Temperatures, Firm Size and Exports in Developing Countries

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Abstract

We study how temperature shocks affect exports in developing countries both at the firm- and aggregate-level. We find that while the average effect of temperature rise on exports is negative, small firms are disproportionately harmed compared with others. This feature is robust across sub-samples, specifications and confounding factors. We show that this heterogeneity across firms has aggregate implications. In particular, we find that the overall trade deterring effect of temperatures would be significantly larger in absence of the largest exporters. We also show that firm structure matters for exports under future climate change scenarios, with large firms reducing the costs of predicted temperature rise. We conclude that the existing firm distribution in developing countries may increase the cost of climate change.

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

JEL Codes: F14 ; F18 ; O13 ; Q56

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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

Two features of importance make trade activities in low- and middle-income countries particularly sensitive to the adverse effects of climate change. First, those countries are more subject to extreme climate events, and climate models predict that this unequal vulnerability will worsen in the coming decades, especially for those located in the tropics (Bathiany et al., 2018; Hoegh-Guldberg et al., 2018). Second, those countries have less exporters, a smaller average exporter size, and a lower concentration of exports at the top of the firm-size distribution in comparison with high-income countries (Fernandes et al., 2016). Given these characteristics and provided that international trade can be a crucial driver of economic development (e.g., World Bank, 2020), it is thus crucial to understand how climate shocks alter trade in developing countries, and to do so by explicitly accounting for firms' structure.

In this paper, we assess the impact of temperature shocks on several export outcomes using a firm-level perspective. Our first goal is to study how heterogeneous exporting-firms cope differently when facing the same temperature variation. To guide our analysis, we hypothesize that firm size reduces the potentially negative effect of temperature on exports through four main channels. 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, numerous evidence point that labor productivity is negatively affected by temperatures (Heal and Park, 2016). 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. Third, temperature shocks have contrasting effects across skilled and unskilled workers, notably since ventilation and air-conditioning systems allow adaptation (Seppanen et al., 2006). 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 temperature variations. Fourth, 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 temperature shocks (e.g., in agriculture see Garcia-Verdu et al., 2019). In all, firm size is thus expected to attenuate the detrimental effect of temperature on economic activity, here firm-exports. The first goal of our paper is to document this heterogeneous firm-level elasticity of exports to temperature.

Our second goal is to highlight the aggregate consequences of these firm-level responses. Assuming that temperatures have a negative effect on exports that vanishes for the largest firms, if those firms represent a large share of a country's exports, then the aggregate elasticity of exports to temperatures should be null. On the contrary, if large exporters account for a low share of aggregate exports then this aggregate elasticity is expected to be significantly negative. The aggregate elasticity of exports to temperatures, which averages firm-level elasticities depending on their share in total exports, will thus vary depending on firm-level elasticities and on firm structure. Our second goal is to identify the role of firm structure in shaping the aggregate elasticity, and then assess its consequences for a country's exports.

To do this, we take advantage of a database covering exporter-level customs transactions in 10 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 those 10 countries and under confidentiality conditions. We combine it with weather data providing measures of local climate conditions on temperature, precipitations and humidity.

Using year-to-year fluctuations in temperatures, as well as firm, country, year, and sector fixed-effects as our main identification strategy, we first find that temperature variations have a differential effect across exporting firms depending on their size. While the average response of exports is hardly negative, this result hides an important heterogeneity: large firms are significantly and quantitatively less harmed than smaller ones when facing the same temperature shock. We find that a 5% increase in temperature decreases exports by 20% for firms in the first (country-specific) decile (*i.e.*, for the smallest firms). However, as firm size increases, this negative effect decreases and even vanishes for the largest firms. The same 10% increase in temperature then deters exports only by 2% for the firms in the top decile. Importantly, we show that these results are robust to the use of alternative measures of temperature shocks, exports and firm size. It also resists 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.

To quantify the macroeconomic implications of these firm-level responses, we run a counterfactual exercise measuring the aggregate impact of temperature on export outcomes if all firms in a country had the same size. We find that keeping the firm-specific response to temperatures constant but excluding the disproportional role of large firms in the aggregate – as supported in Gabaix (2011); Carvalho and Grassi (2019); Fernandes et al. (2016) – would signficantly increase the global deterring effect of temperatures. This result implies that increasing the role of large exporters in the economy could help reducing the costs of temperature shocks on exports, and sheds light on the economic mechanisms explaining why the tradable sector in some countries is more impacted by temperature shocks than in other countries.

Finally, we further build on this approach to evaluate the implications of our results in a climate change context. In particular, we quantify the anticipated, marginal impact of *projected* temperatures on aggregate exports, using climate projections (World Bank Climate Change Knowledge Portal) derived from Mitchell et al. (2004). The result is straightforward: without large exporting firms, the aggregate export growth will be much lower under future climate scenarios. In our sample, we estimate that the marginal effect of temperatures on exports would be at least three times without the large exporters.

By documenting evidence on the links between temperature and firm exports, this paper contributes to several strands of the literature. A close paper to ours is Jones and Olken (2010) who study how the annual growth rate of a country's exports in a particular product category is affected by the country's weather in that year. They find an overall 2.2% decrease in export growth in poor countries for each degree of temperature rise, and no effect for precipitation. However, the authors do not work at the firm-level export nor 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) who 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. This shift is particularly important in our case as the average insignificant effect of temperatures on exports hides a substantial heterogeneity across exports.

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 that documents, for instance, the effects of climate shocks on economic growth as well as 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. Our work suggests that 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 temperature shocks and 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), as well as provide a framework allowing adaptation strategies to be implemented. It suggests that firm structure and the potential concentration of market shares across

[1] Recent 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.

exporters could be used as a complementary policy tool to mitigate the impact of climate shifts.

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, of a set of 10 developing countries. Figure A.1 shows each country coverage in time. 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. This means that there is no information on other firm characteristics, in particular firm location, age, ownership, employment, or sales in the domestic market.

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 by firm, and the average number of HS6 products and destinations served by firms.

- Table 1 here -

We can see that our sample displays a large heterogeneity across countries in terms of firm structure: Mexico has around 100 times more exporters than Malawi or Burkina Faso, and all trade margins are heterogeneous across countries.

Climate variables. We gather temperature data from the Climatic Research Unit of the University of East Anglia (CRU version v4.02) (Harris et al., 2014). This dataset provides a set of country-year average temperature, precipitation and humidity index. For illustration, Figure 1 plots the average temperature in Peru, Mexico and Uruguay and their linear fit in time. We observe a steady increase since 1990 in those three countries.

- Figure 1 here -

In order to assess the robustness of our analysis, we will also consider the average minimum and maximum daily temperatures from the same source. Furthermore, in our robustness checks, we follow the literature based on agronomy and convert daily mean temperatures into degree days (DD) (Hsiang, 2016) with thresholds of 32°C and 34°C. Appendix A.2 provides all the details of our approach.

The other weather covariates included in our analysis are precipitations (in milimeters/month) and humidity (number of rainy days per year) from the same source.

Macroeconomic Controls. Lastly, we collect a set of macroeconomic variables used as controls in our estimations. These include include population size, growth indicators as well as effective exchange rate and price index, all taken from the World Development Indicators (Azevedo, 2011).

Descriptive Statistics. Table 2 provides some descriptive statistics of the main sample.

- Table 2 here -

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 21°C over our period of study, with an average maximum of 29°C for Burkina Faso and Senegal. Panel C provides the characteristics of the destinations served by the exporters of our sample. We observe that destination countries were more than 4 times richer than the exporters, and that average temperature there was almost 2°C lower.

3 Firm-level impact of local temperatures

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

3.1 Empirical strategy

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

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

where $Exports_{ft}$ is the general measure of export outcome for a firm f in year t. The variable $Temp_{i(f)t}$ denotes temperature in country i, where firm f operates, in year t. $FirmSize_{ft-1}$ accounts for firm size and is measured at the previous year $t-1$ in order to avoid simultaneity with export outcome in year t. Our baseline temperature measure is the average yearly temperature (in Celsius), and our baseline measure of firm size is the lagged export values (in US$). To measure the differential effect of temperature across firms, we include the interaction term $Temp_{i(f)t} \times FirmSize_{ft-1}$. It captures the heterogeneous effect of a same temperature variation on exports across firms of different sizes.[3]

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, that capture economic and social context in exporting countries: shocks to these variables could have an average effect – captured by the δ coefficient – and some heterogeneous effect – captured by μ. Controlling for these other time-varying variables allows us to isolate the strict effect of temperature. In practical terms, we first consider weather controls such as the average level of precipitations and humidity (Dallmann, 2019). Second, we include economic controls such as exporting countries' GDP, real effective exchange rate, and effective average tariffs (faced by the exporter). Our approach is thus consistent with gravity equations at both the aggregate and the firm levels (Head and Mayer, 2014).

