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Weather Shocks and Firm Exports in Developing Countries^{*}

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Abstract

In this paper, we study how weather shocks affect firm-level exports in low and middle income countries. While the impacts are negative on average, we find that large firms are significantly less affected. This feature is robust across sub-samples, specifications and confounding factors. We then examine the aggregate implications of these firm-level effects by studying changes in total exports under different climate scenarios by the end of the century. Results show that the overall trade-detering effect of future weather conditions would be lower if there were more large firms in low and middle income countries. It suggests that the existing firm-size distribution may increase the aggregate cost of climate change.

Keywords: *Climate change ; Economic development ; International trade; Firms*

JEL Codes: F14 ; F18 ; O13 ; Q56

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Declarations of interest: none.

Data availability statement: Some data used in this article is under confidentiality. In particular, the data employed in this paper are transaction-level customs data. The data was collected by the Trade and Integration Unit of the World Bank Research Department, as part of their efforts to build the Exporter Dynamics Database described in Fernandes, Freund and Pierola (2016). The sources for the data for each country are detailed at <https://www.worldbank.org/en/research/brief/exporter-dynamics-database>

1 Introduction

Low and middle income countries (LMIC) are particularly exposed to the adverse effects of climate change and this vulnerability is expected to worsen in the coming decades ([Bathiany et al., 2018](#); [Hoegh-Guldberg et al., 2018](#); [Carleton et al., 2022](#)). Since international trade can be a crucial tool for economic development (e.g., [World Bank, 2020](#)), it is important to understand how climate change affects trading sectors in LMIC.

In this paper, we study how changes in weather conditions impact firm-level exports in 9 low and middle income economies. Relative to high income countries, LMIC tend to have fewer exporters and a lower concentration of exports at the top of the firm-size distribution, as documented by [Fernandes et al. \(2016\)](#). These stylized facts show the existence of important differences in the structure of exports between high and poor economies, which can in turn explain how environmental conditions affect differently a firm's exports in LMIC.

We study the impact of variations in weather conditions, measured by temperatures and precipitations, on several export outcomes at the firm-level. Our first goal is to assess how heterogeneous exporters cope differently when facing the same changes in weather conditions. To guide our analysis, we hypothesize that firm size reduces the potentially negative effect of weather shocks on exports.

There are at least four main channels to support this hypothesis on differential adaptation. First, the attenuation of climate shocks in the agricultural sector is determined by the ability to irrigate land as well as many other techniques, requiring innovation and investment. As these techniques are not available to all firms ([Jones et al., 2019](#)), only the largest firms are expected to have sufficient funds to innovate and acquire these technologies. Second, the largest exporters tend to have a high share of imported inputs relative to domestic ones ([Amiti et al., 2014](#)), which straightforwardly leads firms' output to be less sensitive to local weather shocks (e.g., in agriculture see [Garcia-Verdu et al., 2019](#)). In all, firm size is thus expected to attenuate the detrimental effect of climate change on economic activity, here firm-exports. Third, numerous evidence point that labor productivity is negatively affected by temperatures ([Heal and Park, 2016](#); [Somanathan et al., 2021](#)). Since capital to labor ratios tend to be increasing in exporter size ([Bernard et al., 2007](#); [Forslid and Okubo, 2011](#)), the largest firms are again expected to be less affected by temperatures. Finally, weather shocks have contrasting effects across skilled and unskilled workers, notably since ventilation and air-conditioning systems allow adaptation. Since these technologies are more likely to be available to skilled workers and as the largest exporters tend to have a lower share of unskilled workers ([Bernard et al., 2007](#)), these firms are expected to be less exposed to weather variations. The first goal of our paper is to document this heterogeneous firm-level impact.

For this purpose, we take advantage of a database covering exporter-level customs transactions in low- and middle-income countries between 1993 and 2013. These data are a subset from the Export

Dynamics Database introduced by [Fernandes et al. \(2016\)](#), available at this level of disaggregation only for some countries, including Burkina Faso, Guatemala, Jordan, Mexico, Malawi, Peru, Senegal, Uruguay and Yemen. Within each country, data cover all export transactions at firm-HS6 product - destination country -year dimension. We combine it with weather data providing measures of local temperatures and precipitations.

The second goal of this paper is to highlight the aggregate consequences of the firm-level responses. Assuming weather shocks have a negative effect on exports that is dampened for the largest firms, if those firms represent a large share of a country's exports, then the aggregate elasticity of exports to weather measures should be low. On the contrary, if large exporters account for a low share of aggregate exports then this aggregate elasticity is expected to be large and negative. The aggregate elasticity of exports to past and future weather shocks, which averages firm-level elasticities depending on their share in total exports, will thus vary depending on firm-level elasticities and on firm-size distribution. We exploit those variations to study the consequences for a country's exports in the future. This is the second analytical part of the paper.

In the first part, we find that year-to-year fluctuations in weather conditions have a differential effect across exporting firms depending on their size. While the average response of exports to increases in temperature and precipitations is negative, this result hides an important heterogeneity. Indeed, previously large exporters are significantly and quantitatively less harmed than smaller ones when facing the same shock. Elasticity of exports to temperatures and precipitations are close to -0.3 for the smallest exporters but closer to -0.1 for the largest ones. This feature is robust across countries and relies on the within-country distribution of exporters.

These results are also robust to the use of alternative measures of exports and firm size proxies. Results also resist to the inclusion of many potential omitted variables, such as additional weather covariates and other macroeconomic determinants of exports. Likewise, controlling for product- and destination-specific shocks of the export flows does not alter our results.

In the second part, we quantify the macroeconomic implications of these firm-level responses and run counterfactual exercises measuring the aggregate impact of future weather conditions on export outcomes. Under a business-as-usual scenario, we find future weather conditions would lower total exports in the countries of our sample by 9% on average. This impact depends both on the firm-size distribution of exporters in each country and on future climate conditions.

We further disentangle those two channels by studying two counterfactuals: one where all countries face the same climate scenario, and another where they share the same firm-size distribution. Our results show that, under our counterfactual climate scenario, exports losses in Burkina Faso would be 2.05 percentage points (p.p.) lower by the end of the century. Likewise, if the country had the firm-size distribution of Mexico (more large firms), the results show that export losses would be 0.15 p.p. lower

relative to the business-as usual. In all, the exercise shows that while climate change will substantially affect exports, differences in firm-size distribution can explain why some countries can adapt better than others.

By documenting evidence on the links between temperature and firm exports, this paper contributes to several strands of the literature. Close to our paper, [Jones and Olken \(2010\)](#) estimate how the annual growth rate of a country's exports in a particular product category is affected by the country's weather. Estimates suggest an overall 2.2% decrease in export growth in poor countries for each degree of temperature rise, and no effect for precipitation. However, the analysis is done at the aggregate level and does not highlight any heterogeneous firm effect, contrary to what we do here. [Karlsson \(2021\)](#) also studies how temperature affects exports but do not highlight any firm size heterogeneity and focuses on the United States. Other related works include [Dallmann \(2019\)](#) which estimates a negative effect of temperature variations on total trade and bilateral trade at the country level. While this level of analysis is very informative, the results may suffer from aggregation bias.¹ The existence of these bias calls for an investigation at a more disaggregated level, as we do in this paper.

By identifying heterogeneous firm effects, our paper also connects to a trade literature documenting heterogeneous impacts of exogenous shocks on firms' trade outcomes and aggregate trade patterns.² This work also echoes a general trend in the trade literature, based on heterogeneous firms ([Bernard et al., 2007](#); [Melitz, 2003](#)), emphasizing the non-straightforward links between micro-evidence and aggregate outcomes ([Imbs and Mejean, 2015](#); [Costinot et al., 2020](#); [Gaubert and Itskhoki, 2021](#)).

Finally, our paper is also connected to a large growing literature documenting the effects of climate shocks on economic growth and on other outcomes ([Hsiang, 2010](#); [Dell et al., 2012](#); [Strobl and Valfort, 2013](#); [Dell et al., 2014](#); [Colmer, Forthcoming](#)), at different levels of aggregation ([Burke and Tanutama, 2019](#); [Damania et al., 2020](#); [Kalkuhl and Wenz, 2020](#); [Zhang et al., 2018](#)). None of those studies focus on exporting firms in developing countries as we do here.

Overall, our paper provides an explanation for some results present in the literature. For instance, [Jones and Olken \(2010\)](#) show that poor countries exhibit larger trade deterring effects of climate shocks than others. The lower concentration of exports at the top of the firm-size distribution in these countries could explain this result, provided that large firms are less sensitive to weather shocks but account for a lower share of total exports in poor countries. This feature could explain the aggregate trade pattern and trade growth under temperature shocks. Our findings also inform debates on the impact of climate on economic development ([Nordhaus, 1993](#); [Greenstone and Jack, 2015](#); [Budolfson et al., 2018](#)), and provide insights about adaptation strategies in the tradable sector.

¹Recent evidence on those potential bias include [Imbs and Mejean \(2015\)](#) for trade or [Damania et al. \(2020\)](#) for economic growth and precipitations.

²[Berman et al. \(2012\)](#) document the heterogeneous adjustment of French exporters to exchange rate variations, while [Héricourt and Nedoncelle \(2018\)](#) focus on exchange rate volatility. [Bricongne et al. \(2012\)](#) provide evidence that the 2008-2009 trade collapse had a differential effects across firms. [Asprilla et al. \(2019\)](#) identify the heterogeneous shift in market power across exporters in 12 emerging countries after changes in trade policy.

The rest of the paper is organized as follows. The next section presents the data and summary statistics. Section 3 provides the results at the firm level, while Section 4 draws the aggregate implications of the micro-level results. Section 5 discusses the results and concludes.

2 Data

In this section, we detail our dataset combining firm-level exports with information on climate conditions and other controls for each country of our sample.

Firm-level exports. We use the exporter-level version of the Exporters Dynamics Database (Fernandes et al., 2016). This dataset provides a collection of country-specific exporter-level customs transactions made available to external researchers, under confidentiality conditions. Our data covers the exports from 1993 to 2013. Our sample includes data on 9 LMIC: Burkina Faso, Guatemala, Jordan, Mexico, Malawi, Peru, Senegal, Uruguay and Yemen. Within each country, the dataset covers all export transactions at firm-HS6 product - destination country -year dimension. Since the data come from customs agencies, it covers export transactions only, and provides no information on other firm characteristics, in particular firm location, age, ownership, employment, or sales in the domestic market. The available time span for each country is plot in Figure A.1, in Appendix.

Regarding the export structure within each country of the sample, Table 1 displays the average number of exporting firms per year, the average export value in USD by firm, the first and 9th decile of exports per country, and the average number of HS6 products and destinations served by firms.

