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The impact of climate change on international trade: A gravity model estimation

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Abstract

The aim of this article is to analyse the impact of climate change on bilateral trade flows. To this end, we estimate a theory-grounded gravity model using bilateral trade flows on a sample of 67 countries over the period from 1986 to 2016. We use temperatures and extreme weather events (and their consequences) as indicators of climate change. In general, we find that international trade flows are less affected by the evolution of temperatures than domestic ones, while the opposite occurs with extreme weather events. However, there is a clear heterogeneity across countries and types of events. In particular, the results suggest that biological events, such as (*epidemics* and *insect infestation*), *extreme temperatures*, *storms* and *landslides* have a negative impact on international flows relative to internal ones. Interestingly, the influence of China and Japan on the global result is decisive, especially for *storms* in the first case and *extreme temperatures* in the second. Finally, our General Equilibrium estimations suggest a more detrimental impact of *insect infestation* and *extreme temperatures* on welfare than the rest of events.

KEYWORDS

climate change, domestic flows, international flows, temperatures, weather events

1 | INTRODUCTION

Nowadays, climate change is one of the biggest concerns in the world and it is becoming increasingly important over time. The socioeconomic consequences of this phenomenon are certainly very broad and diverse and, will undoubtedly have a substantial impact on the well-being of citizens. In this research, we focus on the impact of climate change on international trade, an area of great institutional interest but lacking in rigorous studies in the academic field; on the contrary, many studies have examined the effect of international trade on climate change.

The World Bank (Brenton & Chemutai, 2021; Onder, 2012; or World Bank, 2010), the World Trade Organization and United Nations Environmental Program (WTO and UNEP Report, 2009) and the OECD (for instance, Dellink et al., 2017; Van Hassel, 2017; or Yamaguchi, 2021) raise concerns about the relationship between trade and climate change in various reports and working papers. However, their analyses are merely descriptive, qualitative, or rest on projections based on simulations.

Following Grossman and Krueger (1992) and Copeland and Taylor (2003), we know that international trade can influence climate change through three main channels: the 'scale effect' (the increase in the GDP of countries derived from the expansion of trade induces more polluting emissions), the 'composition effect' (in those countries with lower environmental standards trade liberalisation may lead to excessive specialisation in pollution-intensive activities) and, finally, the 'technique effect' (trade allows less developed countries to gain access to cleaner technologies that will create less pollution and more efficient use of resources). Antweiler et al. (2001) find that the first and third channels are relevant, but not the second, which mainly depends on the specific characteristics of the countries, such as their abundance of capital or environmental standards.

Additionally, international awareness of global warming has led countries to increasingly consider the environmental consequences of their actions. This is the reason why environmental provisions are increasingly included in the negotiations of preferential trade agreements (deep agreements). The argument is that trading partners can take action to mitigate the harmful impact of international trade flows on the environment. The literature on this area is scarce. For instance, Baghdadi et al. (2013) evaluate the effectiveness of these provisions in reducing emissions and conclude that only those regional trade agreements (RTAs) with environmental harmonisation policies manage to reduce pollution at absolute and relative levels. Monteiro (2016) establishes a typology of this kind of provision while Clive and Shunta (2018) analyse the extent of its implementation in RTAs. Trade integration agreements improve environmental quality with or without environmental provisions in the analysis of Martínez-Zarzoso (2018). More recently, Yamaguchi (2020a, 2020b) studies the practices available to promote these provisions in integration agreements, while Abman et al. (2021) find that environmental provisions are capable of limiting deforestation in tropical developing countries. Finally, Bellmann and Bulatnikova (2022) show how RTAs can serve as a mechanism to regulate and promote international trade related to environmental services.