To absorb unobserved heterogeneity, a set of fixed effects FE is included in equation (1). First, we include a firm fixed effect. The identifying variation is thus the change in export outcomes for a given firm (in a given country, as no firm changes of exporting country) across years. This fixed effect absorbs firm-specific time-invariant characteristics that affect exports. For instance, it could control for 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 firm FE controls for the origin country as well.

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-country-year fixed effect, for unobserved heterogeneities 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 temperatures and other aggregate covariates. Further, notice that this fixed effect holds constant the total exports of the HS2 sector from each country-year period. As a result, the identifying variation in our exercise is across firms that all belong to the same sector-country and thus face the same temperature 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[4].

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

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

[4] Our preferred cluster level would be at the country-year level, as it is exactly the level of the temperature shock. 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).

estimator and a log specification. 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 the number of HS6 products and the number of destinations served by a firm, following Arkolakis et al. (2010).

3.2 Results

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 each column represents a different specification.

- Table 3 here -

Column 1 shows that an increase in temperature decreases exports (with low precision), independently of firms' characteristics and export trend of the other firms. Since we have included a firm fixed effect, identification comes from exports variations across years for a given firm. This specification thus provides the average, firm-level exports response to temperature, controlling for aggregate, country-wide trade determinants as effective exchange rates and local GDP. On average, in our sample, firm-level exports are hardly deterred by local temperature shocks. Column 2 confirms this result when controlling for more demanding fixed effects. Specifically, a 1% increase in temperature lowers the level of exports by less than 2.8%.

Regarding additional weather covariates, such as precipitations and humidity, we estimate that higher precipitations are uncorrelated to exports while humidity exhibits a negative (hardly significant) impact. Importantly, on average, we still estimate that the log of exports' values at the firm-level decreases when temperature increases.

In columns 3 to 6, the results show that this hardly significant average effect of temperatures hides a strong heterogeneity across firms. Column 3 conditions the impact of temperature on the lagged exports at the firm level (in any destination). We find a positive and significant coefficient associated to the interaction between temperature and lagged exports, around 0.13. This means that the negative impact of temperature is dampened for firms with large lagged exports. In columns 3 and 4, we find that, for firms with low lagged exports, a 1% increase in temperature lowers the level of exports by around 4.2%. The positive interaction term shows that this negative effect is decreasing with firm size. Column 4 allows all other covariates to have heterogeneous effects across firms too. We can see that our main result remains.

Column 5 introduces a country-sector-year fixed effect, absorbing the unconditional effect of temperature shocks, but controlling for all country-wide shocks. Armed with this fixed effect, we again estimate a positive coefficient to the interaction term, with a point estimate close to that of columns 3 and 4. We can thus infer that temperature shocks decreases exports, but that this effect is decreasing with firm size. Notice that the point estimate jumps around 0.5, which is then confirmed in column 6 allowing other weather shocks to have some differential effects across firms.

The results at the intensive margin provide an important description of the link between temperature and firm dynamics. Overall, we identify that the average response of exports to temperature is negative (but hardly significant), but that large firms are less impacted by these shocks than smaller ones. We now turn to the extensive margin.

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 temperature shocks on the number of HS6 products exported to any destinations (columns 1, 2 and 3), and on the 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.

- Table 4 here -

Results displayed in Table 4 suggest that temperature deters both measures of the extensive margin of trade (columns 1 and 4). We can also see that, as for the intensive margin, firm size dampens this negative effect. The interaction terms coefficients are significant in columns 2, 3, 5 and 6 when using demanding fixed effects.

Hence, on average, temperature shocks deter exports at both trade margins: intensive and extensive. This effect, in both cases, is dampened by firms' size. This is the core result of our paper. We further note that 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 a rise in temperature appears to be occurring at the intensive margin. For this reason, we mainly focus our robustness checks on this dimension.

3.3 Robustness analysis

In this section, we assess the robustness of our results to variables' measures, omitted variables as well as product and destination shocks.

3.3.1 Sensitivity to key variables

We now check the sensitivity of our results to the measures of the following variables: exports value, firm size, temperatures. To do this, we estimate the following equation:

$$\begin{aligned} Exports_{ft} &= \beta FirmSize_{ft-1} + \gamma(Temp_{i(f)t} \times FirmSize_{ft-1}) \\ &+\mu(Covariates_{it} \times FirmSize_{ft-1}) + FE_f + FE_{ist} + \varepsilon_{ft}, \end{aligned} \tag{2}$$

where we alternatively replace the measures of $Exports_{ft}$, $FirmSize_{ft-1}$, $Temp_{i(f)t}$ and of the weather covariates included in $Covariates_{it}$. The key part of our robustness exercise is to challenge the significance and magnitude of the coefficient γ. To save space we follow Simonsohn et al. (2020) and provide a "specification curve" of the coefficients of interest. We obtain a set of estimates (N=120) displayed in Figure 2. The top panel shows the estimated γ while the bottom panel shows the characteristics of the corresponding estimation.

- Figure 2 here -

First, we run a sectoral decomposition between agricultural and manufacturing products of our baseline result that focused on total exports. We find that the dampening effect of firm size on the impact of temperature holds for both types of products, and that this effect holds regarding export volumes. Second, Figure 2 shows that the results are not sensitive to our measure of temperature. Indeed, using average minimum and maximum daily temperatures, as well as degree-days, does not affect the sign and significance of our main coefficients of interest.[5] Third, we find that our results remain when we change the proxy of firm size. In Figure 2, we use alternatively the two-year lagged exports, the lagged number of products (in $t-1$ or $t-2$) or the lagged number of destinations (in $t-1$ or $t-2$). The interaction coefficients are significant, positive and close in point estimates.

This exercise confirms a robust pattern: firm size dampens the negative effect of temperature on firm level exports. This pattern is robust to several measures of export outcomes, temperature and firm size. We estimate a differential effect that is significant and economically meaningful, around 0.45 on average.

3.3.2 Omitted Variables

Although the fixed effects included in our specification capture potentially omitted variables, we cannot exclude that some covariates, not included in our model so far, could explain the differential effect of temperature across firms. For this reason, we now add a cumulative measure of temperature, some indexes of countries' governance, and two variables related to credit access. Table 5 presents the results of this robustness exercise.

- Table 5 here -

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

Column 1 includes temperatures 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 temperature 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 temperature 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 temperature and firm size, confirming our benchmark estimation. Notice that the point estimate is slightly higher here. Finally, temperature shocks may be correlated with firm's access to credit. If this is the case, what we attribute to temperature could be simply the result of a better access to varying credit loans and banks across firms. We find that 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: temperature shocks have a differential impact across firms, in favor of larger firms.

3.3.3 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:

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

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 6.

- Table 6 here -

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. Colummn 2 introduces additional trade determinants, which do not allow to estimate a signficant impact of temperaratures on exports.

Column 3 however supports that this average null effect hides heterogeneity across local firms: larger firms are less negatively affected by temperature shocks at home, even when controlling for home and foreign aggregate shifts in GDP and trade determinants.

Columns 4 to 6 further support that the differential effect of local temperature shocks holds when taking into account the potential differential effect of foreign temperatures and foreign macroeconomic shocks (and by including demandig fixed effects). The interaction term in only slightly affected, without any change on its significance. The coefficient is stable across specification, 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

Appendix B displays additional supporting results that we discuss here.

Temperatures in levels, instead of logs. Table B.1 replicates our baseline estmations using the level of temperatures as the main measure of temperatures, instead of the log temperatures. We estimate coefficients with different magnitudes but conclusions are not affected by such a change of specification.

Alternative estimators. Table B.2 shows the results when using a pseudo-poisson maximum likelihood (PPML) estimator on the rectangularized dataset, 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 magntiudes.

Table B.3 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 exogeneity issues. Results – using firm and year fixed effects – confirm the differential effect of firm size on the elasticity.

Subsamples. Table B.4 replicates our baseline estimates differentiating agricultural and manufacturing exports, without emphasizing robust differences in estimates across the two subsamples. Table B.5 displays the results when focusing on alternative subsamples, by continent. Results appear to be consistent across continents.

Additional firm characteristics. Table B.6 shows results when including lagged exports and other firm characteristics in the same specification. Table B.6 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. Results shows that lagged export in 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.

Non-linearities along firm size. Figure B.1 checks where, in the distribution, the differential effect of temperature 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:

$$\begin{aligned} Exports_{ft} = \alpha Temp_{i(f)t} + \delta Covariates_{it} + \sum_{d=1}^{10} \beta_d \mathbb{1}[Decile_{ft-1} = d] \\ + \sum_{d=1}^{10} \gamma_d (\mathbb{1}[Decile_{ft-1} = d] \times Temp_{i(f)t}) + FE + \varepsilon_{ft} \end{aligned} \tag{4}$$

where $\mathbb{1}[Decile_{ft-1} = d]$ is a set of dummy variables for each decile d in the lagged exports distribution. Figure B.1 plots the estimates of all γ_d for $d = \{1, ..., 9\}$, as the last decile is the reference group. Compared to the top firms, we estimate that export growth is dampened by 50% for the median firm, and by 80% for firms in first decile. The differential effect of temperature across firms however appears to be linear along firm size. This implies that the interaction coefficient in our estimation is thus a good approximation of the differential effect across firms.