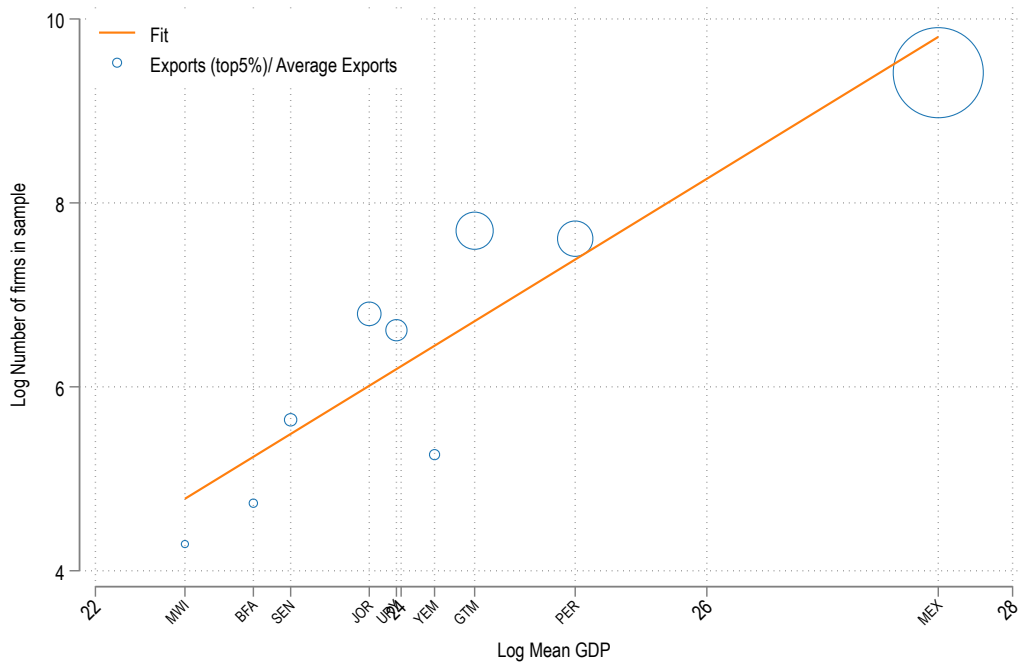
Table 1: Statistics about firm-level exports, by country

Country	Start	End	Nb. Exporters	Mean Exports	P10	P90	# Prod.	# Dest.
Burkina Faso	2,006	2,012	223	227,989	1,835	251,635	16	6.8
Guatemala	2,006	2,013	2,801	238,014	1,644	306,505	28	6.3
Jordan	2,004	2,012	1,305	264,925	2,817	318,483	13	11
Malawi	2,007	2,012	223	361,878	1,937	613,498	9.1	6.2
Mexico	2,001	2,012	19,585	424,722	1,819	420,005	23	7.9
Peru	1,997	2,013	3,501	225,876	1,699	321,227	19	9.7
Senegal	2,001	2,012	394	120,028	1,793	166,408	23	11
Uruguay	2,002	2,012	993	425,240	2,560	709,500	8.9	13
Yemen	2,009	2,012	313	220,370	2,215	385,685	17	7.7

Our sample displays a large heterogeneity across countries in terms of firm-size distribution: Mexico has around 100 times more exporters than Malawi or Burkina Faso, and all trade margins are heterogeneous across countries.

Figure 1 digs further into the export structure. Richer countries have more exporters, and within each country, the top 5% of exporters are much larger than the average exports than in “poorer” countries. firm-size distributions are different across countries, in particular, regarding the importance of the top firms.

Figure 1: Exports structure



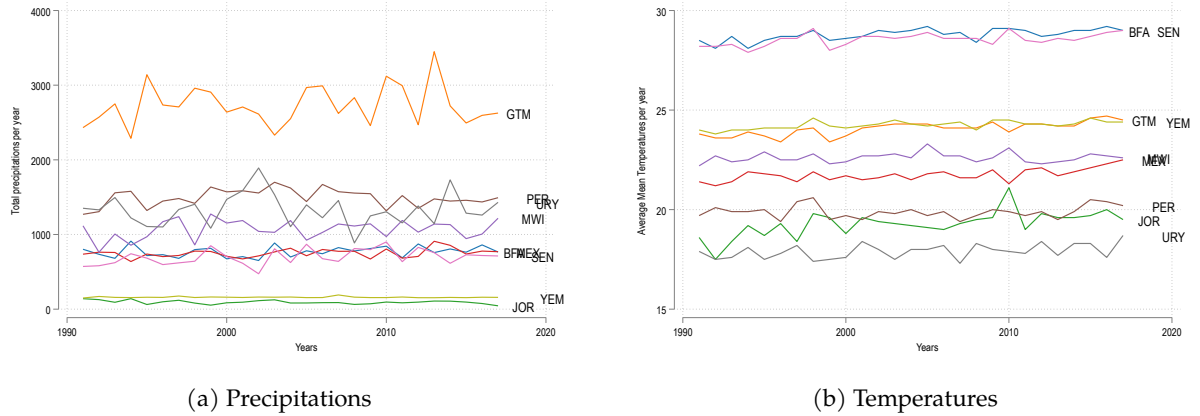
Climate variables. We gather weather data from the Climatic Research Unit of the University of East Anglia (CRU version v4.02) (Harris et al., 2014). This dataset is widely used in the literature (Auffhammer et al., 2013) and provides a set of weighted country-year weather information³.

In the main analysis, we use the yearly average of daily mean temperatures and total monthly precipitations from this source. Figure 2 plots the total precipitations (2a) and average temperature (2b) in each country in our sample. We observe a steady within-country increase in temperatures over time, and some variations in precipitations within country and across years.

To assess the robustness of our analysis, we will consider the average minimum and maximum daily temperatures from the same source as an alternative to daily mean temperature. Second, we will also use humidity (“wet day frequency”) as an alternative measure to precipitations. Furthermore, in our robustness checks, we follow the literature based on agronomy and convert daily mean temperatures

³The CRU CY dataset consists of country averages at a monthly, seasonal and annual frequency, for ten variables. Spatial averages are calculated using area-weighted means. <https://crudata.uea.ac.uk/cru/data/hrg/>

Figure 2: Weather in Sample



into degree days (DD) (Hsiang, 2016) with thresholds of 32°C and 34°C. Appendix A.2 provides all the details of our approach.

Macroeconomic Controls. Lastly, we collect a set of macroeconomic variables used as controls in our estimations. These include include effective exchange rate, tariffs, growth indicators as well as quality of governance, all taken from the World Development Indicators (World Bank, 2016).

Descriptive Statistics. Table 2 provides some descriptive statistics of the main sample. Panel A shows the exports characteristics of the firms in our sample, pooling all countries together. On average, firms export the equivalent of 322269 US\$ per year, which represents slightly more than 800 US\$ per unit of exported good. Panel B shows the average characteristics of the origin countries, in terms of weather and other trade determinants. Average temperature in the exporting countries of our sample was 22°C over our period of study, with an average maximum of 29°C for Burkina Faso and Senegal. Regarding precipitations, the average level in our sample was slightly over a thousand of millimeters a month. Panel C provides the characteristics of the destinations served by the exporters of our sample. Destinations were more than 4 times richer than the exporters. Foreign average temperature was almost 2°C lower, while the level of precipitations was higher than at origin, on average.

3 Firm-level trade impact of local weather

In this section, we first present our empirical strategy, then display the results as well as several robustness checks.

Table 2: Descriptive statistics of the sample

Panel A: Firm-Product-Destination-Year Variables					
variable	mean	sd	min	max	N
Exports (in value)	322269.25	2.22e+06	1000.00	9.92e+07	2.47e+06
Exports (in volume)	220385.41	5.93e+06	0.00	2.04e+09	1.11e+06
Unit Value	833.51	61829.91	0.00	3.80e+07	1.11e+06

Panel B: Origin Country-Year Variables					
variable	mean	sd	min	max	N
Temperatures	22.56	5.38	10.70	29.20	117.00
Precipitations	1,019.89	665.39	63.60	3,449.00	117.00
GDP per cap.	3,126.49	3,135.63	193.07	15,171.58	117.00

Panel C: Destination Country-Year Variables					
variable	mean	sd	min	max	N
Dest. Temperatures	19.33	7.76	0.40	29.30	2,575.00
Dest. Precipitations	1,145.59	833.71	21.80	4,915.10	2,621.00
Dest. GDP per cap.	13,076.38	20,343.22	102.60	185721.79	2,956.00

3.1 Empirical strategy

To estimate the impact of weather variations on exports at the firm-level, as well as its potentially differential effect across firms of different sizes, we choose the following general specification:

$$\begin{aligned}
Exports_{ft} = & \alpha Temp_{i(f)t} + \beta Prec_{it} + \delta FirmSize_{ft-1} \\
& + \gamma (Temp_{i(f)t} \times FirmSize_{ft-1}) \\
& + \mu (Prec_{it} \times FirmSize_{ft-1}) \\
& + \xi Covariates_{it} + \{FE\} + \varepsilon_{ft},
\end{aligned} \tag{1}$$

where $Exports_{ft}$ is the general measure of export outcome for a firm f in year t . The variables $Temp_{i(f)t}$ and $Prec_{i(f)t}$ denote temperature (in Celsius) and precipitations (in millimeters) in country i , where firm f operates, at year t . We include the temperatures in levels (hence providing a semi-elasticity of trade flows) and precipitations in logs (providing an elasticity).

$FirmSize_{ft-1}$ is a general measure for firm size and is measured at the previous year $t - 1$ to avoid simultaneity with export outcome in year t . Since we do not have information about firms' output, employment or any other outcomes, we rely on the export outcomes to measure a firm's size. Our baseline measure is the lagged export values (in US\$) at the firm-year level from the Customs data. Total exports can proxy for firm size as exports and firm outcomes are highly correlated (Bernard et al., 2007). We will however test the sensitivity of the results to the use of alternative proxies of firm size.

To measure the differential effect of weather shocks across firms, we include the interaction terms of temperature and precipitations with $FirmSize_{ft-1}$. These capture the heterogeneous effect of a same variation in temperature or precipitations on exports across firms of different sizes.⁴

⁴Following Freund and Pierola (2020), we expect the differences in firms' size to capture most of the cross-firms' heterogeneity.

The model described in equation (1) also includes country-year confounders, $Covariates_{it}$, that may explain export outcomes at the firm level. These variables act as alternative variables, potentially omitted, capturing economic and social context in exporting countries: shocks to these variables could have an average effect captured by the ξ coefficient. In some specifications, we also interact it with firm size to capture additional heterogeneous effects. Controlling for these other time-varying variables allows us to isolate the strict effect of weather variables. In practical terms, we include economic controls such as exporting countries' GDP in benchmark and further controls in robustness. Our approach is thus consistent with gravity equations at both the aggregate and the firm levels (Head and Mayer, 2014).

