.0070**
	(0.0077)	(0.0073)	(0.0029)
Local prec. lag	Yes	Yes	Yes
Local temp. lag	Yes	Yes	Yes
Lagged sectoral GDP	Yes	Yes	Yes
Fixed-effects			
Municipality	Yes	Yes	Yes
Year	Yes	Yes	Yes
Fit statistics			
Observations	88,899	88,829	88,934
R^2	0.15836	0.10678	0.11939
Within R^2	0.08208	0.04953	0.03916

Clustered (Region) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

When only local climate anomalies are considered, dry spells are associated with a considerable reduction in sectoral growth, with different levels in each sector. Agriculture activity suffers more, with growth in this sector falling by more than 3.8 p.p. Next in magnitude comes the manufacturing sector, whose growth falls by 2 p.p. from a local dry spell. The impact of the same local shock is smaller in the services sector, at 0.7 p.p.

But since aggregate economic activity responds to remote climate shocks, in Table 14, we estimate sector-specific versions of Equation 3 to explore sectoral heterogeneity in responses to supply chain shocks. The first columns relates to agricultural GDP, the second column correspond to manufacturing GDP, and the last column presents the results on GDP in the services sector. In the case of each sector, the regressions include the intensity breakdown of customer-side climate shocks and for the supplier-related climate shocks.

Table 14: Influence of local and remote supply chain climate shocks on agriculture GDP

Dependent Variables:	Agr. GDP growth	Man. GDP growth	Ser. GDP growth
Model:	(1)	(2)	(3)
Variables			
Wet spell	-0.0568***	-0.0159	-0.0095*
	(0.0153)	(0.0116)	(0.0049)
Dry spell	-0.0416***	-0.0106	-0.0031
	(0.0107)	(0.0078)	(0.0034)
Mod. customer wet spell	-0.0036	0.0207	0.0186
	(0.0394)	(0.0416)	(0.0129)
Mod. customer dry spell	-0.0413**	-0.0177	0.0024
	(0.0194)	(0.0280)	(0.0107)
Int. customer dry spell	-0.0459	-0.0520	-0.0110
	(0.0576)	(0.0777)	(0.0317)
Mod. supplier wet spell	0.0205	-0.0272	-0.0115
	(0.0369)	(0.0714)	(0.0224)
Mod. supplier dry spell	-0.0261	-0.0131	-0.0026
	(0.0226)	(0.0241)	(0.0103)
Int. supplier dry spell	0.0092	-0.1574**	-0.0260
	(0.0592)	(0.0723)	(0.0337)
Local prec. lag	Yes	Yes	Yes
Local temp. lag	Yes	Yes	Yes
Lagged sectoral GDP	Yes	Yes	Yes
Fixed-effects			
Municipality	Yes	Yes	Yes
Year	Yes	Yes	Yes
Fit statistics			
Observations	34,534	34,474	34,550
R^2	0.24601	0.15521	0.22302
Within R^2	0.10644	0.05839	0.05806

Clustered (Region) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Agriculture economic activity is very sensitive to supply chain climate anomalies, in addition to local shocks. The economic spillovers recorded by the agricultural sector from climate anomalies in remote trade counterparties are attributable to moderate shocks. Moderate customer dry spells depress agriculture growth by 4.1 p.p. Local wet and dry spells are associated with economically-meaningful lower growth at circa 5.7 p.p. for the former and 4.1 p.p. for the latter.

In contrast to agriculture, manufacturing economic activity responds strongly supply chain climate shocks, but only when they are intense. Another difference is on the supply chain role: anomalies in municipalities with supplier firms tend to depress manufacting activity. This intense dry shock at supplier municipalities appears to completely dominate the local drought effect in the second column of Table 13.

As for the services sector, local wet spells lead to lower activity even when considering supply chain climate shocks. However, climate anomalies at supply chain counterparties do not appear to significantly influence this sector.

In short, the three broad sectors respond differently to local and supply chain shocks - both with respect to the type of climate anomaly (wetter or drier periods) and the intensity. The agricultural sector is materially sensitive to both local and supply chain shocks, with an overall profile that is consistent with the average aggregate effect of Brazilian municipalities. Manufacturing is also sensitive to shocks occurring in remote supply chain-connected locations, albeit only when these shocks are intense. And finally, the services sector is not insulated from climate physical risks, but it responds to local conditions rather than remote climate anomalies of any intensity.