Non-linearities in temperature. The literature emphasizes that temperature may have a non-linear effect on economic outcomes (Burke et al., 2015; Deschênes and Greenstone, 2011). Table B.7 accounts for this features by controlling for squared temperatures. Controlling for squared temperatures and squared terms of other weather covariates does not alter our main coefficient.

Clustering level. Tables B.8 and B.9 show results when clustering the standard errors at the country-HS2 sector level and HS2 sector-year level, respectively, without affecting inference.

4 Aggregate Implications

In this section, we develop 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 environment by Héricourt and Nedoncelle (2018) or Erbahar (2019).

In section 3, we identified the heterogeneous firm-specific elasticity of exports to temperatures ΔX_{fit}: larger firms exhibit a lower negative response to an increase in temperature. Hence, aggregate country-wide exports should be affected only to the extent that the market is highly diversified and composed with numerous smaller firms, which are particularly harmed by temperatures shocks. We empirically investigate this intuition here by performing a set of counterfactual exercises relative to the structure of exports and to climate scenarios. This allows us to quantify the crucial role of market concentration for exports in developing economies facing climate shocks.

4.1 The dampening effect of firm size: aggregate consequences

Consider a country i made of many exporting firms f. In this country, the aggregate elasticity of exports ΔX to temperatures at year t can be written as the weighted sum of firm-specific elasticity to temperatures:

$$\Delta X_{it} = \sum_{f \in i} \omega_{ft-1} \times \Delta X_{fit}, \tag{5}$$

where ω_{ft-1} is the market share of firm f in the aggregate exports at year $t-1$. Equation (5) thus decomposes the aggregate impact of temperatures on exports into two forces: market concentration ω_{ft-1} and firm-specific elasticity ΔX_{fit}.

Now, to assess the role played by firm-size distribution in country i, we compute a first counterfactual aggregate exports response, denoted $\Delta X'_{it}$, in which every firm accounts for the same share of total exports. It reads:

$$\Delta X'_{it} = \sum_{f \in i} \omega_{it-1} \times \Delta \hat{X}_{fit}. \tag{6}$$

In equation (6), the term ω_{it-1} is a country-year specific market share equal to $1/n_{it-1}$, where n_{it-1} is the total number of exporting firms in country i in $t-1$. The specification of ω_{it-1} thus assumes a uniform distribution of exports across firms in the economy. This allows us to quantify the role played by larger firms in the aggregate marginal export response to temperature variation.

Figure 3 displays the results with variables aggregated at the country-year level. In red color is plotted the ratio between exports as predicted by the model and exports from the counterfactual using uniform market shares.

- Figure 3 here -

For every country-year but one, we observe a ratio below 1 and mostly below 0.5. This means that exports under uniform market shares would be much lower compared to the effective, observed distribution of firms. On average, counterfactual observations lie around a ratio of 0.4, implying a massive temperature-led export loss.

This implies that firm structure accounts for almost 60% of the aggregate adaptation to higher temperature in our sample. The negative impact of temperature on exports, at the country level, would be significantly larger if all firms in the economy had the same weight. This result thus highlights the crucial role played by firm structure in shaping the aggregate marginal export response to a temperature shocks.

To further assess the role of firm-size distribution, we compute a second counterfactual aggregate exports response, denoted $\Delta X''_{it}$, in which we increase the role of large firms. Precisely, we consider:

$$\Delta X''_{it} = \sum_{f \in i} \frac{X^2_{ft-1}}{\sum_f (X^2_{ft-1})} \times \Delta \hat{X}_{fit}. \quad (7)$$

This "concentrated" pattern aggregates firms' reaction using (relative) squared firm-specific shares, i.e. increasing the relative role of large firms in the aggregate. The ratio between these counterfactual exports and the predicted, model-implied exports are plotted in green color in Figure 3. We find – in line with intuition – that increasing the relative size of the largest firms dampens the negative impact of temperature shocks. If large firms would have been even larger (i.e. accounting for a larger share of total countrywide exports), exports would have been higher than observed, still conditional on each firm's response to temperatures. The results from this quantitative exercise thus support that firm size distribution is crucial and determines the aggregate costs of current temperature shocks.

Robustness checks. Figure C.1 in Appendix C shows the results using the decile-specific response (Figure B.1) of firms instead of the interaction term from the baseline regression (Table 3). We obtain a close picture. Excluding the differential role played by firms in deciles 9 and 10 (which drive most of the null effect across firms in average) further emphasizes the aggregate importance of these firms in shaping the aggregate trade outcomes. We obtain similar differences between the model and the counterfactual export variations.

4.2 Firm size and adaptation to climate change

We further build on the method developed in section 4.1 to quantify the anticipated, marginal impact of *projected* temperatures on aggregate exports. We collect data from Mitchell et al. (2004) and obtain for each country of the sample the projected temperatures for the 2020-2040, 2040-2060, 2060-2080 and 2080-2100 periods, under 4 climate scenarios.

We proceed in several steps. First, the firm-specific (conditional on its size) response to future temperature shifts in period $t+n$, $\Delta \hat{X}_{fit+n}$, is computed. Second, these micro-level marginal effects are aggregated using the three alternative weighting schemes (already presented) allowing us to identify the role of firm structure. Consider the following general form:

$$\Delta X'_{it+n} = \Omega \times \Delta \hat{X}_{fit+n}. \quad (8)$$

We again study three specific forms corresponding to different patterns for Ω:

- The "observed" pattern aggregates firms' reaction using their effective and observed share in the data: $\Omega = \sum_{f \in i} \omega_{fit-1}$;
- The "constant" pattern aggregates firms' reaction using a constant share across firms: $\Omega = \sum_{f \in i} \omega_{it-1}$;
- The "concentrated" pattern aggregates firms' reaction using (relative) squared firm-specific shares, i.e. increasing the relative role of large firms in the aggregate: $\Omega = \sum_{f \in i} (\omega_{ft-1})^2$, where $(\omega_{ft-1})^2 = X^2_{ft-1} / \sum_{f} (X^2_{ft-1})$.

Figure 4 plots the aggregate export patterns (relative to the last observed exports in data) under the alternative weighting schemes and the alternative climate scenarios. For a given weighting scheme, we plot the range of the estimated trade growth across the 4 climate scenarios we consider, i.e. RCP 2.6 (the most optimistic), RCP 4.5, RCP 6.0 and RCP 8.5 (the most pessimistic).

- Figure 4 here -

First, in any of the counterfactuals presented here, aggregate exports in the developing economies of our sample are predicted to be lowered by climate change. The negative impact ranges from 1% (RCP 2.6, concentrated shares, period 2020-2040) to 12% (RCP 8.5, constant shares, period 2080-2100), and the case of constant market shares is systematically dominated by other counterfactuals.

Second, we observe that the more concentrated the market is, the less variance there is in the distribution of the negative impacts of the different climate scenarios. Indeed, when comparing the concentrated shares counterfactual to the observed and constant shares ones, we see that the predicted aggregate exports under RCP8.5 are systematically closer to those predicted under RCP2.6. This highlights the role of market concentration in adapting to different climate scenarios.

We further estimate that in most cases export growth with higher firm concentration and a pessimistic scenario (triangle shape on the graph) could dominate export growth under an optimistic climate change scenario (square shape on the graph) but with lower firm concentration. As a result, *ceteris paribus*, firm structure may act as an engine for trade growth even with large temperature shifts.

We find only two cases where the effect of climate scenarios dominate the one of market shares. This is for periods 2060-2080 and 2080-2100, where aggregate exports under RCP2.6 and observed shares would be less damaged by temperatures than aggregate exports under RCP8.5 and concentrated shares.

In all, this shows that firm structure and the potential concentration of market shares across exporters could plausibly help against the adverse effect of climate shocks, complementing for instance other policies favoring mitigation in temperatures increase.

5 Concluding remarks

In this paper, we analyze the impact of temperature shocks on firm-level exports in 10 developing countries. For this purpose, we combined weather data with various information on exporting firms. Our main identification strategy uses year-to-year fluctuations in temperatures, as well as country, year and sector fixed-effect.

We find a differential effect of temperature rise across exporting firms depending on their size. While the average response of exports to temperature is negative, this result hides a large heterogeneity across exporters: large exporters are significantly and quantitatively less harmed than smaller ones when facing a same temperature shock. For illustration, compared to the top firms, we estimate that, for a given temperature shock, export growth is dampened by 50% for the median firm, and by 80% for the 10% of smallest firms in our sample.