However, climate change could also affect trade through three main channels: infrastructure damage and lower growth productivity of factors of production on the negative side, and the possibility of opening up new trade routes on the positive one. The first of these channels arises as a consequence of extreme weather events (such as tornados, tropical cyclones, convective storms, floods, forest fires, etc.) as well as the rise in sea level. The second channel, in the short or medium term, derives from the first: it deals with the effects on labour productivity and biological consequences such as insect infestation or the spread of viruses (e.g., COVID-19). Finally, the thaw (resulting from global warming) can facilitate the opening of new routes for maritime transport.

The objective of this article is to analyse the impact of climate change on international trade flows. To this end, we estimate a theory-grounded gravity equation using data from a sample covering 67 countries over the period 1986–2016. Our estimation strategy takes into account all best practices in the estimation of gravity equations (Yotov et al., 2016), including the use of panel data techniques (to account for unobserved bilateral heterogeneity and endogeneity), the inclusion of controls for multilateral resistance terms, the use of the Poisson Pseudo Maximum Likelihood (PPML) estimator (to deal with the econometric problems resulting from heteroscedastic residuals and the prevalence of zeros in bilateral trade flows), and the use of intranational (in addition to international) trade flows.

We make two contributions to the literature on trade and climate change. We examine for the first time (to our knowledge) the effect of climate change on trade using the gravity equation taking into account all known biases.[1] Second, we focus directly on an output measure of climate change rather than on an input-based measure. With the exception of the paper by Abman et al. (2021) that focuses on deforestation, the rest of the works in this context use emissions as the variable of interest. More specifically, the United Nations defines 'Climate change' as 'long-term shifts in temperatures and weather patterns'. Additionally, it states that the main responsible for this is 'human activities' … 'primarily due to burning fossil fuels like coal, oil and gas' that '… generates greenhouse gas emissions that act like a blanket wrapped around the Earth, trapping the sun's heat and raising temperatures'. Relying on these definitions, we can conclude that greenhouse gas emissions, the commonly used variable, are the input in producing a harmful environment, while the increase in temperatures and other meteorological events are the outcomes. Hence, this is our second main contribution: our measure of output from climate change consists of temperature increases and extreme weather events measured with data gathered from the Climate Change Knowledge Portal (World Bank) for temperatures and the 'International Disasters Database' (EM–DAT) for extreme natural events, respectively.

To preview our results, we find that the gradual rise in temperatures increases international trade relative to domestic trade, while extreme meteorological events decrease international trade relative to internal one. However, there are non-trivial differences in these relationships across countries and events. Regarding the increase in temperatures, the countries especially affected (in which domestic trade costs are growing compared with the international ones) are Malawi, Morocco and Hungary. In relation to events, our results suggest that biological events (*epidemics* and *insect infestation*), *extreme temperatures, storms* and *landslides* have a negative impact on international flows relative to internal ones. Interestingly, the analysis by countries reveals that China (the largest exporter) together with Japan (the fifth one) mainly drive the overall result. An in-depth analysis shows that *storms*, in the case of China, and *extreme temperature* events, in the case of Japan, are especially relevant.

The next section briefly explains the channels through which climate change can affect international trade. Section 3 outlines the methodology and describes the data. Section 4 presents the results. Finally, Section 5 concludes.

[1]Gassebner et al. (2010) analyse the impact of disasters (technological and natural) on international trade. They find that disasters have a detrimental impact on the poorest and least democratic countries. The authors do not include country-year fixed effects that allow multilateral resistance to vary over time, nor do they consider domestic trade flows.

2 | HOW CAN CLIMATE CHANGE AFFECT INTERNATIONAL TRADE?

There is a general consensus on the systematic increase in temperatures in recent decades around the world. Figure 1 shows the evolution of average temperatures for our dataset during the period 1986–2016. At first glance, there is a clear upward trend in average annual temperatures that has become more pronounced in recent years. We have plotted the same information for each country and have obtained a similar picture (to a higher or lower extent) with very few exceptions (see Figure A1 in Appendix A).