To absorb unobserved heterogeneity, we include a set of fixed effects $\{FE\}$ in equation (1) that varies across specifications. First, we consider a firm fixed effect to absorb firm-specific time-invariant characteristics affecting exports. For instance, it could be a firm's specialization across products, its management strategy, the average (over time) skills of its labor force, whether it is a multinational firm, *etc.* As no firm changes of origin country, this fixed effect controls for the origin country as well, and absorbs for instance initial differences between climate conditions across countries.⁵ Our sample is slightly affected by this inclusion as we have to drop firms that appear only 1 year in the sample. Second, we include a (HS2) sector-year set of fixed effects: it allows to compare exporters in the same sector-year, and more generally to absorb common shocks faced by exporters⁶. Third, in some specifications, we also include a (HS2) sector-country-year fixed effect, for unobserved heterogeneity across sector-countries in the sample. This fixed effect controls for all pre-existing differences in the specialization of countries across types of products and industries, as well as for differences in the level of development across countries. It also absorbs the differences across countries in average weather conditions and other aggregate covariates. Further, this fixed effect holds constant the total exports of the HS2 sector from each country-year period. As a result, in this specification, the identifying variation in our exercise is across firms all belonging to the same sector-country and thus face the same weather shocks.

Finally, ε_{ft} is a random error term capturing all omitted factors, which we allow to be heteroskedastic and correlated across HS2 sectors and years. In all our regressions we report the standard errors clustered at the HS2 sector-country-year level.⁷

Trade margins, dependent variables and estimators. At the intensive margin, the export outcome is the level of exports at the firm level, X_{ft} . When estimating this equation, we use a linear estimator and a log specification for exports. We thus focus only on positive export flows at the firm level. Our preferred measure of exports is the exported values (in US\$). At the extensive margin, the export outcomes are

⁵Results then account for the fact that a shock to average temperature in a very hot country like Burkina Faso may impact exports very differently than the same shock in a country with more moderate temperatures, like Mexico.

⁶Think for instance of technological shocks or variations in foreign demand.

⁷Our preferred cluster level would be at the country-year level, as it is exactly the level of the weather shocks. However, in our sample, the number of clusters in this dimension would be too small ($N = 26$ in our baseline regressions), thus affecting the inference quality (Cameron et al., 2008).

the number of HS6 products and the number of destinations served by a firm, following [Arkolakis et al. \(2010\)](#).

3.2 Results

In this section, we start by providing results for the intensive margin and then for the extensive one. We then turn to several robustness checks, focusing on potential omitted variables and product- and destination-specific shocks.

Baseline results: intensive margin. Table 3 presents the benchmark estimation of equation (1) at the intensive margin. The dependent variable is the log of exports, and we gradually add interaction terms and fixed-effect specifications.

Looking at column 1, we see that increases in temperatures and in precipitations decrease average firm-level exports. This specification provides the average, firm-level exports response to weather covariates, controlling for aggregate, country-wide trade determinants GDP and lagged firm export outcome. Since we have included a firm fixed effect, identification comes from exports variations across years for a given firm.

On average, past exports and GDP also play a role in to explain the variation in the value of exports. We estimate that a 1°C increase in temperatures decreases exports by around 5.6 % on average, whereas a 1% increase in total precipitations is associated with a decrease of 0.3 %.

This set of average weather effects on exports hides significant heterogeneity across firms. Columns 2, 3, and 4 examine how firm-size (measured by lagged firm exports) shapes the influence of temperature and precipitations on exports. Results show that increases in precipitations have some heterogeneous effects across firms. We always estimate a positive and significant interaction between precipitations and lagged firm exports, independently of the set of fixed effects included in specifications. Larger firms reduce less their exports compared to smaller firms, conditional on precipitation changes.

We find the same pattern regarding temperatures. Larger exporters are less harmed by changes in temperatures than smaller exporters. Point estimates are however naturally smaller as the temperatures enter in levels in the models. We hence estimate semi-elasticities.

In column 4, we introduce a country-sector-year fixed effect, absorbing the unconditional effect of weather shocks, and controlling for all country-wide shocks. This change in specification does not affect our conclusions.

Overall, in all instances, although the unconditional effect of the weather shock is negative, we observe that the interaction terms between weather and firm size are positive and statistically significant. This suggests that both temperature and precipitation shocks decrease firm-level exports, but that this effect decreases with firm size.

Table 3: Results: Intensive Margin

	Dep. Variable:($\ln X_{ft}$)			
	(1)	(2)	(3)	(4)
Temperatures	-0.056*** (0.015)	-0.085** (0.036)	-0.130*** (0.034)	
Log Precipitations	-0.306*** (0.040)	-1.053*** (0.118)	-1.019*** (0.111)	
Log GDP	1.104*** (0.106)	1.128*** (0.105)	1.372*** (0.133)	
Log Firm Exports (t-1)	0.264*** (0.011)	-0.226*** (0.075)	0.305** (0.155)	0.394** (0.159)
Temperatures \times Log Firm Exports (t-1)		0.003 (0.003)	0.007** (0.003)	0.005* (0.003)
Log Precipitations \times Log Firm Exports (t-1)		0.062*** (0.009)	0.058*** (0.008)	0.055*** (0.009)
Log GDP \times Log Firm Exports (t-1)			-0.022*** (0.006)	-0.024*** (0.006)
Observations	146360	146360	146360	145500
R^2	0.910	0.910	0.910	0.914
Firm FE	x	x	x	x
Sector-Year FE	x	x	x	
Country-Sector-Year FE				x

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard Errors are clustered at the Country-HS2 Sector-Year level.

Quantification of the differential effects. How much do these differences across firms matter?

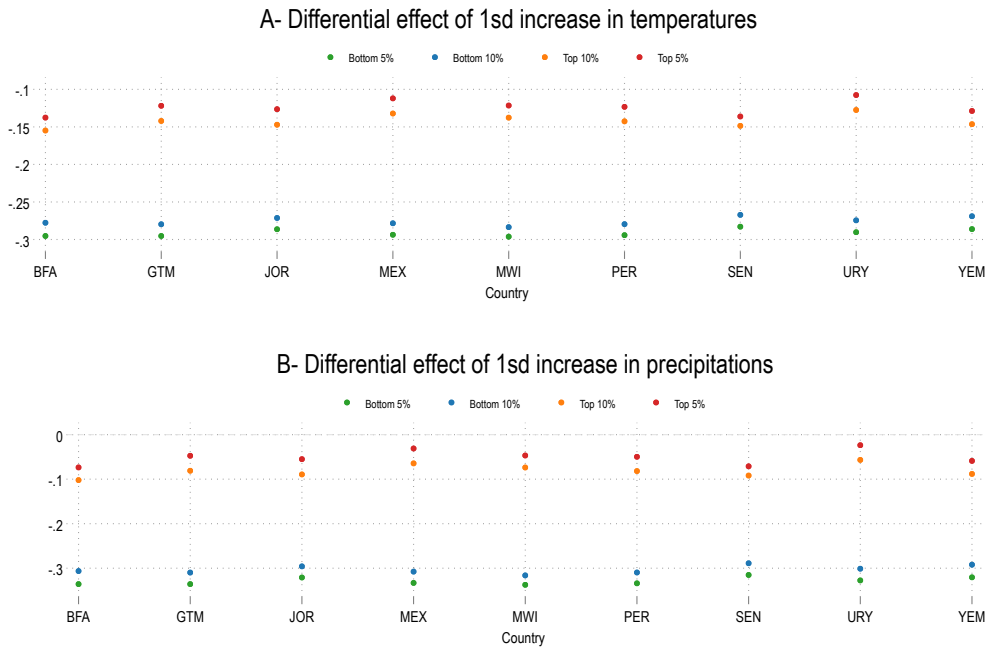
Figure 3 plots the country-by-country expected exports response of firms belonging to the bottom and top 5%, bottom 10%, top 5% and top 10% for a one standard deviation increase in temperatures (Panel A) and in precipitations (Panel B). These results are based on the third column of Table 3.

For a given temperature variation, for every country of our sample, the bottom 5% of firm-size distribution is disproportionately and negatively affected relative to the top 5%. In Mexico or Uruguay the smallest firms are almost three times more affected than the largest ones.

This differential effect of weather across firms is even more pronounced regarding the impact of precipitations. Estimates in Panel B suggest that the top firms' exports are almost left unaffected by the shock, while exports are very deterred for small exporters. The effect is -0.4% for the 5% of the top firm-size distribution in Mexico, while it is -0.5% for the bottom 5%.

Eventually, note that this feature is robust across countries, even though the magnitude of the differential effect appears heterogeneous. Finally, note also that even though point estimates of temperatures and precipitation are not of the same magnitude in the tables, their quantitative implications are very close in size.

Figure 3: Quantification: Effects of a one standard increase in temperatures and precipitations within country



Non-linearities along firm size. Figure 4 checks where, in the distribution, the differential effect of weather across firms comes from. Whereas our baseline interaction coefficient provides an average

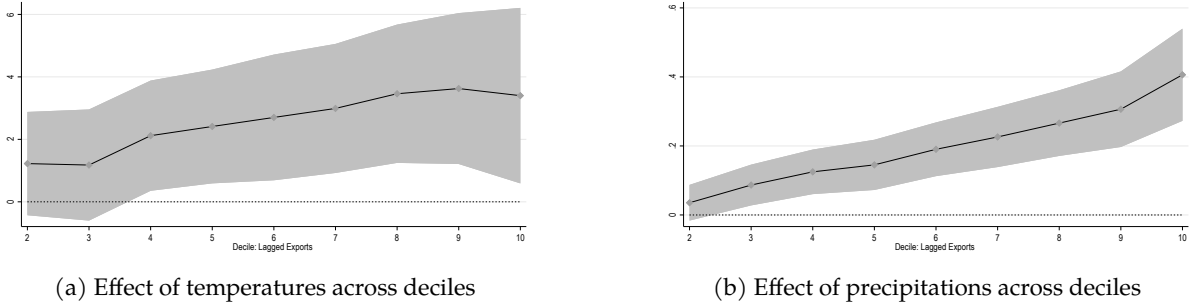
measure of the effect of firm size on the elasticity, we allow this elasticity to vary non-linearly, along firm-size distribution. We estimate the following model:

$$\begin{aligned}
 Exports_{ft} = & \alpha Temp_{i(f)t} + \delta Covariates_{it} + \sum_{d=1}^{10} \beta_d \mathbb{1}[Decile_{ft-1} = d] \\
 & + \sum_{d=1}^{10} \gamma_d (\mathbb{1}[Decile_{ft-1} = d] \times Weather_{i(f)t}) + FE + \varepsilon_{ft}
 \end{aligned} \tag{2}$$

where $\mathbb{1}[Decile_{ft-1} = d]$ is a set of dummy variables for each decile d in the lagged exports distribution, and where $Weather_{i(f)t}$ is temperatures and precipitations.