These micro-level results have macroeconomic implications that are critical for economic development. For this reason, in the second part of this paper, we investigate how the impact of temperature estimated at the firm-level influences aggregate exporting outcomes. We find that in absence of large exporting firms, the aggregate trade deterring effect of temperature would be signficantly larger overall. This counterfactual exercise shows the importance of exports' concentration at the top of the firm size distribution in order to cope with the rise of temperature in developing countries. Using projected temperatures over the next 80 years also confirms this result, as we find 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 distribution in low- and middle-income countries, characterized with a lower share of large exporters, could increase the aggregate cost of climate shocks on trade. While increasing firm concentration could help mitigating the adverse effect of temperature, such a shift in firm structure may affect other aggregate outcomes. Indeed, whereas trade deepening already favored inequalities in developing countries (Pavcnik, 2017), firm concentration has affected markups (De Loecker and Eeckhout, 2018), labor share (Autor et al., 2020), investment (Gutiérrez and Philippon, 2017), among others, in advanced economies. These dynamics may also be at play in developing countries.[6] Future research could thus also account for the potential trade-offs in such a policy in an integrated aggregate framework. We believe this kind of analysis to be an important research avenue, in particular in a climate change context, making these questions even more challenging.

[6] See in particular De Loecker and Eeckhout (2018) for a discussion on the regional differences in market power shifts.

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Tables

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

Country	Nb. firms	Average Exports	P10	P90	Nb. HS6 products	Nb. Dest.
BFA	223.36	227989.14	1,835.19	251634.69	16.01	6.77
BGR	7,146.85	117746.25	1,596.19	177317.03	23.63	8.17
GTM	2,801.43	238014.27	1,643.63	306504.78	28.04	6.28
JOR	1,304.56	264925.31	2,816.90	318483.19	12.75	11.05
MEX	19,584.63	424722.36	1,819.00	420004.50	22.88	7.93
MWI	223.10	361878.17	1,936.51	613498.25	9.14	6.15
PER	3,501.27	225875.52	1,699.20	321226.88	18.95	9.70
SEN	394.48	120027.79	1,793.43	166408.14	22.74	11.45
URY	993.07	425239.65	2,559.60	709500.00	8.93	12.80
YEM	313.36	220369.99	2,215.24	385685.31	16.90	7.65
Total	11,737.18	322269.25	1,788.70	351658.00	21.56	8.43

Table 2: Descriptive statistics

Panel A: Firm-Product-Destination-Year Variables					
variable	**mean**	**sd**	**min**	**max**	**N**
Exports- Value	322269.25	2.22e+06	1,000.00	9.92e+07	2.47e+06
Exports- Volume	220385.41	5.93e+06	0.00	2.04e+09	1.11e+06
Unit Value	833.51	61,829.91	0.00	3.80e+07	1.11e+06
Panel B: Origin Country-Year Variables					
Temperatures	21.20	5.04	10.70	29.10	99.00
Precipitations	1,072.51	704.30	63.60	3,449.00	99.00
Humidity	98.99	45.80	21.20	201.20	99.00
GDP per cap.	3,810.44	3,209.35	332.26	15,171.58	99.00
REER	131.09	200.57	0.71	732.40	99.00
Panel C: Destination Country-Year Variables					
variable	**mean**	**sd**	**min**	**max**	**N**
Dest. Temp.	19.33	7.76	0.40	29.30	2,575.00
Dest. Prec.	1,145.59	833.71	21.80	4,915.10	2,621.00
Dest. GDP pc	13,076.38	20,343.22	102.60	185721.79	2,956.00
Dest. REER	551.86	2,187.95	0.02	31,558.91	2,641.00

Table 3: Intensive margin

	Dep. Variable: Firm-level Exports, (ln X_{ft})					
	(1)	(2)	(3)	(4)	(5)	(6)
Temperatures	-2.949*	-2.838*	-4.014***	-4.200***		
	(1.512)	(1.467)	(1.494)	(1.212)		
GDP	4.734***	4.521***	4.628***	4.689***		
	(0.601)	(0.584)	(0.578)	(0.699)		
Humidity	-2.264*	-2.262**	-1.935*			
	(1.252)	(1.151)	(1.135)			
Preci.	-0.418	-0.340	-0.441			
	(0.505)	(0.470)	(0.462)			
REER	-6.849***	-6.650***	-6.789***	-13.520***		
	(1.282)	(1.239)	(1.225)	(1.946)		
Exports $(t-1)$	0.228***	0.221***	-0.159	-0.939***	-0.255	-2.360***
	(0.015)	(0.015)	(0.162)	(0.262)	(0.209)	(0.673)
Temperatures × Exports $(t-1)$			0.128**	0.617***	0.393***	0.550***
			(0.055)	(0.084)	(0.075)	(0.090)
REER × Exports $(t-1)$				0.719***	0.309***	0.388***
				(0.116)	(0.056)	(0.061)
GDP × Exports $(t-1)$				-0.150***	-0.081***	-0.050***
				(0.021)	(0.013)	(0.014)
Preci. × Exports $(t-1)$						-0.238***
						(0.079)
Humidity × Exports $(t-1)$						0.481***
						(0.145)
Observations	111944	111895	111895	111895	91172	91172
R^2	0.871	0.875	0.875	0.876	0.916	0.916
Firm FE	x	x	x	x	x	x
Country FE						
Sector-Year FE	x	x	x	x		
Country-Year FE						
Country-Sector-Year FE					x	x
Cluster	cnty-sec-yr	cnty-sec-yr	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. All variables are in logs.

Table 4: Extensive margin

	Dep. Variable: Nb. Products			Nb. Dest		
	(1)	(2)	(3)	(4)	(5)	(6)
Mean Temp.	-1.899***	-3.919***		-1.534***	-2.799***	
	(0.633)	(0.748)		(0.495)	(0.528)	
GDP	0.528**	0.412*		0.203	0.172	
	(0.221)	(0.241)		(0.178)	(0.191)	
REER	-0.837*	-3.092***		-0.274	-1.415***	
	(0.486)	(0.623)		(0.400)	(0.462)	
Precipitations	0.010	2.271***		0.261*	1.564***	
	(0.200)	(0.620)		(0.143)	(0.322)	
Humidity	-1.064**	-5.129***		-1.221***	-3.826***	
	(0.502)	(1.112)		(0.370)	(0.608)	
Exports $(t-1)$	0.050***	-1.591***	-1.472***	0.038***	-0.847***	-0.834***
	(0.004)	(0.359)	(0.369)	(0.003)	(0.196)	(0.199)
Mean Temp. × Exports $(t-1)$		0.200***	0.201***		0.130***	0.130***
		(0.042)	(0.043)		(0.025)	(0.026)
Precipitations × Exports $(t-1)$		-0.189***	-0.181***		-0.110***	-0.104***
		(0.049)	(0.050)		(0.024)	(0.025)
Humidity × Exports $(t-1)$		0.350***	0.334***		0.225***	0.220***
		(0.085)	(0.087)		(0.043)	(0.044)
GDP × Exports $(t-1)$		-0.003	-0.008		-0.007*	-0.008*
		(0.006)	(0.006)		(0.004)	(0.004)
REER × Exports $(t-1)$		0.194***	0.199***		0.097***	0.097***
		(0.031)	(0.031)		(0.018)	(0.018)
Observations	111895	111895	111650	111895	111895	111650
R^2	0.853	0.853	0.856	0.860	0.861	0.863
Firm FE	x	x	x	x	x	x
Year FE						
Sector-Year FE	x	x		x	x	
Country-Year FE						
Country-Sector-Year FE			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. All variables are in logs.

Table 5: Omitted variables

	Dep. Variable: Firm-level Exports, (ln X_{ft})					
	(1)	(2)	(3)	(4)	(5)	(6)
Exports ($t-1$)	0.872***	-2.110***	-2.427***	-3.637***	-1.304***	-1.512***
	(0.289)	(0.275)	(0.439)	(0.968)	(0.302)	(0.219)
Temperatures × Exports ($t-1$)	0.951***	0.338***	0.789***	1.118***	0.582***	0.497***
	(0.197)	(0.050)	(0.102)	(0.165)	(0.057)	(0.053)
Temp. ($t-1$) × Exports ($t-1$)	0.067					
	(0.126)					
Temp. ($t-2$) × Exports ($t-1$)	-0.749***					
	(0.213)					
GDP × Exports ($t-1$)	-0.054***	0.030***	0.015	-0.015	-0.019**	0.024***
	(0.008)	(0.007)	(0.011)	(0.018)	(0.009)	(0.007)
Preci. × Exports ($t-1$)		-0.373***	-0.565***	-0.555***	-0.516***	-0.642***
		(0.040)	(0.104)	(0.152)	(0.058)	(0.071)
Humidity × Exports ($t-1$)		0.677***	0.887***	1.087***	0.876***	1.039***
		(0.065)	(0.138)	(0.279)	(0.095)	(0.105)
Tariffs × Exports ($t-1$)		0.040***				
		(0.012)				
Voice/Accountability × Exports ($t-1$)			0.076***			
			(0.014)			
Government Eff. × Exports ($t-1$)				-0.000		
				(0.009)		
Nb. Banks × Exports ($t-1$)					-0.079***	
					(0.012)	
Domestic Credit × Exports ($t-1$)						-0.180***
						(0.029)
Observations	123403	140218	137605	113322	107958	176024
R^2	0.891	0.914	0.883	0.879	0.895	0.883
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. All variables (except Voice and Accountability and Gov. Effectivness) are in logs.