Rising temperatures are considered one of the main drivers for a higher prevalence of extreme weather events such as tornadoes, *storms, floods* and other directly related adverse consequences such as *wildfires*, sea level rise, *insect infestations* or *epidemics*. As Figure 2 shows, there is a remarkable positive correlation between these events and temperatures. These phenomena may affect international trade through three different channels: damage to infrastructures, reduced labour productivity and the opening of new routes.

First of all, the aforementioned meteorological events could damage infrastructures directly related to international trade such as ports, airports, routes, etc. Additionally, indirect effects could also appear because these events may require more frequent maintenance of these infrastructures or have a negative impact on the operation of electronic devices related to international trade. Dellink et al. (2017) provide an in-depth analysis of the material consequences of climate change.

Second, climate change may reduce the productivity growth of production factors and, in particular, the productivity of the labour input. International trade, as an economic activity, could also be affected by this fact. The connection between high temperatures and the productivity of labour has been previously analysed in the literature. Heat stress affects human performance (Hancock et al., 2007) and, among other things, has a detrimental impact on labour productivity 'involving

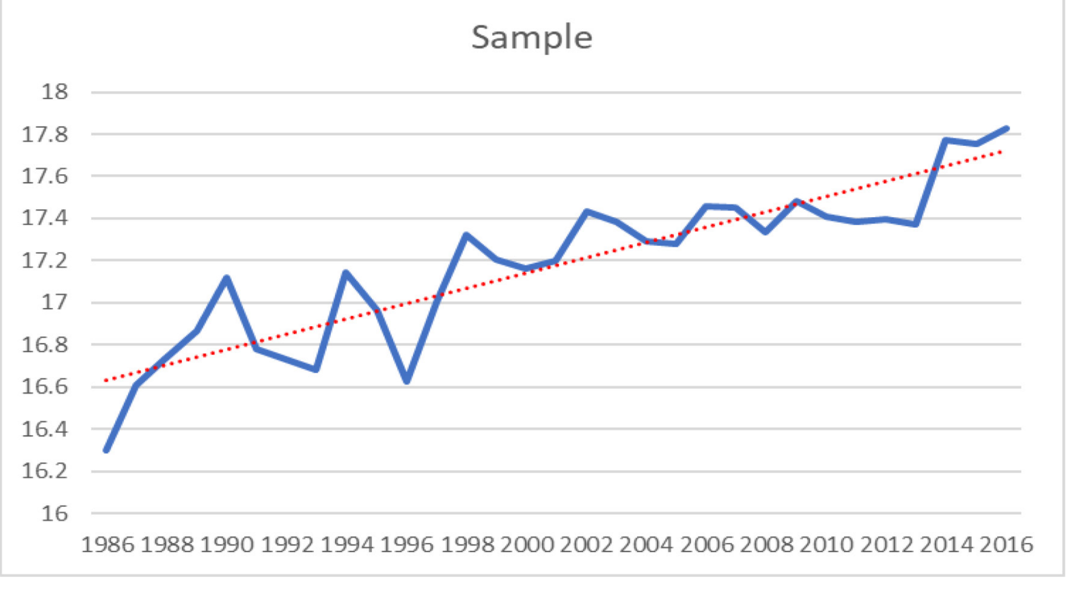

FIGURE 1 Evolution of average yearly temperature in our sample (67 countries). *Note*: Own elaboration based on data from Climate change knowledge Portal (World Bank). [Colour figure can be viewed at wileyonlinelibrary.com]