6 Climate change losses

Both local and remote climate physical shocks are economically relevant. Based on the output elasticity of these climate shocks, we can measure the contribution of climate change on overall economic activity. Armed with these estimates, we can further make use of the richness of our data to measure the downward bias in loss estimates from climate change if only local shocks are considered. Our setting allows an empirical counterfactual test of the relevance of explicitly including supply chain linkages between municipalities. We adapt the counterfactual exercises of Zappalà (2023) to study whether estimates of climate change on local GDP really encompass in aggregate the wealth of local interactions that are reflected, for example, in trade interlinkages as claimed by Burke, Hsiang, and Miguel (2015), Burke and Tanutama (2019) and Kalkuhl and Wenz (2020). We then estimate the contribution of moderate shocks compared to an estimate that only looks at the transmission of intense shocks.

The first step is to calculate SPEI counterfactuals. Given our network estimation starts in 2012, we use precipitation and temperature data from 1961-2011 to calculate a linear trend for each of the climate variables, estimating $J_{imt} = \alpha_i + \lambda_m + \beta_i t + \varepsilon_{imt}$, where $J = \{P, T\}$, i indexes municipalities and m is the month of the year. Then we use the estimated slope for precipitation and temperature, $\widehat{\beta}_i^{(J)}$ to project a linear climatic path for each municipality between 2012 and 2019:

$$\begin{aligned}\tilde{P}_{t\in\{2012-2019\}} &= P_t + \widehat{\beta}_i^{(P)}(t - P_t)\\ \tilde{T}_{t\in\{2012-2019\}} &= T_t + \widehat{\beta}_i^{(T)}(t - T_t).\end{aligned} \tag{4}$$

Armed with these municipality-specific counterfactual precipitation and temperature values based on extrapolating past linear trends (Figure 6), a counterfactual SPEI for each municipality is calculated, $\widetilde{\text{SPEI}}_{it}$. This value would represent the estimate of climate variables today if they had not undergone climate change in the last years. We then project the losses in GDP growth using the coefficient $\widehat{\beta}^{\text{Dry}}_{\text{Customers}}$ from the second regression of Table 7; this regression is the one that is statistically more different from a pure local shocks model, as per the Wald test statistic. Note that this coefficient was estimated with only the distant municipality pairs, but in this exercise we apply to all customer municipalities.

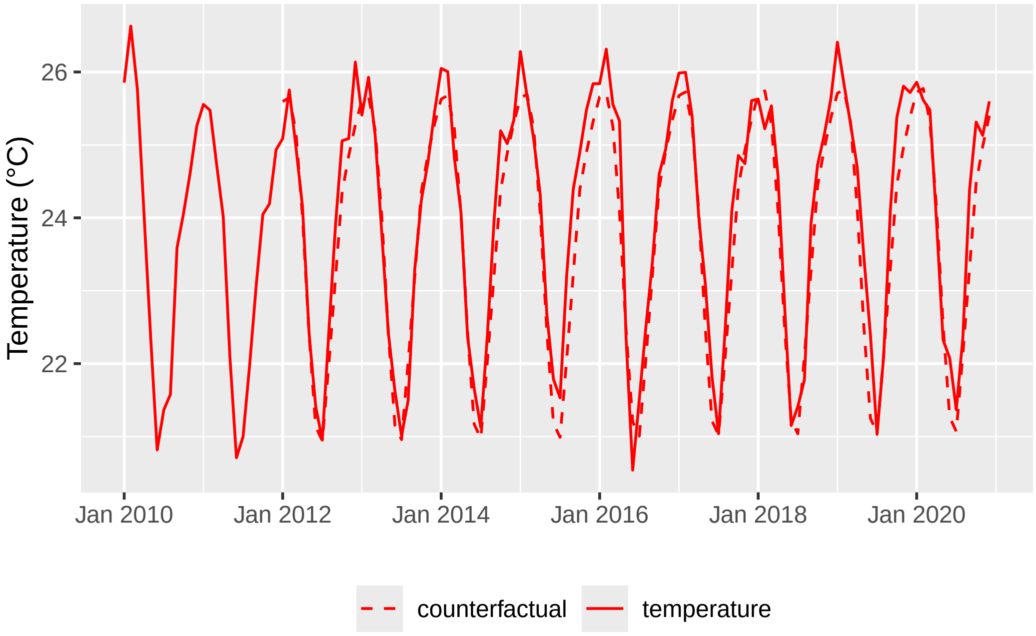
The difference between the predicted losses in GDP growth using the actual data and the extrapolated values from the past linear trends represents one measure of the amount of economic loss attributable to climate change (regardless of its cause) that is transmitted between municipalities, or $\xi_{i,t}$. That is, this exercise measures the effect of the actual anomalies compared to the anomalites that would happen if the pattern in the last decades would still hold, which is arguably as good as possible approximation to climate change that can be made with this dataset. Formally, using $\tilde{\eta}^{\text{Dry}}_{j,t}$ to indicate when $\widetilde{\text{SPEI}}_{j,t} < -1$,