Table 6: Destination- and Product Specific Shocks

	Dep. Variable: Exports, (ln X_{fjpt})					
	(1)	(2)	(3)	(4)	(5)	(6)
Temperatures	-0.426	-0.492	-2.412***	-4.315***	-1.297	
	(0.306)	(0.370)	(0.595)	(0.479)	(0.848)	
GDP	0.385***	0.037	0.112	-0.065	0.073	
	(0.060)	(0.114)	(0.114)	(0.124)	(0.290)	
Exports $(f, t-1)$	0.195***	0.199***	-0.202**	-1.571***	-0.963***	-0.880***
	(0.007)	(0.008)	(0.098)	(0.135)	(0.267)	(0.293)
Dest. GDP	0.415***	0.381***	0.382***			
	(0.028)	(0.030)	(0.030)			
Dest. Temp.	-0.242***	-0.289***	-0.284***			
	(0.060)	(0.064)	(0.064)			
REER		-0.578***	-0.521***	-0.256	-0.158	
		(0.156)	(0.156)	(0.157)	(0.405)	
Preci.		-0.170*	-0.174*	1.023***	0.636	
		(0.090)	(0.090)	(0.282)	(0.542)	
Humidity		-0.095	-0.073	-3.381***	-2.146**	
		(0.174)	(0.173)	(0.462)	(0.892)	
Dest. Precip.		0.111**	0.110**			
		(0.051)	(0.051)			
Dest. Humidity		-0.044	-0.041			
		(0.106)	(0.106)			
Dest. REER		-0.032***	-0.032***			
		(0.009)	(0.009)			
Temperatures × Exports $(f, t-1)$			0.133***	0.228***	0.131***	0.122**
			(0.033)	(0.029)	(0.045)	(0.048)
GDP × Exports $(f, t-1)$				0.027***	0.001	-0.001
				(0.004)	(0.007)	(0.008)
REER × Exports $(f, t-1)$				-0.021***	-0.005	-0.002
				(0.005)	(0.007)	(0.008)
Preci. × Exports $(f, t-1)$				-0.084***	-0.066*	-0.068*
				(0.019)	(0.036)	(0.039)
Humidity × Exports $(f, t-1)$				0.229***	0.174***	0.177***
				(0.031)	(0.056)	(0.062)
Dest. Temp. × Exports $(f, t-1)$					0.013	0.024
					(0.025)	(0.027)
Dest. GDP × Exports $(f, t-1)$					0.012***	0.009**
					(0.005)	(0.005)
Dest. Precip. × Exports $(f, t-1)$					0.024	-0.000
					(0.021)	(0.022)
Dest. Humidity × Exports $(f, t-1)$					-0.025	0.016
					(0.027)	(0.028)
Observations	431682	332367	332367	667011	272267	251066
R^2	0.857	0.854	0.854	0.865	0.910	0.912
Firm FE	x	x				
Home-Destination FE	x	x				
Product-Year FE	x	x				
Firm-Product-Destination FE			x	x	x	x
Year FE			x	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. All variables are in logs. home sector year cluster