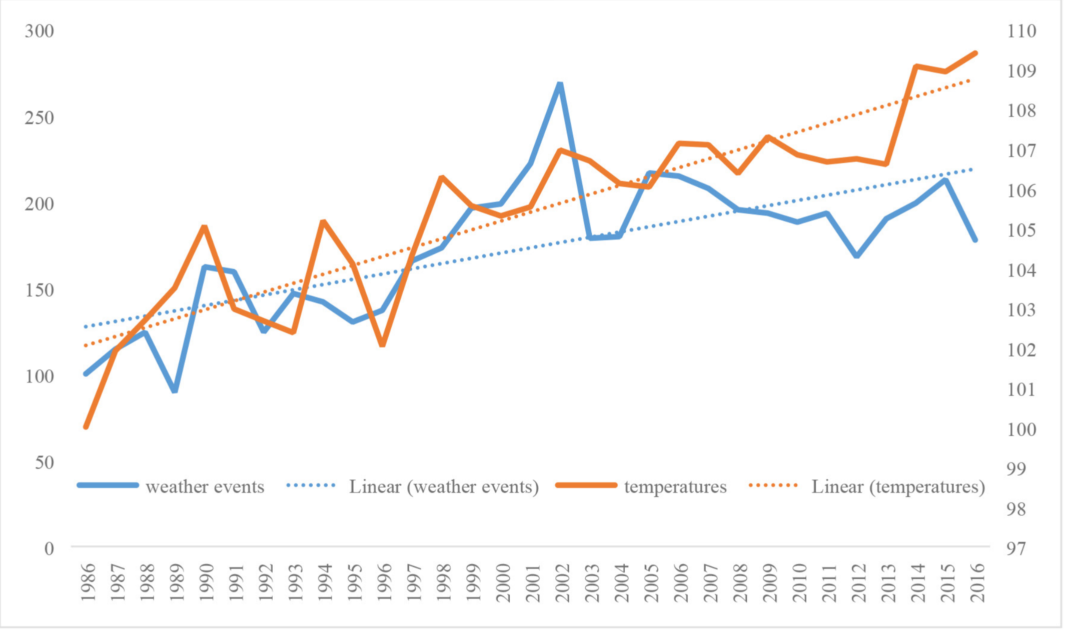

FIGURE 2 Evolution of average yearly temperature and weather events. *Note*: Own elaboration based on data from Climate change knowledge Portal (World Bank) and 'International Disasters Database' (EM–DAT). [Colour figure can be viewed at wileyonlinelibrary.com]

office, factory, or outdoor workers' (Federspiel et al., 2004). In this sense, Gosling et al. (2018) estimate up to 10%–15% loss of productivity for the countries of Southern Europe and between 2% and 4% for those of the North in the most adverse scenario of non-mitigation and adaptation, being the impact greater for outdoor activities. Deryugina and Hsiang (2014), for the US, estimate a loss of labour productivity of around 1.7% for each degree Celsius increase in average daily temperature above 15°C and a cost of about $20 per person if the temperature exceeds 30°C. An additional negative consequence of climate change on labour productivity stems from unnaturally high temperatures leading to diverse biological effects, such as *insect infestation* or the spread of viruses.

Third, widespread higher temperatures accelerate melting in the Arctic, facilitating the opening of new routes, such as the Arctic seaways: The Northeast Passage, also called the Northern Sea Route (NSR), the Northwest Passage (North of Canada) and the Polar Route. These new routes could reduce shipping distances by 20% to 40% compared with the routes through the Panama and Suez Canal. However, the reduction in transportation costs is not necessarily of a similar magnitude because transportation difficulties differ between these routes. Bekkers et al. (2015) study the foreseeable impact on trade of the opening of the NSR. According to their estimations, the commercial use of this route will represent a reduction in shipping distances and a decrease in average transport days of around a third compared with the currently used Southern Sea Route. These trade cost reductions will boost trade flows between Northeast Asia (i.e., Japan, South Korea and China) and Northwest Europe by an average of around 10%. These reductions may also have other implications, such as the restructuring of global supply chains within Europe and between Europe and Asia. However, it seems that Artic routes remain very limited (Babin et al., 2020).

Determining which of the aforementioned factors dominates is an empirical matter. In this article, we focus on examining this issue. To this end, we estimate the structural gravity equations of trade accounting for all the biases known in the literature so far (Yotov et al., 2016).