Figure 4 plots the estimates of all γ_d for $d = \{2, \dots, 10\}$, as the first decile is the reference group. Compared to the smallest firms, export growth is increased throughout the firm-size distribution. Besides, the differential effect of weather shocks across firms appears to be linear along firm size. The (implicitly linear) interaction coefficient in our estimation is thus a good approximation of the differential effect across firms.

Figure 4: Variation across Deciles



Note: The figure plots the estimated $\{\gamma_d\}_{d=\{1..10\}}$ from equation 2

Baseline results: extensive margin. Table 4 replicates the analysis for the extensive margin of trade, still at the firm-level. We estimate the impact of weather shocks on the log number of HS6 products exported to any destinations (columns 1, 2 and 3), and on the log number of destinations served (columns 4 to 6). We follow [Arkolakis et al. \(2010\)](#) and consider that, on top of the intensive margin, exporters choose presence at export destination and product scope. In theory, these two measures capture the extensive margin of trade as expanding product scope and serving additional markets requires the payment of additional fixed costs. The inability to cover for these costs leads some firms to exit foreign market and/or reduce their product scope, which can be seen as firm selection.

Results displayed in Table 4 suggest that weather shocks deter both measures of the extensive margin of trade (columns 1-2 and 4-5), as for the intensive margin. Again, firm size dampens this negative effect, in particular for precipitations. The interaction with lagged firm exports systematically lower the effect of weather shocks across our specifications.

Table 4: Results: Extensive Margin

	Dep. Variable: Nb. Products			Nb. Dest		
	(1)	(2)	(3)	(4)	(5)	(6)
Temperatures	-0.041*** (0.007)	-0.054*** (0.011)		-0.055*** (0.007)	-0.056*** (0.011)	
Log GDP	0.056 (0.039)	0.117** (0.046)		0.226*** (0.037)	0.383*** (0.042)	
Log Precipitations	-0.122*** (0.020)	-0.246*** (0.043)		-0.133*** (0.018)	-0.342*** (0.043)	
Log Firm Exports (t-1)	0.060*** (0.003)	0.104** (0.046)	0.103** (0.047)	0.073*** (0.003)	0.353*** (0.043)	0.320*** (0.040)
Temperatures \times Log Firm Exports (t-1)		0.001* (0.001)	0.000 (0.001)		0.000 (0.001)	0.000 (0.001)
Log Precip. \times Log Firm Exports (t-1)		0.010*** (0.003)	0.013*** (0.003)		0.016*** (0.003)	0.020*** (0.003)
Log GDP \times Log Firm Exports (t-1)		-0.005*** (0.002)	-0.005*** (0.002)		-0.015*** (0.001)	-0.015*** (0.001)
Observations	146360	146360	145500	176912	176912	176024
R^2	0.894	0.894	0.898	0.850	0.851	0.858
Firm FE	x	x	x	x	x	x
Sector-Year FE	x	x		x	x	
Country-Sector-Year FE			x			x
Cluster	cty-sec-yr	cty-sec-yr	cty-sec-yr	cty-sec-yr	cty-sec-yr	cty-sec-yr

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard Errors are clustered at the Country-HS2 Sector-Year level.

The interaction term with temperatures is significant at the 10% level in column 3, but becomes non significant and with value zero in the other specifications.

The overall magnitude of the effects is smaller than for the intensive margin (see Table 3). The unconditional effects of weather conditions are around 50% lower for precipitations, and decreased by 20% for temperatures. The differential effects we identify for precipitations are much smaller than at the intensive margin.

3.3 Robustness analysis

Temperature and precipitation shocks deter exports at both intensive and extensive trade margins. This effect, in both cases, is dampened by firms' size. This is the core result of our paper. The dampening effect of firms' size appears to be quantitatively more important at the intensive margin (compared to the unconditional effect). As a result, most of the differential adjustment to weather shocks appears to be occurring at the intensive margin. For this reason, we mainly focus our robustness checks on this dimension. In this section, we assess the robustness of our results to variables' measures, omitted variables as well as product and destination shocks.

Sensitivity to weather variables First, Table 5 shows that results are not sensitive to our measures of temperatures or precipitations. Indeed, using average maximum and minimum daily temperatures, as well as degree-days⁸ does not affect the sign and significance of our main coefficients of interest. Column 4 also shows that results are unaffected when using the number of wet days ('humidity') as an alternative to precipitations.

Sensitivity to firm size measure Second, results do not depend on the choice of proxy for firm size. In Table 6, we consider many measure of exporter size (as an alternative to lagged exports) and include their interactions with weather variables. We consider the 1-year and 2-year lagged export volumes as well as 2-year lagged exports values as proxies of firm size. The interaction coefficients are significant, positive and close in point estimates.

Omitted Variables Third, although the fixed effects included in our specification capture potentially omitted variables, some covariates, not included in our model so far, could explain the differential effect of weather shocks across firms. Table 7 presents the results of this robustness exercise.

⁸The degree-days index was computed using 32°C and 34°C thresholds, as detailed in Appendix A.2.

Table 5: Results: Sensitivity to weather variables

	Dep. Variable: Firm-level Exports, ($\ln X_{ft}$)			
	(1)	(2)	(3)	(4)
Exports ($t - 1$)	0.399** (0.158)	0.387** (0.159)	-0.789*** (0.260)	-0.002 (0.166)
Mean Max. Temperature \times Exports ($t - 1$)	0.005** (0.003)			
Log Precipitations \times Exports ($t - 1$)	0.058*** (0.009)	0.052*** (0.009)	0.152*** (0.016)	
Log GDP \times Exports ($t - 1$)	-0.026*** (0.006)	-0.021*** (0.006)	-0.026*** (0.007)	-0.014** (0.006)
Mean Min. Temperature \times Exports ($t - 1$)		0.005 (0.003)		
Degree Days \times Exports ($t - 1$)			0.084*** (0.019)	
Mean Temperature \times Exports ($t - 1$)				0.007** (0.003)
Log Humidity \times Exports ($t - 1$)				0.107*** (0.014)
Observations	145500	145500	123608	145500
R^2	0.914	0.914	0.915	0.914
Firm FE	x	x	x	x
Country-Sector-Year FE	x	x	x	x
Cluster	cnty-sec-yr	cnty-sec-yr	cnty-sec-yr	cnty-sec-yr

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard Errors are clustered at the Country-HS2 Sector-Year level.

Table 6: Results: Sensitivity to firm size variables

	Dep. Variable: Firm-level Exports, (ln X_{ft})		
	(1)	(2)	(3)
Firm Size:	Q_{ft-1}	Q_{ft-2}	X_{ft-2}
Firm size	-1.658*** (0.177)	0.394** (0.159)	-1.668*** (0.183)
Temperature \times Firm size	0.009*** (0.002)	0.005* (0.003)	0.009*** (0.002)
Log Precipitations \times Firm size	0.076*** (0.015)	0.055*** (0.009)	0.059*** (0.016)
Log GDP \times Firm size	0.049*** (0.006)	-0.024*** (0.006)	0.048*** (0.007)
Observations	57904	145500	41532
R^2	0.910	0.914	0.915
Firm FE	x	x	x
Country-Sector-Year FE	x	x	x
Cluster	cnty-sec-yr	cnty-sec-yr	cnty-sec-yr

Note: * p < 0.1, ** p < 0.05, *** p < 0.01. Standard Errors are clustered at the Country-HS2 Sector-Year level. All firm size measures are logged.

Table 7: Results: Omitted Variables

	Dep. Variable: Firm-level Exports, ($\ln X_{ft}$)					
	(1)	(2)	(3)	(4)	(5)	(6)
Log Firm Exports (t-1)	-0.344*** (0.117)	0.398** (0.164)	0.544* (0.298)	1.602*** (0.252)	2.232*** (0.253)	1.558*** (0.273)
Temperatures \times Log Firm Exports (t-1)	0.058*** (0.011)	0.006** (0.003)	0.026*** (0.005)	0.054*** (0.007)	0.006* (0.003)	0.005* (0.003)
Log Precipitations \times Log Firm Exports (t-1)	0.084*** (0.020)	0.048*** (0.009)	0.094*** (0.023)	0.078*** (0.017)	0.032*** (0.010)	0.035*** (0.009)
Temp. ($t - 1$) \times Log Firm Exports (t-1)	0.003 (0.008)					
Temp. ($t - 2$) \times Log Firm Exports (t-1)	-0.062*** (0.015)					
Log Precip. ($t - 1$) \times Log Firm Exports (t-1)	0.093*** (0.026)					
Log Precip. ($t - 2$) \times Log Firm Exports (t-1)	-0.083*** (0.032)					
Log GDP \times Log Firm Exports (t-1)		-0.022*** (0.006)	-0.051*** (0.010)	-0.112*** (0.017)	-0.083*** (0.010)	-0.050*** (0.008)
Tariffs \times Log Firm Exports (t-1)		-0.013 (0.010)				
Voice/Accountability \times Log Firm Exports (t-1)			0.051*** (0.011)			
Government Eff. \times Log Firm Exports (t-1)				-0.011 (0.010)		
Nb. Banks \times Log Firm Exports (t-1)					-0.104*** (0.013)	
Domestic Credit \times Log Firm Exports (t-1)						-0.101*** (0.023)
Observations	123403	140218	137605	113322	107958	176024
R^2	0.891	0.914	0.882	0.878	0.894	0.882
Firm FE	x	x	x	x	x	x
Country-Sector-Year FE	x	x	x	x	x	x
Cluster	ctry-sec-yr	ctry-sec-yr	ctry-sec-yr	ctry-sec-yr	ctry-sec-yr	ctry-sec-yr //

Note: * p < 0.1, ** p < 0.05, *** p < 0.01. Standard Errors are clustered at the Country-HS2 Sector-Year level.

Column 1 includes temperatures and precipitations in t , $t - 1$ and in $t - 2$, in the specification and shows that our main coefficient does not capture the differential effect of previous weather shocks. Column 2 controls for the differential effect of tariffs dynamics, without affecting the estimated interaction coefficient. In columns 3 and 4, we use the data from [Dahlberg et al. \(2018\)](#) to test the impact of changes in the quality of governance in exporting countries. Column 3 estimates the differential trade effects of weather controlling for changes in the "Voice and Accountability" measure, while in column 4 we control for the government effectiveness and for political stability. The sample size is affected but we still estimate a positive and significant coefficient of weather and firm size, confirming our benchmark estimation. Notice that the point estimate is slightly higher here. Finally, weather shocks could be correlated to changes in the economic environment of firms, and thus access to credit. Changes in domestic credit (as a share of GDP) in column 5 and changes in the number of banks in column 6 indeed have a differential effect across firms, but it does not alter our main conclusion: weather shocks have a differential impact across firms, in favor of larger firms.