$$\xi_{i,t} = \widehat{\beta}^{\text{Dry}}_{\text{Customers}} \omega_{i,j,t} (\eta^{\text{Dry}}_{j,t} - \tilde{\eta}^{\text{Dry}}_{j,t}). \tag{5}$$

Note also that if $\xi_{i,t}$ is lower than zero, then it also corresponds to a scenario where not incorporating supply chain considerations would lead to an underestimation of the effects of climate change.

Figure 6: Average 12-months of actual and linear trend climate values, Brazil average

(a) Temperature



(b) Precipitation

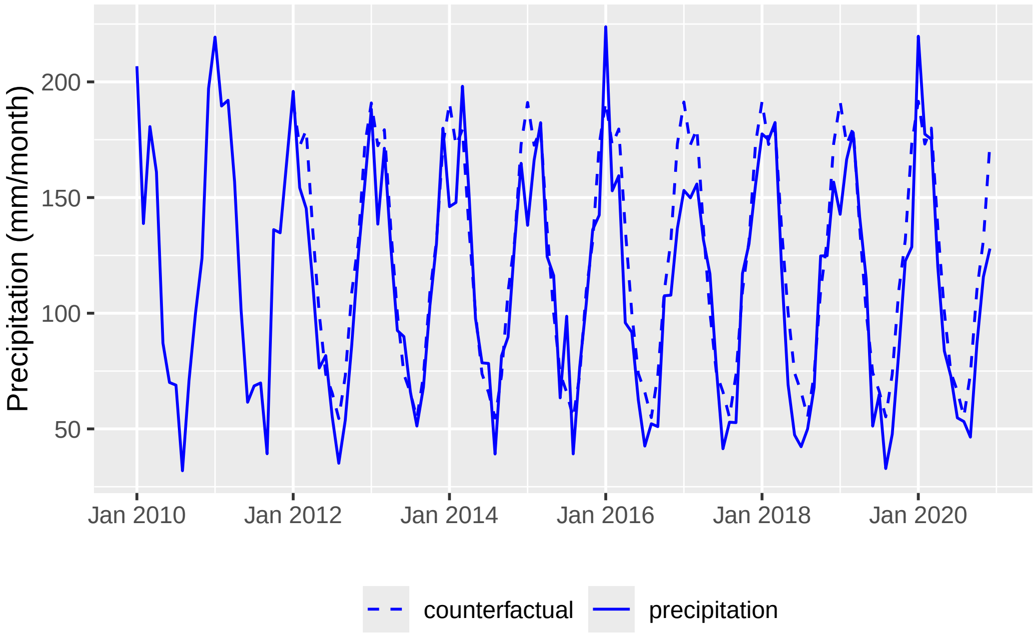
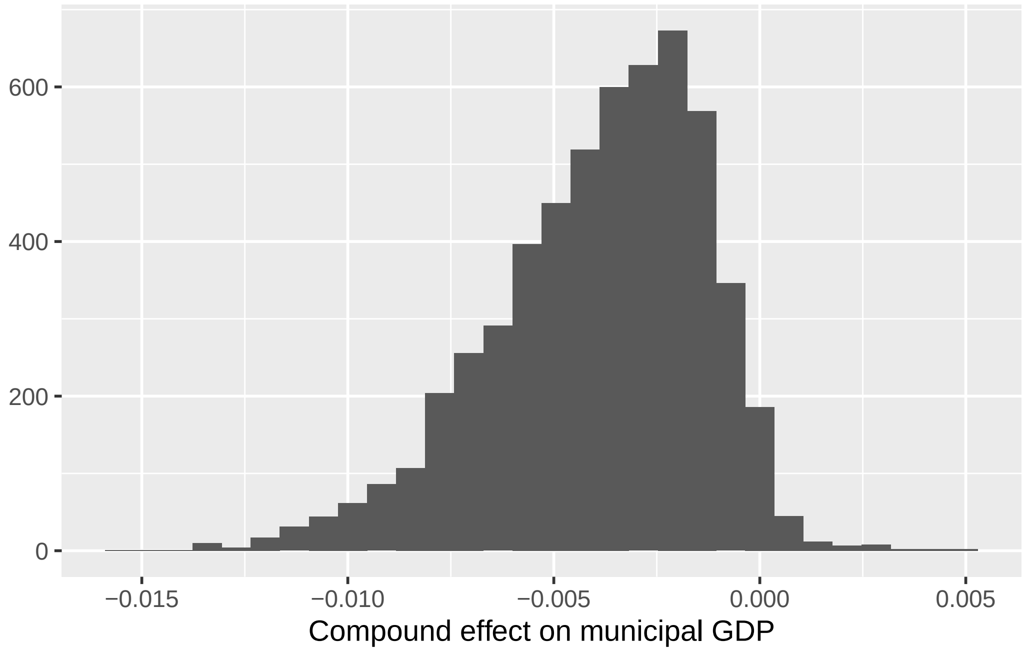