Figures

Figure 1: Temperatures across Years

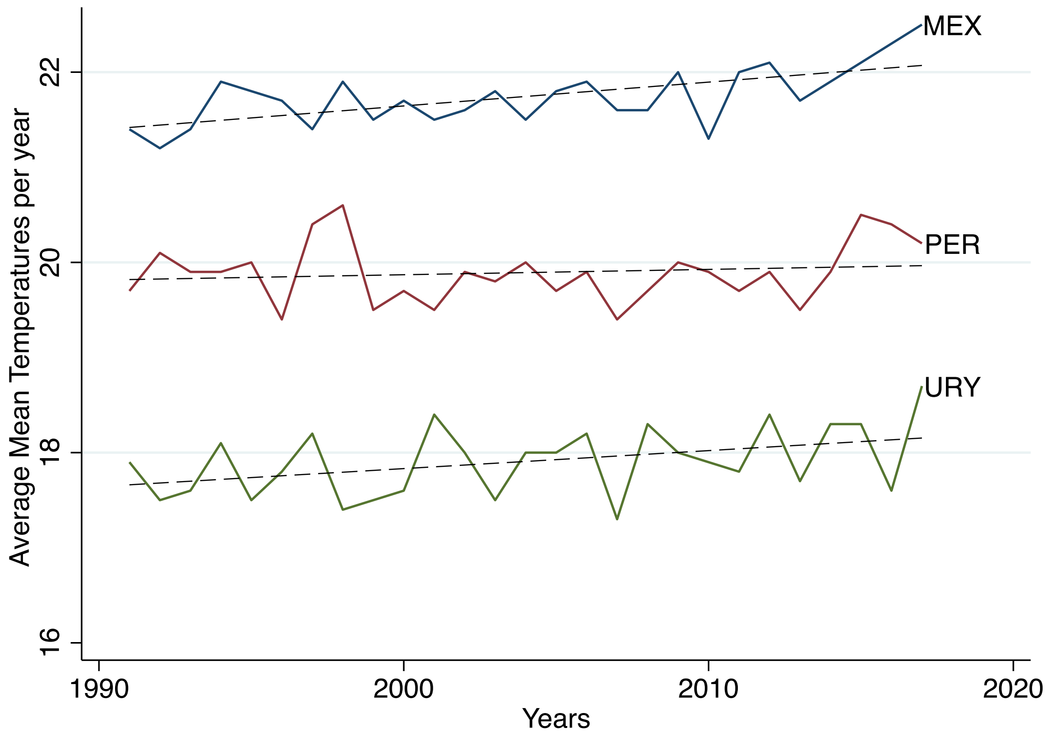


Figure 2: Specification Curve: Estimated γ Across Specification Choices

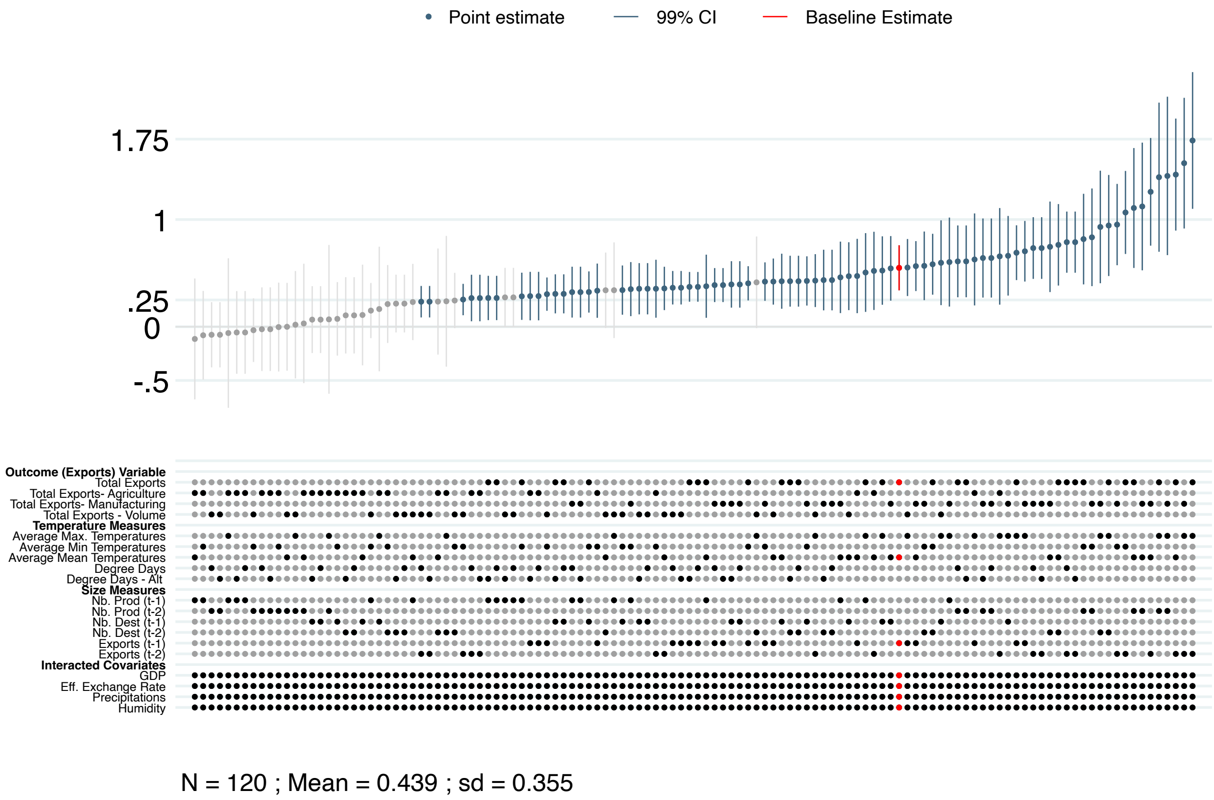


Figure 3: Counterfactual: differences in aggregate export responses

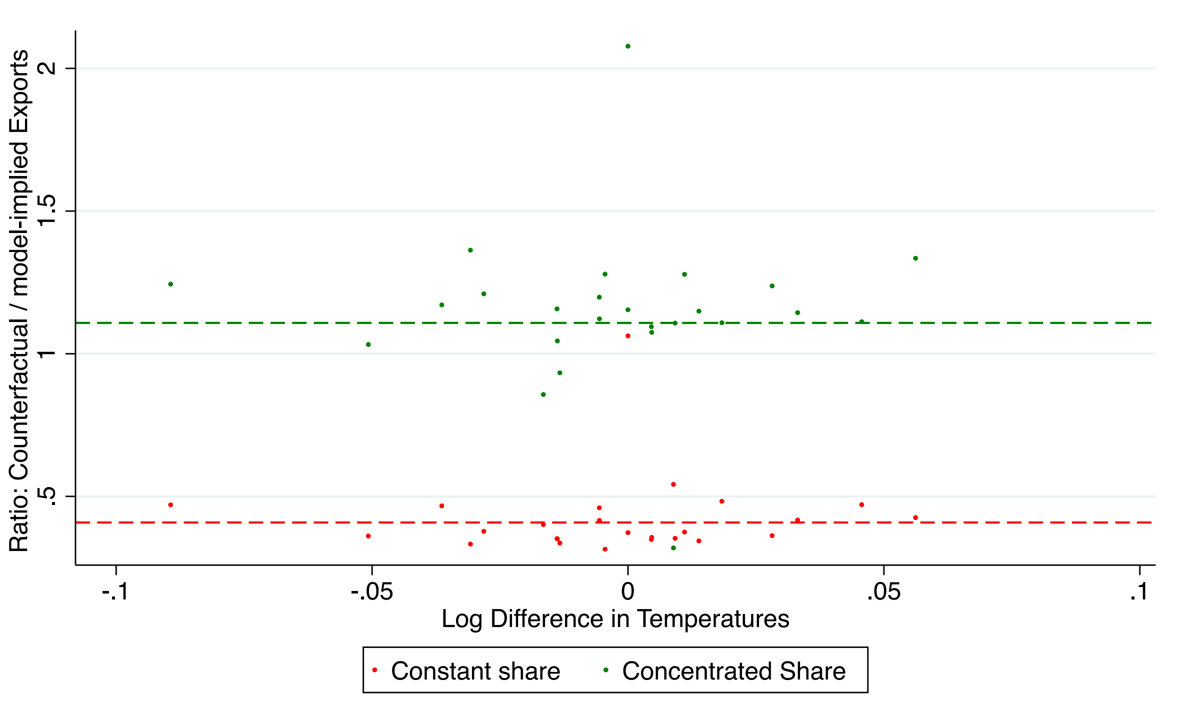
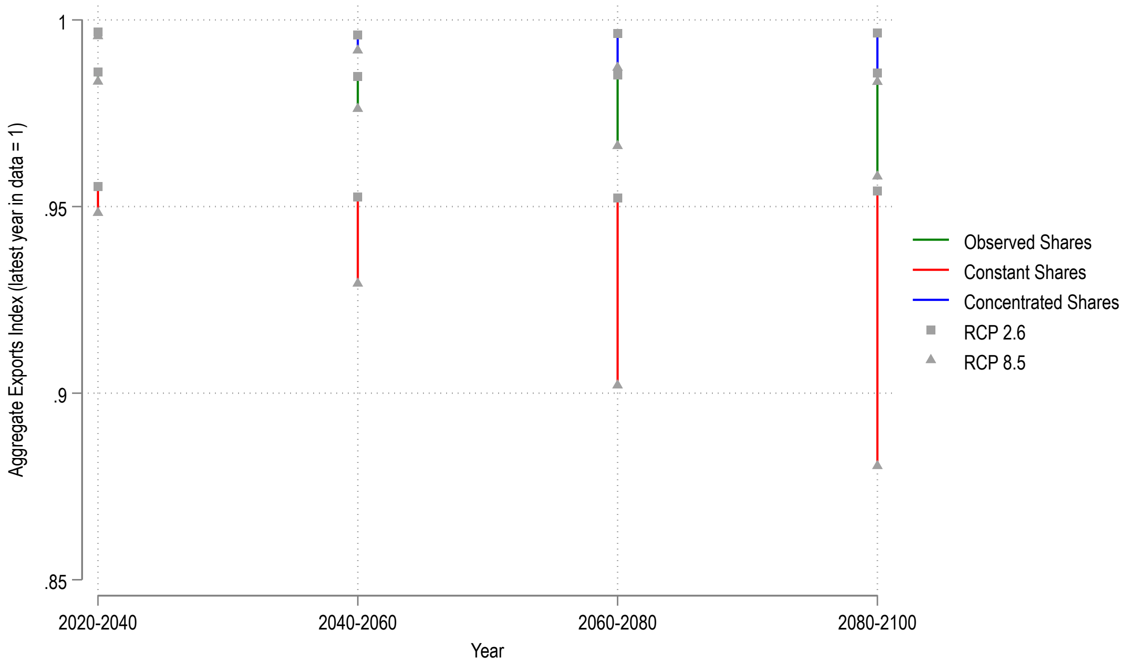


Figure 4: Projected exports over 80 years under alternative scenarios



Appendix for

Temperatures, Firm Size and Exports in Developing Countries

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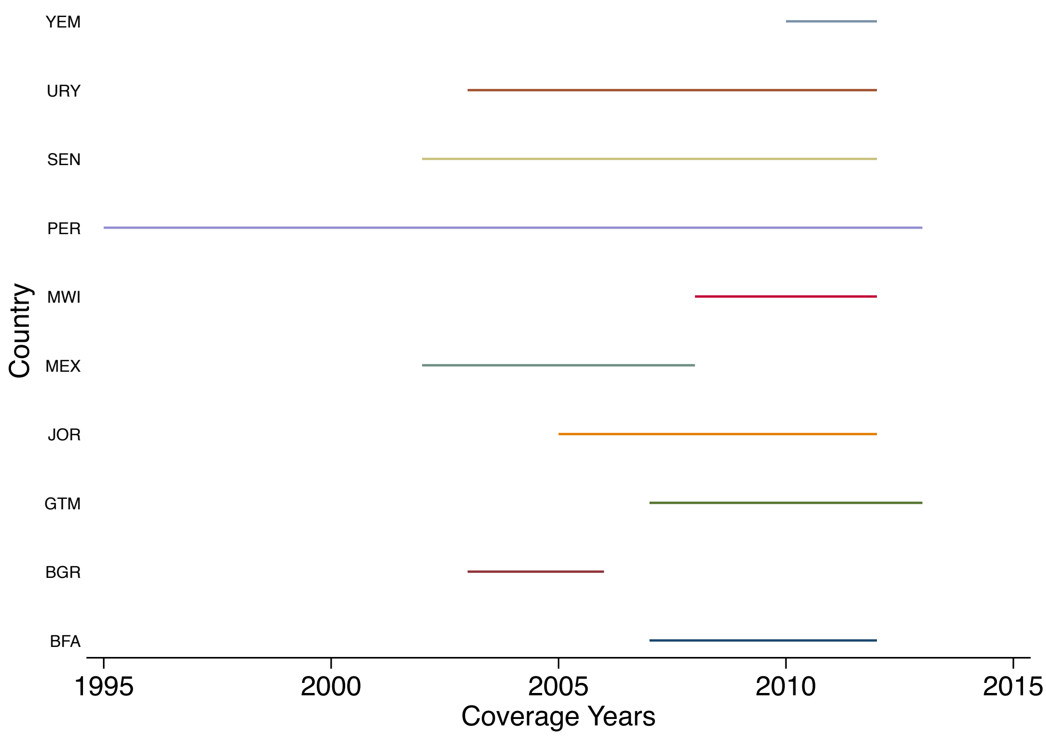
A Data Information

A.1 Coverage

Figure A.1: Country Coverage Across Years



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:

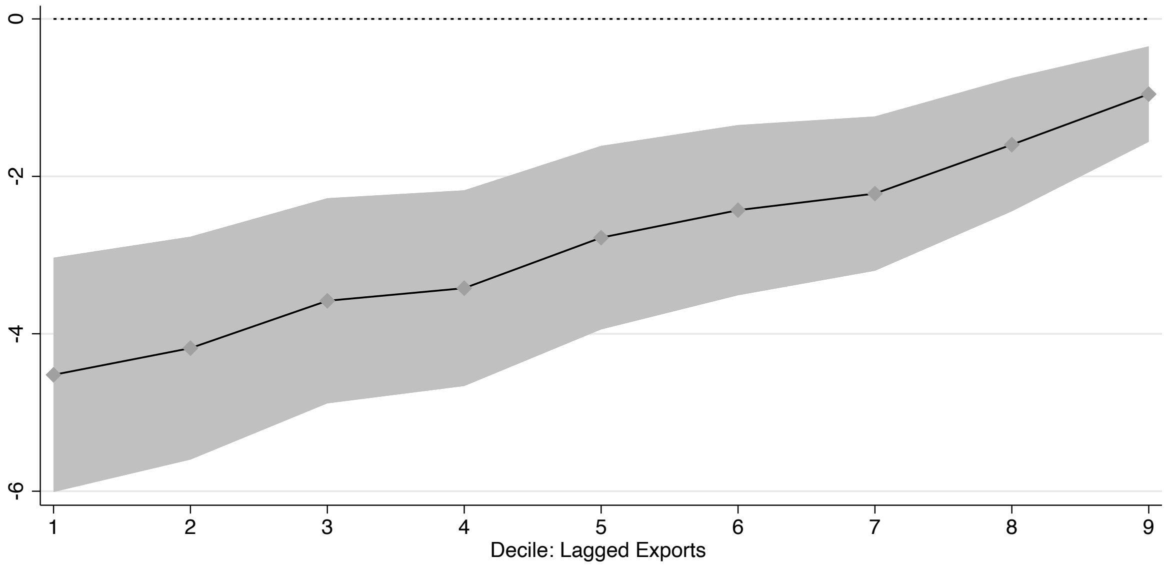
$$\text{DD}_{it} = \begin{cases} 0 & \text{if } T_{idt} \leq 8C \\ T_{idt} - 8 & \text{if } 8C < T_{idt} \leq 32C \\ 24 & \text{if } T_{idt} > 32C \end{cases}$$

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".

Robustness. For robustness checks, we have computed an alternative measure of degree-days, using 8°C and 34°C as thresholds in the computation above.

B Additional Results: Firm-year dimension

Figure B.1: Variation across Deciles: Estimated γ_d for $d = 1...9$



Note: The figure plots the estimated $\{\gamma_d\}_{d=\{1..9\}}$ from:

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

Table B.1: Results: Intensive Margin - Temperatures in levels

	Dep. Variable: Firm-level Exports, (ln X_{ft})					
	(1)	(2)	(3)	(4)	(5)	(6)
Temperatures	-0.224	-0.211***	-0.292***	-0.190**		
	(0.229)	(0.060)	(0.067)	(0.086)		
GDP	4.338**	4.171***	4.229***	5.236***		
	(1.586)	(0.486)	(0.481)	(0.674)		
Humidity	-0.060	-0.056***	-0.053***			
	(0.039)	(0.009)	(0.009)			
Precipitations	0.001	0.001***	0.001***			
	(0.002)	(0.000)	(0.000)			
REER	-6.428*	-6.297***	-6.289***	-14.678***		
	(3.229)	(0.933)	(0.921)	(1.871)		
Exports $(t-1)$	0.227***	0.220***	0.075	0.306	0.508**	-1.643***
	(0.058)	(0.015)	(0.068)	(0.254)	(0.222)	(0.606)
Temperatures × Exports $(t-1)$			0.007**	0.042***	0.026***	0.040***
			(0.003)	(0.006)	(0.005)	(0.007)
REER × Exports $(t-1)$				0.719***	0.312***	0.409***
				(0.115)	(0.056)	(0.062)
GDP × Exports $(t-1)$				-0.160***	-0.086***	-0.054***
				(0.022)	(0.014)	(0.014)
Preci. × Exports $(t-1)$						-0.277***
						(0.086)
Humidity × Exports $(t-1)$						0.571***
						(0.158)
Observations	111944	111895	111895	111895	91172	91172
R^2	0.871	0.875	0.875	0.876	0.916	0.916
Firm FE	x	x	x	x	x	x
Country FE						
Sector-Year FE	x	x	x	x		
Country-Year FE						
Country-Sector-Year FE					x	x
Cluster	cnty-sec-yr	cnty-sec-yr	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. All variables (excare in logs.

Table B.2: Results: PPML Estimator

	Dep. Variable: Firm-level Exports, (X_{ft})				
	(1)	(2)	(3)	(4)	(5)
Mean Temp.	0.238	0.450	-1.051	-4.897***	
	(0.347)	(0.345)	(0.718)	(0.839)	
GDP	0.612***	0.727***	0.770***	0.580***	
	(0.127)	(0.126)	(0.128)	(0.184)	
lreer_i	-0.744***	-0.581***	-0.550***	0.354*	
	(0.158)	(0.151)	(0.153)	(0.205)	
Exports $(t-1)$	0.431***	0.431***	0.140	-0.989***	-0.686**
	(0.012)	(0.012)	(0.118)	(0.228)	(0.269)
Precipitations		-1.055***	-1.055***	1.477**	
		(0.121)	(0.121)	(0.678)	
Humidity		1.616***	1.638***	-4.554***	
		(0.231)	(0.230)	(1.060)	
Mean Temp. $\times$ Exports $(t-1)$			0.096**	0.298***	0.233***
			(0.040)	(0.052)	(0.058)
Precipitations $\times$ Exports $(t-1)$				-0.112**	-0.101**
				(0.044)	(0.051)
Humidity $\times$ Exports $(t-1)$				0.310***	0.273***
				(0.067)	(0.077)
GDP $\times$ Exports $(t-1)$				-0.003	-0.003
				(0.008)	(0.008)
$\text{lreer}_i \times$ Exports $(t-1)$				-0.046***	-0.046***
				(0.009)	(0.009)
Observations	186222	186222	186222	154831	153783
R^2					
Firm FE	x	x	x	x	x
Sector-Year FE	x	x	x	x	
Country-Sector-Year FE					x
Cluster	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. All variables are in logs.

Table B.3: Results: Dynamic Panel Estimation

	Dep. Variable: Firm-level Exports, (ln X_{ft})				
	(1)	(2)	(3)	(4)	(5)
Exports (t-1)	1.251***	1.239***	-4.929***	-2.194***	-8.792***
	(0.039)	(0.038)	(0.355)	(0.412)	(0.644)
Exports (t-2)					-0.132***
					(0.004)
Temperatures	-0.781***	-0.990***	-19.548***	-6.720***	-27.393***
	(0.268)	(0.270)	(1.459)	(1.231)	(2.135)
GDP	-1.320***	-1.291***			
	(0.028)	(0.028)			
Preci.		-0.517***		-1.380***	-3.982***
		(0.085)		(0.209)	(0.290)
Humidity		0.568***			
		(0.145)			
Temperatures × Exports (t-1)			1.560***	0.480***	2.135***
			(0.118)	(0.100)	(0.163)
Preci. × Exports (t-1)				0.076***	0.310***
				(0.017)	(0.023)
Observations	135712	135712	135712	135712	94785

Note: * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$. All specifications include firm FE and year FE. All variables are in logs.

Table B.4: Results: Intensive Margin - Subsamples

	Dep. Variable: Firm-level Exports, (ln X_{ft})					
	(1)	(2)	(3)	(4)	(5)	(6)
Temperatures	-2.217	-2.774		-2.486	-3.740**	
	(1.623)	(1.732)		(1.669)	(1.719)	
GDP	2.076***	2.156***		4.097***	4.201***	
	(0.712)	(0.718)		(0.665)	(0.657)	
REER	-2.499*	-2.622*		-6.343***	-6.459***	
	(1.494)	(1.502)		(1.440)	(1.423)	
Preci.	0.454	0.404		-0.483	-0.602	
	(0.548)	(0.555)		(0.517)	(0.508)	
Humidity	-2.898**	-2.734**		-1.684	-1.308	
	(1.267)	(1.293)		(1.286)	(1.265)	
Exports $(t-1)$	0.174***	-0.015	-3.967***	0.228***	-0.174	-6.109***
	(0.025)	(0.224)	(1.161)	(0.017)	(0.178)	(1.712)
Temperatures × Exports $(t-1)$		0.063	0.582***		0.136**	1.176***
		(0.078)	(0.154)		(0.061)	(0.200)
REER × Exports $(t-1)$			0.658***			0.775***
			(0.116)			(0.138)
Preci. × Exports $(t-1)$			-0.361**			-0.835***
			(0.153)			(0.228)
Humidity × Exports $(t-1)$			0.720***			1.496***
			(0.272)			(0.406)
GDP × Exports $(t-1)$			-0.049**			-0.058**
			(0.025)			(0.023)
Observations	28354	28354	28156	87297	87297	87112
R^2	0.889	0.889	0.893	0.879	0.880	0.883
Sample	AGR	AGR	AGR	MAN	MAN	MAN
Firm FE	x	x	x	x	x	x
Country FE		x			x	
Sector-Year FE	x	x		x	x	
Country-Year FE						
Country-Sector-Year FE			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. All variables are in logs.