Product-specific and destination-specific shocks Export patterns at the firm level are also determined by product-specific shocks such as changes in tastes, and by destinations-specific shifts such as varying GDP. Here we test the robustness of our results when accounting for such possible shocks. Suppose for instance that weather shocks in country c_1 and c_2 are correlated, and that c_2 imports goods from c_1 . Following these weather shocks, part of our main result could come from changes in c_2 imports that, in turn, affect exports in c_1 . Cross-country correlation of weather shocks is thus a potential challenge in our case. To neutralize these issues, we estimate the following specification, using export information at the firm-destination-product level:

$$\begin{aligned}
Exports_{fjpt} = & \alpha Weather_{i(f)t} + \beta Exports_{ft-1} + \delta Covariates_{it} + \nu Shocks_{jt} \\
& + \gamma (Weather_{i(f)t} \times Exports_{ft-1}) + \mu (Covariates_{it} \times Exports_{ft-1}) \\
& + \eta (Shocks_{jt} \times Exports_{ft-1}) + FE + \varepsilon_{ft}
\end{aligned} \tag{3}$$

where j denotes the destination market, p denotes the HS6 product category. $Shock_{jt}$ captures destination-specific aggregate shocks that may have both an average effect on exports and a differential effect across exporting firms. We include a set of fixed effects to account for unobserved heterogeneity, combining firm-, product-, sector- and destination- effects. Both these combinations of product- and destination-specific fixed effects and the inclusion of destination-year macroeconomic control variables allows us to absorb competing mechanisms, and we cluster the standard errors at the origin- HS2 sector-year level. Results are displayed in [Table 8](#).

Column 1 shows that temperatures in home country do not deter the average exports at the intensive margin once accounting for destination temperatures and GDP. Yet, precipitation at home still deter ex-

Table 8: Destination- and Product Specific Shocks

	Dep. Variable: Exports, ($\ln X_{fjpt}$)			
	(1)	(2)	(3)	(4)
Temperatures	-0.001 (0.020)	-0.046 (0.034)	-0.052 (0.050)	
Log Precipitations	-0.208*** (0.039)	-0.841*** (0.121)	-0.744*** (0.185)	
Dest. Temperatures	-0.050*** (0.012)	-0.051*** (0.012)		
Log Dest. Precip.	0.083** (0.038)	0.088** (0.038)		
Temperatures \times Log Firm Exports (t-1)		0.003* (0.002)	0.005** (0.003)	0.005* (0.003)
Log Precipitations \times Log Firm Exports (t-1)		0.044*** (0.008)	0.042*** (0.012)	0.041*** (0.014)
Dest. Temperatures \times Log Firm Exports (t-1)			0.002 (0.002)	0.002 (0.002)
Log Dest. Precip. \times Log Firm Exports (t-1)			0.005 (0.011)	0.008 (0.012)
Log GDP	0.061 (0.112)	0.182 (0.114)	0.262 (0.281)	
Log Firm Exports (t-1)	0.199*** (0.008)	-0.185*** (0.066)	-0.432** (0.211)	-0.343 (0.229)
Log Dest. GDP	0.386*** (0.030)	0.383*** (0.030)		
REER	-0.555*** (0.154)	-0.402*** (0.156)	-0.003 (0.394)	
Log Dest. REER	-0.031*** (0.009)	-0.032*** (0.009)		
Log GDP \times Log Firm Exports (t-1)			-0.010 (0.006)	-0.013* (0.007)
REER \times Log Firm Exports (t-1)			-0.014** (0.007)	-0.011 (0.008)
Log Dest. GDP \times Log Firm Exports (t-1)			0.015*** (0.005)	0.015*** (0.005)
Observations	332367	332367	272267	251066
R^2	0.854	0.854	0.910	0.912
Firm FE	x			
Home-Destination FE	x			
Product-Year FE	x			
Firm-Product-Destination FE		x	x	x
Year FE		x		
Destination-Product-Year FE			x	
Home-Destination-Product-Year FE				x

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard Errors are clustered at the Country-HS2 Sector-Year level.

ports on average. Column 2 however supports this average effects hide heterogeneity across local firms: larger firms are less negatively affected by temperature and precipitations shocks at home, even when controlling for home and foreign aggregate shifts in GDP and trade determinants. Columns 3 to 4 further support that the differential effect of local temperature shocks holds when taking into account the potential differential effect of foreign weather shocks and foreign macroeconomic shocks (and by including demanding fixed effects). The interaction term is only slightly affected, without any change in its significance. The coefficient is stable across specifications, which reinforces confidence in the estimation and in the model we estimate. Overall, whereas cross-country correlation of weather shocks could explain our results, we show that this is not the case. This confirms the differential effect previously estimated at the firm-year dimension.

3.4 Additional results

Additional results are available in Appendix, section B. This subsection presents the flavor of these results.

Alternative estimator: Dynamic Panel Table B.1 shows results when using a dynamic panel specification (Arellano and Bond, 1991) and accounting for the potential Nickell bias (Nickell, 1981). As our specification includes the lagged exports as a right-hand side variable, this raises potential endogeneity issues. Results –using similar sets of fixed effects – in particular in columns 3 and 4 – confirm the differential effect of firm size on the elasticity, in favor of the largest firms.

Alternative estimator: PPML Table B.2 shows the results when using a pseudo-Poisson maximum likelihood (PPML) estimator on the rectangular dataset (i.e. over firms and years, not across destinations and products), to account at least for both trade margins simultaneously, for heteroskedasticity and for zero-trade flows. We obtain coefficients very close to the baseline ones, in sign and in magnitudes.

Alternative Clustering levels. Tables B.3, B.4, B.5, and B.6 show results when clustering the standard errors at the country-year, country-HS2 sector level, HS2 sector-year level, and firm respectively, without affecting inference. The differential effect of firm size on the exports effects of precipitation changes appears as the most robust effect, compared to temperatures.

Non-linearities of weather and interactions between weather variables. Temperatures and precipitations may have a non-linear effect on economic outcomes (Burke et al., 2015; Deschênes and Greenstone, 2011). Table B.7 accounts for this feature by controlling for squared temperatures (col.1 onwards), for squared log precipitations (col.2 onwards), without affecting the estimated differential effects across firms. Accounting for the interaction between precipitations and temperatures (which have also been

advocated to be detrimental to economic activity (Dell et al., 2012)) does not alter our main coefficient (column 4).

Sub-samples. Results are also robust to (i) excluding data from Mexico, which represents a very large share of the observations, see Table B.8, and (ii) to excluding very small trade flows (bottom 5% of exports within each country, potentially adding noise) from the sample, see Table B.9.

Additional firm characteristics. Table B.10 shows results when including lagged exports and other firm characteristics in the same specification. Table B.10 allows temperatures to have a differential effect across firms along their experience on the export market, their continuous experience in exporting (i.e. controlling for consecutive years), their number of products and destinations served. Lagged export is the main variable that allows to capture the differential effect. The major part of the cross-firm variance in the heterogeneous reaction to temperatures is accounted for by lagged exports.

Heterogeneity: Effects across sectors Figure B.1 shows the estimated differential impact of weather variations on exports across broad sectors. Firm-level exports were aggregated by HS2 (chapter) and then by broad sector. Our results imply that all sectors exhibit some differential effects across firms: firms within a sector are heterogeneously affected by precipitation, and to a lesser extent by temperature variations. Indeed, whereas most sectors yield a differential pattern after precipitation changes, the differential impact of temperatures across firms is limited to a small set of sectors.

Firms sorting Finally, larger firms could cluster in areas facing more stable temperatures relative to rural regions where temperature variations could be higher. We note however that it is unlikely to affect our results for at least two reasons. On the one hand, we use year-to-year changes in weather and exports, which limits the potential sorting pattern in space. On the other hand, even in the presence of potential sorting with all exporters moving to milder areas, it would imply in the longer run that workers would also move to these areas. As we rely on aggregated country-year information (i.e. daily station level data, with transformations and aggregation by country), our data captures this potential within-country variation in economic activity.

4 Aggregate Implications

In this section, we explore the aggregate implications of the micro-level results presented previously. We build on the approach developed by Di Giovanni et al. (2018) and adapted to a trade and environment setting by papers such as Héricourt and Nedoncelle (2018) or Erbahar (2019).

In section 3, we identified the heterogeneous firm-specific elasticity of exports to weather shocks: larger firms exhibit smaller negative responses. It follows that aggregate country-wide exports should

be deterred to the extent that exports are realized by numerous smaller firms, which are particularly harmed by precipitations and temperatures shocks.

We empirically investigate this intuition here by performing a set of counterfactual exercises relative to both climate scenarios and the structure of exports. We conduct projections of future exports when all countries face the same changes in climate conditions, and then when they share the same firm-distribution. This allows us disentangle the importance of climate and firm-size effects, as we detail below.

4.1 Data sources and sample

In this exercise, we use additional data from the Climate Knowledge Portal from the World Bank. Data consist of predicted temperatures $T_{i,t}^{exp}$ and precipitation $P_{i,t}^{exp}$ for each country in our sample at the yearly level up to 2100, i.e., $t \in \{2015, \dots, 2100\}$. For each country-year, several indicators are available: we use the projections from the HadGEM3-GC3.1 for CMIP6 model and two climate scenarios, from the most pessimistic (RCP 8.5) to the most optimistic (RCP 2.6).⁹

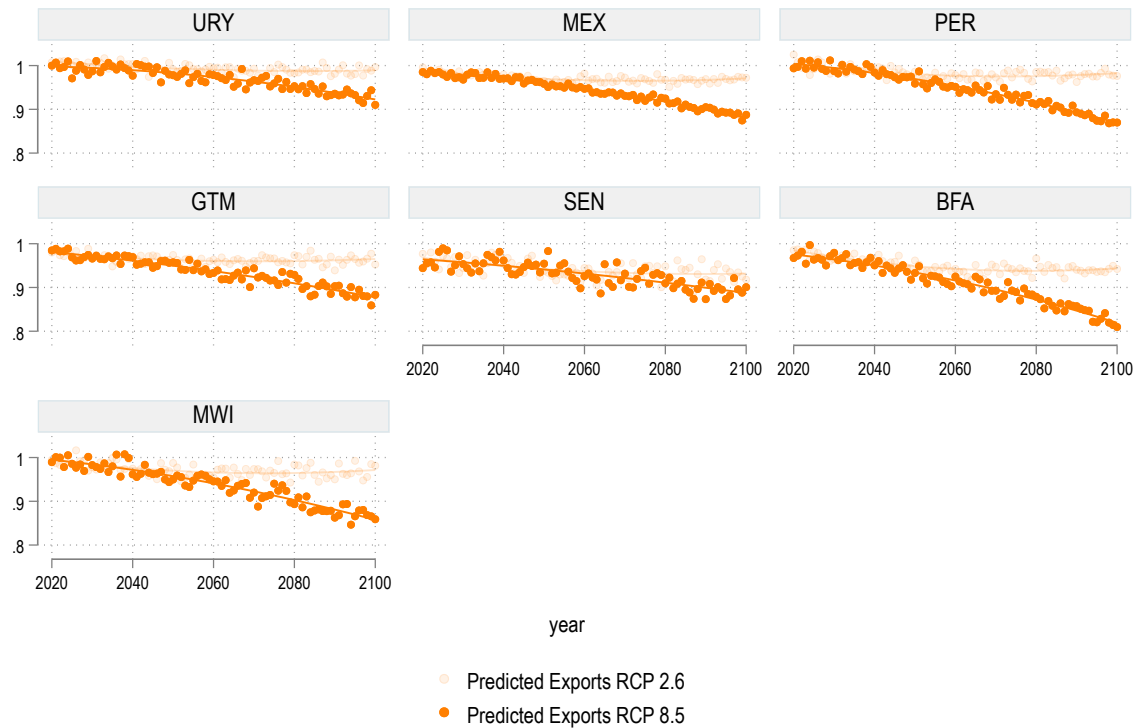
In the Figure A.2 in Appendix, we plot the precipitations (a) and temperatures (b) projections for each country over time for the two climate scenarios (dark or light orange). The RCP8.5 scenario predicts important differences in temperature increases relative to the most optimistic scenario. For instance, in Malawi, the average temperature is expected to increase by 6°C at the end of the century under the RCP8.5 scenario, while it is expected to increase by 1.5°C under the RCP2.6 scenario. For precipitations, the differences are less pronounced, but still important.