Table 15: Contribution of climate change to municipal GDP growth

	Climate change effect	
Year	Mean	SD
2012	-0.001	0.004
2013	0.000	0.002
2014	-0.002	0.004
2015	-0.003	0.005
2016	-0.007	0.005
2017	-0.005	0.005
2018	-0.003	0.004
2019	-0.006	0.005

The results in Table 15 show that only the spillover from customer dry spells contributes a significant amount to mean municipal GDP growth: in some years, the effect of the difference between actual and the SPEI based on linear extrapolation of past climate amount to 1 p.p. lower growth. It is interesting to note, though, that this projected contribution from climate change varies substantially over the years. Another feature of these effects is the level of variation between municipalities. To better illustrate this, we compound the climate change effects on growth transmitted via supply chains across the 2012-2019 period for each municipality to find the average annual effect, $\Xi_i = [\prod_{t=2012}^{2019}(1+\xi_{i,t})]^{1/7} - 1$.

Figure 7: Distribution of the compound effect of climate change through supply chains, 2012-2019



As seen on Figure 7, the vast majority of the distribution of the supply chain-transmitted effects attributed to climate change is negative, indicating a meaningful effect. Averaging across all municipalities, this is around -0.4 p.p. each year, and in extreme cases, municipalities record an average of 1 p.p. lower growth over the 2012-2019 period.

7 Conclusions

In this paper, we explore the economic implications of climate-related physical risks, both when they occur locally and when their local effects are so large as to transmit to firms in other places through interfirm trade. We find significant role of these supply chain definitions. The analyses above take advantage of the geographic, climatic and economic variations found in Brazil to estimate the impact of physical risks on growth - both when these shocks occur locally and in other areas connected by trade.

Our results present considerable evidence that both physical shocks impact local GDP growth and end up transmitting to other areas through supply chain connections. But the effects are heterogeneous, with agricultural activity particularly sensitive to both local and remote shocks, even when they are moderate. The manufacturing sector also responds to supply chain shocks, albeit only those that are intense. The services sector, in contrast, is sensitive to local climate conditions but appears to be more insulated on average from physical risks. We also provide further evidence of the importance of supply chain transmissions of climate shock through other indicators of economic activity, namely foreign trade and employment metrics; and even the configuration of the supply chain itself seems to respond to these shocks. In addition to confirming the relevance of trade connections for spillover of economic conditions from climate risks, our findings also complement the literature as they point to the importance of *moderate* physical shocks. In contrast to many papers in the physical risks literature, who traditionally study intense climate shocks, we find that moderate shocks are important drivers of both local and (for agriculture, especially) supply chain effects.

Climate-related physical shocks are difficult to measure consistently as there are various classes of weather events (eg, droughts, heavy rains, floods, etc), and they are all uniquely complex in how natural occurring phenomena impacts cause economic losses. Some drivers of physical risks are associated with a larger amplitude of climate variations (ie, more extreme weather type of events) while others relate to longer-term, gradual change in temperature and precipitation levels. Hence, part of the literature relies on individual climate-related disasters to identify physical risks. But less consequential climate anomalies that are not catastrophic events, or even medium- to long-term anomalies such as heat waves or droughts that plays out in time also create physical risks. This paper focuses on this more complete picture of physical risks.