Table B.5: Results: Intensive Margin - Subsamples by continent

	Dep. Variable: Firm-level Exports, (ln X_{ft})		
	(1)	(2)	(3)
Exports $(t-1)$	-4.528**	2.617**	1.236***
	(1.939)	(1.132)	(0.393)
Temperatures $\times$ Exports $(t-1)$	1.560***	0.998***	0.350**
	(0.528)	(0.319)	(0.176)
Preci. $\times$ Exports $(t-1)$	-0.138	-0.337**	-0.706***
	(0.174)	(0.143)	(0.096)
Humidity $\times$ Exports $(t-1)$	0.213	0.226	0.851***
	(0.266)	(0.201)	(0.107)
GDP $\times$ Exports $(t-1)$	-0.020	-0.191***	-0.034***
	(0.060)	(0.039)	(0.008)
Observations	3703	7524	145762
R^2	0.860	0.871	0.882
Sample	Africa	Asia	America
Firm FE	x	x	x
Country-Sector-Year FE	x	x	x
Cluster	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. All variables are in logs.

Table B.6: Results: Intensive Margin - Other firm characteristics

	Dep. Variable: Firm-level Exports, (ln X_{ft})					
	(1)	(2)	(3)	(4)	(5)	(6)
Exports ($t-1$)	-1.878***	-1.785***	-1.836***	-1.897***	-1.886***	-1.909***
	(0.249)	(0.252)	(0.251)	(0.250)	(0.249)	(0.250)
Temp. × Exports ($t-1$)	0.441***	0.442***	0.444***	0.448***	0.435***	0.447***
	(0.055)	(0.055)	(0.055)	(0.055)	(0.055)	(0.056)
Preci. × Exports ($t-1$)	-0.416***	-0.404***	-0.411***	-0.416***	-0.406***	-0.412***
	(0.044)	(0.044)	(0.044)	(0.044)	(0.044)	(0.044)
Humidity × Exports ($t-1$)	0.718***	0.701***	0.713***	0.718***	0.701***	0.711***
	(0.068)	(0.069)	(0.068)	(0.068)	(0.069)	(0.068)
GDP × Exports ($t-1$)	0.018***	0.015**	0.016***	0.018***	0.019***	0.019***
	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)
Experience (t-1)		-0.283				
		(0.388)				
Temp. × Experience (t-1)		0.030				
		(0.130)				
Cont. Experience (t-1)			-0.076			
			(0.190)			
Temp. × Cont. Experience (t-1)			-0.015			
			(0.063)			
Nb HS6 Prod. (t-1)				0.077		
				(0.094)		
Temp. × Nb HS6 Prod. (t-1)				-0.025		
				(0.032)		
Nb Dest. (t-1)					0.088	
					(0.117)	
Temp. × Nb Dest. (t-1)					-0.002	
					(0.040)	
Nb Prod-Dest. (t-1)						0.074
						(0.071)
Temp. × Nb Prod-Dest. (t-1)						-0.016
						(0.024)
Observations	176024	176024	176024	176024	176024	176024
R^2	0.882	0.883	0.883	0.882	0.883	0.882
Firm FE	x	x	x	x	x	x
Country-Sector-Year FE	x	x	x	x	x	x
Cluster	cntry-sec-yr	cntry-sec-yr	cntry-sec-yr	cntry-sec-yr	cntry-sec-yr	cntry-sec-y

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

Table B.7: Results: Intensive Margin - Non-Linear Effects of Temperatures

	Dep. Variable: Firm-level Exports, (ln X_{ft})				
	(1)	(2)	(3)	(4)	(5)
Temperatures	-75.453***	-74.422***	-38.862***	-32.500***	-40.355***
	(8.814)	(8.780)	(4.918)	(5.427)	(4.761)
Temperatures × Temperatures	14.300***	13.880***	6.467***	4.931***	6.011***
	(1.782)	(1.786)	(0.906)	(0.977)	(0.868)
GDP	3.041***	3.184***	2.099***	2.547***	1.693***
	(0.464)	(0.459)	(0.146)	(0.196)	(0.140)
Humidity	1.706	1.895	2.307		-7.324***
	(1.208)	(1.193)	(1.560)		(1.617)
Preci.	-1.585***	-1.642***	-4.424***		1.009
	(0.469)	(0.464)	(0.952)		(0.956)
REER	-3.268***	-3.497***			
	(1.005)	(0.998)			
Exports $(t-1)$	0.221***	-0.134	-0.108	0.607***	-2.089***
	(0.015)	(0.163)	(0.136)	(0.192)	(0.241)
Temperatures × Exports $(t-1)$		0.120**	0.135***	0.258***	0.505***
		(0.055)	(0.046)	(0.046)	(0.053)
Humidity × Humidity			0.028		0.015
			(0.178)		(0.173)
Preci. × Preci.			0.208***		0.225***
			(0.068)		(0.068)
GDP × Exports $(t-1)$				-0.042***	0.019***
				(0.006)	(0.006)
Humidity × Exports $(t-1)$					0.761***
					(0.067)
Preci. × Exports $(t-1)$					-0.442***
					(0.043)
Observations	111895	111895	176912	176912	176912
R^2	0.875	0.875	0.875	0.875	0.876
Firm FE	x	x	x	x	x
Sector-Year FE	x	x	x	x	x
Cluster	cnty-sec-yr	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. All variables are in logs.

Table B.8: Results: Intensive Margin: alternative clustering level

	Dep. Variable: Firm-level Exports, (ln X_{ft})					
	(1)	(2)	(3)	(4)	(5)	(6)
Temperatures	-2.838	-2.838	-4.014**	-4.200***		
	(1.986)	(1.986)	(2.006)	(1.279)		
GDP	4.521***	4.521***	4.628***	4.689***		
	(0.541)	(0.541)	(0.539)	(0.720)		
Humidity	-2.262	-2.262	-1.935			
	(1.716)	(1.716)	(1.677)			
Preci.	-0.340	-0.340	-0.441			
	(0.692)	(0.692)	(0.678)			
REER	-6.650***	-6.650***	-6.789***	-13.520***		
	(1.339)	(1.339)	(1.330)	(1.483)		
Exports $(t-1)$	0.221***	0.221***	-0.159	-0.939***	-0.255	-2.360***
	(0.014)	(0.014)	(0.100)	(0.218)	(0.188)	(0.726)
Temperatures × Exports $(t-1)$			0.128***	0.617***	0.393***	0.550***
			(0.036)	(0.072)	(0.054)	(0.083)
REER × Exports $(t-1)$				0.719***	0.309***	0.388***
				(0.072)	(0.045)	(0.057)
GDP × Exports $(t-1)$				-0.150***	-0.081***	-0.050***
				(0.014)	(0.009)	(0.012)
Preci. × Exports $(t-1)$						-0.238***
						(0.088)
Humidity × Exports $(t-1)$						0.481***
						(0.166)
Observations	111895	111895	111895	111895	91172	91172
R^2	0.875	0.875	0.875	0.876	0.916	0.916
Firm FE	x	x	x	x	x	x
Country FE						
Sector-Year FE	x	x	x	x		
Country-Year FE						
Country-Sector-Year FE					x	x
Cluster	Cty-Sec.	Cty-Sec.	Cty-Sec.	Cty-Sec.	Cty-Sec.	Cty-Sec.

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

Table B.9: Results: Intensive Margin: alternative clustering level

	Dep. Variable: Firm-level Exports, (ln X_{ft})					
	(1)	(2)	(3)	(4)	(5)	(6)
Temperatures	-2.838**	-2.838**	-4.014***	-4.200***		
	(1.440)	(1.440)	(1.449)	(1.272)		
GDP	4.521***	4.521***	4.628***	4.689***		
	(0.661)	(0.661)	(0.650)	(0.856)		
Humidity	-2.262**	-2.262**	-1.935*			
	(1.143)	(1.143)	(1.144)			
Preci.	-0.340	-0.340	-0.441			
	(0.478)	(0.478)	(0.473)			
REER	-6.650***	-6.650***	-6.789***	-13.520***		
	(1.357)	(1.357)	(1.330)	(2.320)		
Exports $(t-1)$	0.221***	0.221***	-0.159	-0.939***	-0.255	-2.360***
	(0.016)	(0.016)	(0.148)	(0.247)	(0.194)	(0.695)
Temperatures × Exports $(t-1)$			0.128**	0.617***	0.393***	0.550***
			(0.050)	(0.083)	(0.071)	(0.088)
REER × Exports $(t-1)$				0.719***	0.309***	0.388***
				(0.116)	(0.054)	(0.057)
GDP × Exports $(t-1)$				-0.150***	-0.081***	-0.050***
				(0.021)	(0.013)	(0.014)
Preci. × Exports $(t-1)$						-0.238***
						(0.078)
Humidity × Exports $(t-1)$						0.481***
						(0.146)
Observations	111895	111895	111895	111895	91172	91172
R^2	0.875	0.875	0.875	0.876	0.916	0.916
Firm FE	x	x	x	x	x	x
Country FE						
Sector-Year FE	x	x	x	x		
Country-Year FE						
Country-Sector-Year FE					x	x
Cluster	sec-yr	sec-yr	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. All variables are in logs.

C Additional Aggregate Results

Figure C.1: Robustness in differences between aggregate export responses