4.2 Country-specific predicted exports

Figure 5 plots the predicted exports, derived from our empirical model (column 3 of Table 3), when observed weather conditions are replaced by predicted weather conditions. The firm-specific responses were aggregated by decile of size (measured by lagged exports) under the RCP 2.6 and 8.5 scenarios. Taking this aggregation by country-year yields the total exports patterns over time ($t \in \{2015, \dots, 2100\}$) for each country. Future exports were normalized by the initial level of exports, i.e. the latest aggregate exports available in our sample. Figure 5 hence displays the relative change in exports over time.

⁹Note that Jordan and Yemen are predicted to experience close to zero precipitations in many of the coming years, according to the World Bank data. Given the following exercises, we had to exclude those two countries from our sample for this part of the analysis, as withdrawing the common precipitation variation (for all countries) from the close-to-zero precipitation leads to biased measures. To be consistent in this section, we always run the models on a restricted sample, without Jordan and Yemen.

Figure 5: Predicted exports



Several patterns emerge. First, the amount of exports decreases over time in the 7 countries represented here. Second, the effects are much more important under the most pessimistic scenario. Indeed, with RCP 8.5 it is estimated that exports would decline by 10% because of new weather conditions. This is an average effect across the countries. On the contrary, the most optimistic scenario yields only relatively marginal export losses. Third, there are strong differences between trajectories across countries. For example, exports losses are larger in Malawi than in Uruguay. This differential pattern across countries is valid for both climate scenarios.

4.3 Counterfactual exercises

Two main forces could be driving the differential export patterns described in section 4.2. On the one hand, countries face different changes in weather conditions over time. For instance, changes in temperatures and in precipitations could be larger in some parts of the world, affecting more the exports of some countries compared to others, independently of their structure of exports.

On the other hand, the structure of exports differ between countries: the importance of large firms – which are less harmed by weather shocks – varies between countries. The differential composition of firms in the economy hence generates different patterns of exports under weather shocks.

Table 9: Counterfactuals - Results - RCP8.5

Country	BAU	CF1	CF2
Scenario:			
With average weather conditions		x	
With Mexico firm distribution			x
URY	-6,36	-8,29	-6,28
MEX	-8,74	-8,93	-8,74
PER	-10,27	-10,17	-10,10
GTM	-9,45	-9,61	-9,50
SEN	-5,00	-9,75	-5,04
BFA	-12,70	-10,65	-12,55
MWI	-11,28	-10,46	-10,66
Average Cost (mean)	-9,11	-9,70	-8,98
Dispersion (std)	2,70	0,84	2,58

To shed light on the quantitative importance of these two channels, we perform three counterfactual exercises. First, we replicate the analysis from section 4.2, but considering that all countries in the sample face the same, average change in climate conditions. It means that we build a counterfactual weather scenario that is equal to the average of the 7 country-specific RCP8.5 scenarios. This exercise shuts down the differential climate change effect, and considers that all countries in our sample face the same weather changes from one year to the next one.

Second, we go back to the country-specific projected changes in weather conditions (as in section 4.2), but this time we impose an alternative firm-distribution: all countries have the Mexico firm distribution. As shown in Figure 1, Mexico has a larger firm concentration compared to other countries. In that sense, Mexico can be viewed as relatively polar case. This exercise shuts down the firm distribution differential across countries.

Countries face the same future weather conditions (CF1). Results of the first counterfactual are displayed in Table 9. For each country, the table provides the total changes in exports attributed to weather variations at the 2080 horizon. The first column of results ("BAU") provides the exports under business-as-usual conditions: it reports the exports under country-specific projected weather conditions and country-specific firm distribution. Numbers reflect the trajectory previously described in Figure 5.

Column "CF1" provides the predictions of our model when all countries face the counterfactual change in weather, which is the average of the 6 countries. Unsurprisingly, the countries that are more exposed to adverse future weather shocks would lose less by facing milder weather conditions. This is particularly the case for Malawi and Burkina Faso. On the contrary, countries that are expected to face milder weather change over time would lose more if they were to face adverse weather in the medium and long runs, as Uruguay or Guatemala for instance.

In this counterfactual, results are driven by the relative inequality between countries to face adverse weather conditions. Examining the bottom of the table, we see that removing these inequalities reduces the dispersion of exports response across countries. However, we also estimate that the average costs in terms of reduced exports would be larger in that case, compared to BAU.

Countries have the same firm-distribution (CF2). Column "CF2" shows the results when all countries face their own country-specific changes in weather, but that firm distribution in each country is the one from Mexico. Compared to the BAU case, most countries would benefit from having Mexico's firm distribution. This is direct consequence of our empirical results, suggesting that the negative aggregate impact of weather shock (in the past or in the future) is inversely related to the importance of large exporters, that are less affected by adverse weather conditions. In CF2, we observe for instance that export losses due to climate change would be 0.15 p.p. lower in Burkina Faso if the country had Mexico's structure of exports. In Uruguay, it would be 0.8 p.p. lower.

At the bottom of the table, we provide two aggregates of importance. For each counterfactual, we provide the average export loss and its dispersion across countries. Two main results can be identified from our analysis. On the one hand, considering average weather conditions (instead of the country-specific projected weather) would yield lower dispersion of exports loss across countries but larger average costs. On the other hand, changing firm distribution reduces both aggregate/mean exports loss under climate change and dispersion across countries, though to a smaller extent.¹⁰

Limits. As for any exercise, our quantification presents some limitations. First, it is based on partial elasticities, not structural estimations. Our estimations absorb global, common shocks (in our set of fixed-effects) and identify effects compared to average sectoral values. This means that our counterfactuals ignore, for instance, possible variations in global demand or sector-specific environmental disasters that would affect exports in the context of climate change. Second, our quantification exercise assumes constant firm-size distribution. In fact, future weather conditions may affect this distribution as, for example, smaller firms are disproportionately impacted. While this is beyond the scope of this paper, we think that a similar exercise considering endogenous firm-size distribution would be a promising research avenue.

5 Concluding remarks

In this paper, we analyze the impact of weather shocks on firm-level exports in 9 LMIC. For this purpose, we combined temperature and precipitations data with various information on exporting firms. Our

¹⁰These conclusions are unaffected when considering more optimistic projected weather conditions (RCP2.6), see Table B.11.

main identification strategy uses year-to-year fluctuations in weather conditions, as well as country, year and sector fixed-effects.

In the first part of our analysis, we find differential effects of increases in temperature and precipitations across exporting firms depending on their size. While the average response of exports to these weather covariates are negative, this result hides a large heterogeneity: large exporters are significantly and quantitatively less harmed than smaller ones. Elasticity of exports to temperatures and precipitations are close to -0.3 for the smallest exporters but closer to -0.1 for the largest ones. This feature is robust across countries and relies on the within-country distribution of firms.

In the second part of our analysis, we investigate how this micro-level impacts influence aggregate exporting outcomes. While we estimate that future climate conditions will decrease aggregate exports by 9% on average in our sample, we find that firm-size distribution plays an important role in mitigating this result. Indeed, in a counterfactual exercise, we show that if all countries had the firm-size distribution of Mexico (the country with the largest share of top exporters in our sample), then the negative average impact of climate change would be 0.13 p.p. lower than under business-as-usual. In some countries, like Burkina Faso, it is 0.15 p.p. lower. Overall, this simple exercise highlights that expanding the role of large firms in the economy reduces the costs of future climate shifts on aggregate exports. This is the second important result of this paper.

Given the importance of future climate trends, our results suggest that firm-size distribution in low- and middle-income countries, characterized by a lower share of large exporters, could increase the aggregate cost of climate shocks on trade. In that sense, increasing firm concentration could be beneficial as climate adaptation is seemingly less costly for top exporters. Additionally, we note that more exports from top firms might, in theory, bring important general equilibrium effects not necessarily linked to environmental conditions. One example is the reallocation of labor from low to high-productive firms, allowing significant productivity gains. While this paper did not focus specifically on these implications, we believe this kind of analysis in an integrated aggregate framework to be an important research avenue. Especially in the context of climate change, which makes these questions even more challenging.