Our results also open up interesting new avenues for research: if supply chains transmit economic shocks related to physical shocks, to what extent are they also *shaped* by these occurrences? Can increased severity and frequency of climate anomalies, a perverse consequence from climate change, lead to reshaping of supply chains? And if local and supply chain physical shocks have such an effect on GDP, what percentage of GDP forecasting errors can they represent in aggregate? These are all questions we hope future research can answer.

Appendix

The identification of the supply chains in any given year depends on the ability of the interfirm payment network to capture these relationships, which it does not do perfectly, as discussed in Section 2.2 in the main text. In this appendix, we present results based on three complementary ways of measuring the interconnections between firms in different municipalities. These measures have more disadvantages than advantages for the goal of this study, as discussed in each subsection below. However, results that use these alternative definitions can complement the assessment of our results in the main text. To that end, we re-estimate Table 14 using three alternatives.

The overall results from these alternative estimations appear to confirm the sectoral results for agriculture and manufacturing: a customer dry spell lowers growth in the former, while supplier dry spell depresses growth in the latter. Interestingly, these results also offer some nuance on the impact in the services sector: while our headline results do not reveal any meaningful impact, these alternatives suggest at least some components of the services sector might benefit from physical shocks in customers or in suppliers. If this is related to the sales of services related to reconstruction, we cannot affirm since our data only offers this coarse breakdown. However, as we note, using our preferred supply chain measurement these effects to not appear and so further exploration of such potential effects is left for future research.

Alternative definition of supply chain network

As seen in Figure 4, the amount of captured transactions as a share of the economy grows is larger in most recent years. Part of this could be due to more firms pairs using payments through different banks, thus increasing the ability of our dataset to capture interfirm transactions. So in this subsection, we use the latest year in our sample, 2019, to define the network of municipalities (but the climate shocks still occur at each original year). Note, however, that a serious shortcoming of this alternative measure is that the network itself seems to be endogenous to climate shocks (see Section 4.3).

The results are in Table 16.

Table 16: Influence of local and remote supply chain climate shocks on total and sectoral GDP (Using 2019 network)

Dependent Variables: Model:	GDP growth (1)	Agr. GDP growth (2)	Man. GDP growth (3)	Ser. GDP growth (4)
Variables				
Wet spell	-0.0193***	-0.0646***	-0.0195*	-0.0105*
	(0.0058)	(0.0186)	(0.0114)	(0.0057)
Dry spell	-0.0088**	-0.0516***	-0.0054	-0.0003
	(0.0042)	(0.0124)	(0.0078)	(0.0038)
Mod. customer wet spell	-0.0278	-0.0161	-0.0066	-0.0152
	(0.0249)	(0.0601)	(0.0500)	(0.0191)
Mod. customer dry spell	-0.0067	-0.0697**	-0.0028	0.0009
	(0.0135)	(0.0308)	(0.0367)	(0.0126)
Int. customer dry spell	0.0464	0.0325	0.0950	0.0380
	(0.0468)	(0.1191)	(0.1165)	(0.0300)
Mod. supplier wet spell	0.0803***	0.1141*	0.1143*	0.0792***
	(0.0257)	(0.0618)	(0.0611)	(0.0195)
Mod. supplier dry spell	0.0027	-0.0458	-0.0086	0.0147
	(0.0145)	(0.0463)	(0.0350)	(0.0130)
Int. supplier dry spell	0.0171	0.0319	-0.2127*	0.0050
	(0.0435)	(0.1102)	(0.1137)	(0.0444)
Local prec. lag	Yes	Yes	Yes	Yes
Local temp. lag	Yes	Yes	Yes	Yes
Lagged sectoral GDP	Yes	Yes	Yes	Yes
Fixed-effects				
Municipality	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Fit statistics				
Observations	34,289	34,275	34,195	34,292
R^2	0.17764	0.23143	0.14839	0.20486
Within R^2	0.06496	0.11340	0.06671	0.06199

Clustered (Region) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Customers and suppliers in different municipalities

In some cases, the same pair of municipality can be simultaneously customer and supplier to one another. Since the climate shocks are by definition occurring at the same geographic area, these cases where municipality pairs have both relationships make it difficult to disentangle whether the shock transmitted through the supply chain went downstream, upstream or both. While it seems to make identification of these shocks cleaner, retaining only municipality pairs with a one-way relationship discards many cases where municipalities have a more sophisticated economy.

The results are in Table 17.

Table 17: Influence of local and remote supply chain climate shocks on total and sectoral GDP (Using only one-way relationships)

Dependent Variables:	GDP growth	Agr. GDP growth	Man. GDP growth	Ser. GDP growth
Model:	(1)	(2)	(3)	(4)
Variables				
Wet spell	-0.0181***	-0.0571***	-0.0175	-0.0100**
	(0.0056)	(0.0158)	(0.0117)	(0.0050)
Dry spell	-0.0100***	-0.0407***	-0.0090	-0.0041
	(0.0037)	(0.0106)	(0.0080)	(0.0034)
Mod. customer wet spell	-0.0020	-0.0348	0.0382	0.0331*
	(0.0176)	(0.0370)	(0.0539)	(0.0170)
Mod. customer dry spell	-0.0155	-0.0597**	-0.0023	-0.0041
	(0.0126)	(0.0230)	(0.0312)	(0.0124)
Int. customer dry spell	0.0160	-0.0215	0.0637	0.0505*
	(0.0298)	(0.0673)	(0.0911)	(0.0304)
Mod. supplier wet spell	-0.0163	0.0171	-0.0993	0.0025
	(0.0239)	(0.0583)	(0.0813)	(0.0313)
Mod. supplier dry spell	0.0104	-0.0152	0.0069	0.0082
	(0.0122)	(0.0280)	(0.0335)	(0.0133)
Int. supplier dry spell	-0.0131	-0.0715	-0.1168	0.0021
	(0.0328)	(0.0656)	(0.0778)	(0.0408)
Local prec. lag	Yes	Yes	Yes	Yes
Local temp. lag	Yes	Yes	Yes	Yes
Lagged sectoral GDP	Yes	Yes	Yes	Yes
Fixed-effects				
Municipality	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Fit statistics				
Observations	33,031	33,018	32,961	33,034
R^2	0.19334	0.25177	0.16188	0.22843
Within R^2	0.05607	0.10807	0.05811	0.05745

Clustered (Region) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

Only municipalities with more than two banks

Since our supply chain metric is based on payment transfers between firms with accounts in different banks and banks in Brazil operate nationwide, municipalities with a few banks underestimate the existence of supply chain links more severely than in most cases. To address this, in this section we estimate results considering only municipalities with more than 3 banks. This measure would not be suitable as a baseline given the extensive number of relationships that it discards, including many municipalities that might have less well-developed banking markets but nonetheless contribute substantial economic activity, especially in agriculture.

The results are in Table 18.

Table 18: Influence of local and remote supply chain climate shocks on total and sectoral GDP (Using only municipalities with more than 3 banks)

Dependent Variables:	GDP growth	Agr. GDP growth	Man. GDP growth	Ser. GDP growth
Model:	(1)	(2)	(3)	(4)
Variables				
Wet spell	-0.0042	-0.0406***	0.0029	-0.0038
	(0.0062)	(0.0144)	(0.0163)	(0.0060)
Dry spell	-0.0075*	-0.0322**	-6.23×10^{-5}	-0.0057
	(0.0045)	(0.0134)	(0.0102)	(0.0036)
Mod. customer wet spell	0.0599	0.0097	0.0684	0.0620**
	(0.0410)	(0.0982)	(0.1030)	(0.0290)
Mod. customer dry spell	0.0029	-0.1007	-0.0574	0.0286
	(0.0261)	(0.0608)	(0.0656)	(0.0181)
Int. customer dry spell	0.0033	-0.3292**	0.0391	0.0924
	(0.1055)	(0.1633)	(0.2631)	(0.0843)
Mod. supplier wet spell	0.0476	0.1965	-0.0072	-0.0193
	(0.0548)	(0.1233)	(0.1466)	(0.0416)
Mod. supplier dry spell	0.0016	-0.0118	0.0052	-0.0206
	(0.0245)	(0.0696)	(0.0897)	(0.0196)
Int. supplier dry spell	-0.1778*	-0.3483	-0.5118*	0.0081
	(0.0943)	(0.2680)	(0.2629)	(0.0842)
Local prec. lag	Yes	Yes	Yes	Yes
Local temp. lag	Yes	Yes	Yes	Yes
Lagged sectoral GDP	Yes	Yes	Yes	Yes
Fixed-effects				
Municipality	Yes	Yes	Yes	Yes
Year	Yes	Yes	Yes	Yes
Fit statistics				
Observations	9,301	9,293	9,293	9,301
R^2	0.18384	0.26301	0.12140	0.26468
Within R^2	0.02373	0.11218	0.03448	0.05457

Clustered (Region) standard-errors in parentheses
*Signif. Codes: ***: 0.01, **: 0.05, *: 0.1*

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