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Appendix for

Weather Shocks and Firm Exports in Developing Countries

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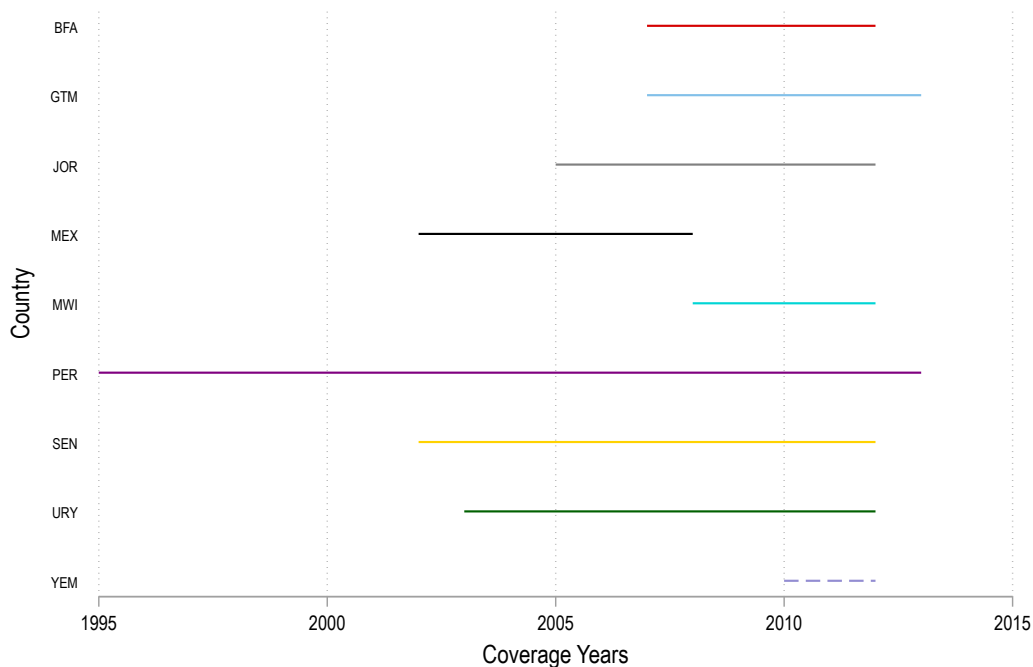
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A Data Information

A.1 Coverage of the export data

Figure A.1: Time Coverage by exporting country



A.2 Alternative Measure of Weather: Degree-Days

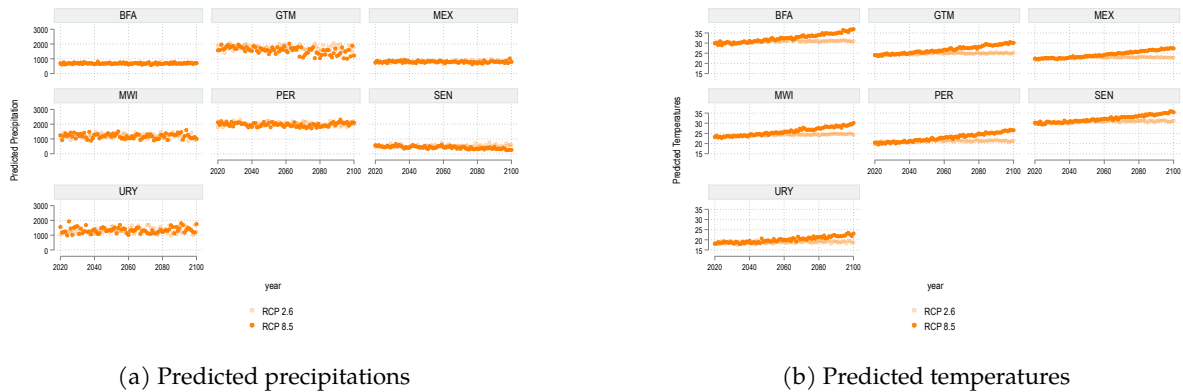
Our estimations also account for potential non linearities in the temperatures (Schlenker and Roberts, 2009). We use data from the NOAA Global Historical Climatology Network, Daily (GHCN-D), providing averaged temperatures at the weather station - country -day dimensions (for our sample countries, this represents around 19 000 000 observations). We have aggregated that data by computing the daily average temperature by country. Armed with these country i average temperatures (in degrees Celsius) at the daily d level, T_{idt} , we have converted them into so-called country-year degree-days, DD_{it} , using the following formula:

$$DD_{it} = \begin{cases} 0 & \text{if } T_{idt} \leq 8C \\ T_{idt} - 8 & \text{if } 8C < T_{idt} \leq 32C \\ 24 & \text{if } T_{idt} > 32C \end{cases}$$

We thus obtain a country-year measure of temperatures, which captures both the number of days of “large temperatures” and a cumulative measure of these “large temperatures”.

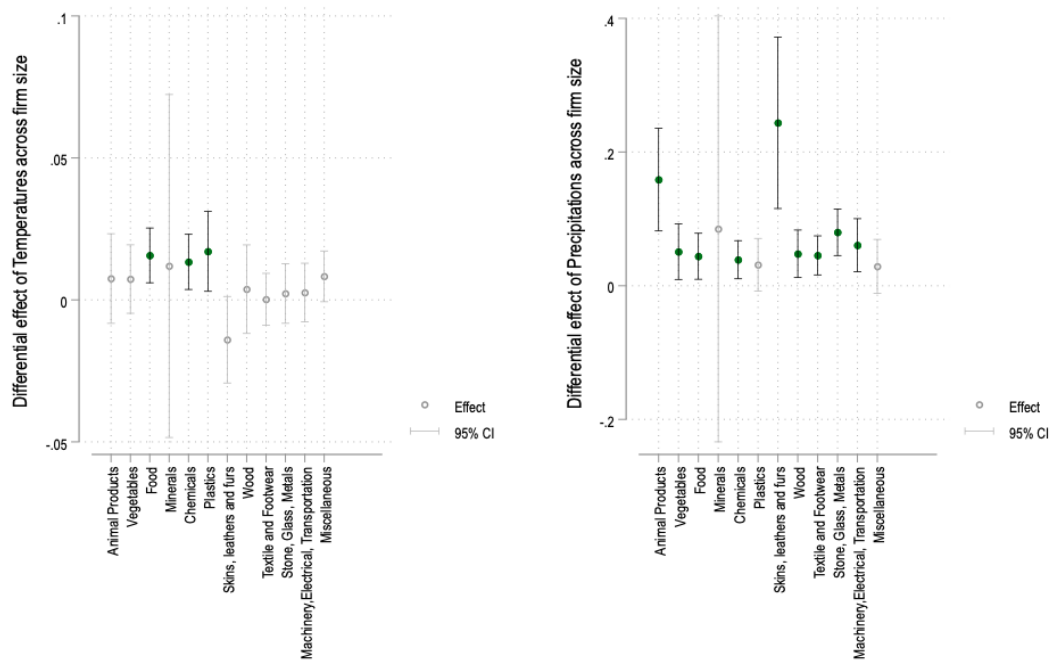
A.3 Projected weather

Figure A.2: Predicted weather



B Additional results

Figure B.1: Differential effects across firms: variation between broad sectors.



Note: Animal Products include HS2 01 to 05. Vegetables include HS2 06 to 15. Food includes HS2 16 to 24. Minerals include HS2 25 to 27. Chemicals include HS2 28 to 38. Plastics include HS2 39 to 40. Skins, leathers and furs include HS2 41 to 43. Wood includes HS2 44 to 49. Textile and Footwear include HS2 50 to 67. Stone, Glass, Metals include HS2 68 to 83. Machinery, Electrical, Transportation include HS2 84 to 89. Miscellaneous include HS2 90 to 97.

Table B.1: Results: Dynamic Panel Estimations

	Dep. Variable: Log Firm-level Exports, ($\ln X_{ft}$)			
	(1)	(2)	(3)	(4)
Temperatures	0.058*** (0.002)			
Log Precipitations	-0.002 (0.012)			
Log GDP	0.000 (0.005)			
Exports (t-1)	-0.256*** (0.016)	-0.223*** (0.014)	-0.305*** (0.022)	-0.451*** (0.017)
Temperatures \times Exports (t-1)		0.001*** (0.000)	0.005*** (0.001)	0.007*** (0.001)
Log Preci. \times Exports (t-1)		0.029*** (0.001)	0.037*** (0.002)	0.055*** (0.002)
Log GDP \times Exports (t-1)				-0.005*** (0.000)
Observations	135712	135712	135712	135712
Firm FE	x	x	x	x
Sector-Year FE	x	x	x	
Country-Sector-Year FE				x

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$.

Table B.2: Results: PPML Estimations

	Dep. Variable: Firm-level Exports, (X_{ft})			
	(1)	(2)	(3)	(4)
Temperatures	0.003 (0.018)	-0.008 (0.043)	-0.064 (0.046)	
Log GDP	1.038*** (0.091)	1.040*** (0.090)	1.294*** (0.166)	
Log Precipitations	-0.317*** (0.045)	-1.165*** (0.159)	-1.157*** (0.161)	
Log Firm Exports (t-1)	0.431*** (0.012)	0.039 (0.079)	0.431*** (0.167)	0.546*** (0.189)
Temperatures \times Log Firm Exports (t-1)		0.001 (0.002)	0.005* (0.003)	0.004 (0.003)
Log Precipitations \times Log Firm Exports (t-1)		0.054*** (0.010)	0.053*** (0.010)	0.041*** (0.011)
Log GDP \times Log Firm Exports (t-1)			-0.017** (0.007)	-0.018** (0.008)
Observations	186222	186222	186222	185099
Firm FE	x	x	x	x
Sector-Year FE	x	x	x	
Country-Sector-Year FE				x
Cluster	ctry-sec-yr	ctry-sec-yr	ctry-sec-yr	ctry-sec-yr

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard Errors are clustered at the Country-HS2 Sector-Year level.

Table B.3: Results: Intensive Margin: alternative clustering level (Country-Year)

	Dep. Variable: Log Firm-level Exports, ($\ln X_{ft}$)			
	(1)	(2)	(3)	(4)
Temperatures	-0.056 (0.040)	-0.085 (0.111)	-0.130 (0.105)	
Log Precipitations	-0.306*** (0.112)	-1.053*** (0.327)	-1.019*** (0.291)	
Log GDP	1.104*** (0.330)	1.128*** (0.322)	1.372*** (0.445)	
Log Firm Exports (t-1)	0.264*** (0.038)	-0.226 (0.227)	0.305 (0.493)	0.394 (0.493)
Temperatures \times Log Firm Exports (t-1)		0.003 (0.009)	0.007 (0.009)	0.005 (0.009)
Log Precipitations \times Log Firm Exports (t-1)		0.062** (0.025)	0.058*** (0.022)	0.055** (0.022)
Log GDP \times Log Firm Exports (t-1)			-0.022 (0.020)	-0.024 (0.021)
Observations	146360	146360	146360	145500
R^2	0.910	0.910	0.910	0.914
Sample				
Firm FE	x	x	x	x
Sector-Year FE	x	x	x	
Country-Sector-Year FE				x
Cluster	cty x year	cty x year	cty x year	cty x year

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard Errors are clustered at the country-year level.

Table B.4: Results: Intensive Margin: alternative clustering level (Sector-Country)

	Dep. Variable: Firm-level Exports, ($\ln X_{ft}$)			
	(1)	(2)	(3)	(4)
Temperatures	-0.056*** (0.016)	-0.085** (0.039)	-0.130*** (0.040)	
Log Precipitations	-0.306*** (0.037)	-1.053*** (0.164)	-1.019*** (0.146)	
Log GDP	1.104*** (0.120)	1.128*** (0.114)	1.372*** (0.143)	
Log Firm Exports (t-1)	0.264*** (0.014)	-0.226** (0.092)	0.305* (0.162)	0.394** (0.160)
Temperatures \times Log Firm Exports (t-1)		0.003 (0.003)	0.007** (0.003)	0.005 (0.003)
Log Precipitations \times Log Firm Exports (t-1)		0.062*** (0.013)	0.058*** (0.011)	0.055*** (0.011)
Log GDP \times Log Firm Exports (t-1)			-0.022*** (0.006)	-0.024*** (0.006)
Observations	146360	146360	146360	145500
R^2	0.910	0.910	0.910	0.914
Sample				
Firm FE	x	x	x	x
Sector-Year FE	x	x	x	
Country-Sector-Year FE				x
Cluster	cnty-sec-yr	cnty-sec-yr	cnty-sec-yr	cnty-sec-yr

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard Errors are clustered at the Sector-Country level.

Table B.5: Results: Intensive Margin: alternative clustering level (Sector-Year)

	Dep. Variable: Firm-level Exports, ($\ln X_{ft}$)			
	(1)	(2)	(3)	(4)
Temperatures	-0.056*** (0.017)	-0.085*** (0.033)	-0.130*** (0.035)	
Log Precipitations	-0.306*** (0.042)	-1.053*** (0.114)	-1.019*** (0.107)	
Log GDP	1.104*** (0.116)	1.128*** (0.116)	1.372*** (0.136)	
Log Firm Exports (t-1)	0.264*** (0.011)	-0.226*** (0.070)	0.305** (0.140)	0.394*** (0.148)
Temperatures \times Log Firm Exports (t-1)		0.003 (0.002)	0.007*** (0.002)	0.005* (0.003)
Log Precipitations \times Log Firm Exports (t-1)		0.062*** (0.008)	0.058*** (0.008)	0.055*** (0.008)
Log GDP \times Log Firm Exports (t-1)			-0.022*** (0.006)	-0.024*** (0.006)
Observations	146360	146360	146360	145500
R^2	0.910	0.910	0.910	0.914
Sample				
Firm FE	x	x	x	x
Sector-Year FE	x	x	x	
Country-Sector-Year FE				x
Cluster	sec-yr	sec-yr	sec-yr	sec-yr

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard Errors are clustered at the sector-year level.

Table B.6: Results: Intensive Margin: alternative clustering level (Firm)

	Dep. Variable: Firm-level Exports, ($\ln X_{ft}$)			
	(1)	(2)	(3)	(4)
Temperatures	-0.056*** (0.014)	-0.085*** (0.022)	-0.130*** (0.023)	
Log Precipitations	-0.306*** (0.033)	-1.053*** (0.090)	-1.019*** (0.088)	
Log GDP	1.104*** (0.071)	1.128*** (0.071)	1.372*** (0.079)	
Log Firm Exports (t-1)	0.264*** (0.006)	-0.226*** (0.049)	0.305*** (0.090)	0.394*** (0.095)
Temperatures \times Log Firm Exports (t-1)		0.003** (0.001)	0.007*** (0.001)	0.005*** (0.001)
Log Precipitations \times Log Firm Exports (t-1)		0.062*** (0.007)	0.058*** (0.007)	0.055*** (0.007)
Log GDP \times Log Firm Exports (t-1)			-0.022*** (0.003)	-0.024*** (0.003)
Observations	146360	146360	146360	145500
R^2	0.910	0.910	0.910	0.914
Sample				
Firm FE	x	x	x	x
Sector-Year FE	x	x	x	
Country-Sector-Year FE				x
Cluster	firm	firm	firm	firm

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard Errors are clustered at the firm level.

Table B.7: Results: Non-linearities in weather

	Dep. Variable: Firm-level Exports, ($\ln X_{ft}$)			
	(1)	(2)	(3)	(4)
Temperatures	-1.071*** (0.138)	-1.176*** (0.140)	-1.237*** (0.138)	-1.734*** (0.165)
Temperatures \times Temperatures	0.026*** (0.003)	0.029*** (0.004)	0.028*** (0.004)	0.031*** (0.004)
Log GDP	2.002*** (0.154)	2.020*** (0.153)	2.435*** (0.190)	2.553*** (0.195)
Log Precipitations	-0.457*** (0.055)	-2.679*** (0.421)	-3.346*** (0.435)	-3.966*** (0.443)
Log Firm Exports (t-1)	0.298*** (0.010)	0.298*** (0.010)	0.751*** (0.163)	0.771*** (0.163)
Log Precipitations \times Log Precipitations		0.166*** (0.030)	0.170*** (0.030)	0.130*** (0.030)
Temperatures \times Log Firm Exports (t-1)			0.009*** (0.003)	0.008*** (0.003)
Log Precipitations \times Log Firm Exports (t-1)			0.050*** (0.008)	0.049*** (0.008)
Log GDP \times Log Firm Exports (t-1)			-0.038*** (0.006)	-0.038*** (0.006)
Temperatures \times Log Precipitations				0.065*** (0.009)
Observations	176912	176912	176912	176912
R^2	0.874	0.874	0.875	0.875
Firm FE	x	x	x	x
Sector-Year FE	x	x	x	x
Cluster	cnty-sec-yr	cnty-sec-yr	cnty-sec-yr	cnty-sec-yr

Note: * p < 0.1, ** p < 0.05, *** p < 0.01. Standard Errors are clustered at the Country-HS2 Sector-Year level.

Table B.8: Results: Intensive Margin - Excluding Mexico

	Dep. Variable: Firm-level Exports, ($\ln X_{ft}$)			
	(1)	(2)	(3)	(4)
Temperatures	-0.017 (0.016)	-0.113*** (0.037)	-0.112*** (0.036)	
Log Precipitations	-0.259*** (0.040)	-0.755*** (0.106)	-0.446*** (0.111)	
Log GDP	0.377*** (0.091)	0.439*** (0.092)	-0.370*** (0.125)	
Log Firm Exports (t-1)	0.316*** (0.010)	-0.132* (0.074)	-1.501*** (0.176)	-1.329*** (0.183)
Temperatures \times Log Firm Exports (t-1)		0.008*** (0.003)	0.009*** (0.003)	0.008*** (0.003)
Log Precipitations \times Log Firm Exports (t-1)		0.042*** (0.008)	0.019** (0.008)	0.019** (0.009)
Log GDP \times Log Firm Exports (t-1)			0.062*** (0.007)	0.055*** (0.007)
Observations	77027	77027	77027	76242
R^2	0.908	0.909	0.909	0.913
Firm FE	x	x	x	x
Country FE				
Sector-Year FE	x	x	x	
Country-Year FE				
Country-Sector-Year FE				x
Cluster	cnty-sec-yr	cnty-sec-yr	cnty-sec-yr	cnty-sec-yr

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard Errors are clustered at the Country-HS2 Sector-Year level.

Table B.9: Results: Intensive Margin - Excluding Small Exports

	Dep. Variable: Firm-level Exports, ($\ln X_{ft}$)			
	(1)	(2)	(3)	(4)
Temperatures	-0.052*** (0.015)	-0.071** (0.036)	-0.121*** (0.034)	
Log Precipitations	-0.288*** (0.038)	-1.058*** (0.118)	-1.024*** (0.111)	
Log GDP	1.034*** (0.099)	1.058*** (0.099)	1.324*** (0.129)	
Log Firm Exports (t-1)	0.274*** (0.011)	-0.208*** (0.074)	0.361** (0.156)	0.455*** (0.162)
Temperatures \times Log Firm Exports (t-1)		0.003 (0.003)	0.006** (0.003)	0.005 (0.003)
Log Precipitations \times Log Firm Exports (t-1)		0.063*** (0.009)	0.059*** (0.008)	0.055*** (0.009)
Log GDP \times Log Firm Exports (t-1)			-0.024*** (0.006)	-0.025*** (0.006)
Observations	139304	139304	139304	138444
R^2	0.912	0.912	0.912	0.916
Firm FE	x	x	x	x
Country FE				
Sector-Year FE	x	x	x	
Country-Year FE				
Country-Sector-Year FE				x
Cluster	cnty-sec-yr	cnty-sec-yr	cnty-sec-yr	cnty-sec-yr

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard Errors are clustered at the Country-HS2 Sector-Year level.

Table B.10: Results: Intensive Margin - Other firm characteristics

	Dep. Variable: Firm-level Exports, ($\ln X_{ft}$)				
	(1)	(2)	(3)	(4)	(5)
Firm Charact.	Experience	Cont. Exper.	Nb. Prod.	Nb. Dest	Nb. Markets
Log Firm Exports (t-1)	0.839*** (0.165)	0.828*** (0.165)	0.791*** (0.163)	0.869*** (0.164)	0.845*** (0.163)
Temperatures \times Log Firm Exports (t-1)	0.008*** (0.003)	0.008*** (0.003)	0.008*** (0.003)	0.009*** (0.003)	0.009*** (0.003)
Log Precipitations \times Log Firm Exports (t-1)	0.048*** (0.008)	0.048*** (0.008)	0.051*** (0.009)	0.037*** (0.009)	0.043*** (0.009)
Log GDP \times Log Firm Exports (t-1)	-0.040*** (0.007)	-0.039*** (0.007)	-0.039*** (0.006)	-0.040*** (0.007)	-0.040*** (0.007)
Log Firm Charact.	0.931** (0.435)	0.326 (0.211)	0.057 (0.139)	-0.550*** (0.184)	-0.139 (0.101)
Temp \times Log Firm Charact.	0.016** (0.007)	0.004 (0.004)	-0.001 (0.002)	-0.005* (0.003)	-0.002 (0.002)
Log Prec. \times Log Firm Charact.	-0.033 (0.021)	-0.006 (0.013)	-0.019** (0.010)	0.033*** (0.012)	0.005 (0.007)
Log GDP \times Log Firm Charact.	-0.049*** (0.017)	-0.019** (0.008)	0.004 (0.005)	0.020*** (0.007)	0.007* (0.004)
Observations	176024	176024	176024	176024	176024
R^2	0.882	0.882	0.882	0.882	0.882
Firm FE	x	x	x	x	x
Country-Sector-Year FE	x	x	x	x	x
Cluster	cty-sec-yr	cty-sec-yr	cty-sec-yr	cty-sec-yr	cty-sec-yr

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. Standard Errors are clustered at the Country-HS2 Sector-Year level.

Table B.11: Counterfactuals - Results - RCP2.6

Country	BAU	CF1	CF2
Scenario:			
With average weather conditions		x	
With Mexico firm distribution			x
URY	-1,91	-2,74	-1,83
MEX	-2,94	-3,34	-2,94
PER	-4,51	-3,39	-4,40
GTM	-1,80	-3,26	-1,80
SEN	-4,67	-5,11	-4,46
BFA	-4,55	-4,66	-4,48
MWI	-2,79	-3,74	-2,64
Average Cost (mean)	-3,31	-3,75	-3,22
Dispersion (std)	1,26	0,84	1,22