3 | METHODOLOGY AND DATA

The gravity model is one of the most successful econometric tools in economics and is particularly adequate for the study of international trade flows since the well-known pioneering book by Tinbergen (1962). In its simplest version, the gravity model relates bilateral trade flows to economic size, the GDP of origin and destination countries, and the geographical distance between the partners. Later developments introduce other variables that affect trade barriers, such as whether the countries share a common border, a common language, they are islands, etc. This is the so-called 'augmented' gravity model. This econometric methodology allows us to carefully examine the determinants of bilateral trade flows.

Over time, the gravity equation has become more sophisticated with the theoretical contributions of diverse authors. In its influential article, Anderson and van Wincoop (2003) state that gravity estimations should take into account not only bilateral trade barriers but also those barriers that the exporter and importer face with respect to third-party partners. These are the multilateral resistance terms, in the terminology of Anderson and van Wincoop (2003). In practice, in a cross-section setting, the introduction into the gravity equation of dummies for the countries that act as exporters and importers allows controlling for these multilateral resistance terms. However, multilateral resistance can change over time. Therefore, in a panel data setting, we have to introduce exporter-time and importer-time dummies into the gravity equation. This is known in the literature as country-year fixed effects (CYFE). Additionally, unobservable constant bilateral heterogeneity and endogeneity are controlled for with county-pair-fixed effects (CPFEs; Baier & Berstrand, 2007; Baldwin & Taglioni, 2007; Gil-Pareja et al., 2008). In another influential article, Santos Silva and Tenreyro (2006) point out that the residuals in the gravity equation are usually heteroscedastic. The latter, together with the existence of zeros in bilateral trade flows, means that the traditional estimates relying on log-linear specifications of the gravity model are biased. Therefore, these authors propose a PPML estimator to solve both problems. Finally, some authors (Baier et al., 2019; Bergstrand et al., 2015; Yotov, 2012; Yotov et al., 2016) have highlighted the need to include both international and intranational trade flows to avoid biased estimations and to properly measure trade creation and trade diversion effects of trade policy. In fact, in our context, the inclusion of intranational trade flows is very important as it allows us to identify the country-specific effects of climate change on trade.

In this article, we estimate a gravity equation with CYFE and CPFE using the PPML estimator and a database that incorporates domestic as well as international flows. It is important to note that, based exclusively on international trade flows, the inclusion of CYFE and CPFE only allows us to identify those variables that are pair-specific and vary over time (e.g., when two countries establish an RTA). However, as has been pointed out by Beverelli et al. (2018), the introduction of domestic flows into the gravity equations allows us to identify the impact of country-specific variables (such as our variables of interest) on international trade, but only *in relation to* intranational trade. Additionally, introducing intranational flows is also an alternative to deal with endogeneity issues.[2]

[2]These authors provide a battery of reasons that support the control for endogeneity through the methodology used. On the one hand, the inclusion of exporter and importer fixed effects control for country-specific behaviour between trade and climate change. On the other hand, the variable of interest is the result of interacting with a dummy for 'international trade' (*int*, which takes the value one for international flows) and climate change. As these authors state, according to Nizalova and Murtazashvili (2016), consistent estimates are obtained because the intrinsic exogeneity of the international trade dummy implies a non-correlation with our measures of climate change. Finally, pair-fixed effects strongly control for omitted variables. Thus, following these authors, our methodology allows avoiding the use of an instrumental variables (IVs) estimation.

Finally, following Bergstrand et al. (2015), we use a set of interactive dummies to control for globalisation trends.[3] In this way, we account for the variation over time of trade costs (fixed and variable) that affect international trade in relation to domestic trade.

We estimate the following gravity equations:

$$X_{ijt} = \exp^{\left(\beta_1 \mathrm{PTA}_{ijt} + \beta_2 (\mathrm{GATT/WTO})_{ijt} + \beta_3 \mathrm{temp}_{i(j)t} + \sum_{1987}^{2016} \beta_t \mathrm{Glob}_{ijt} + \mu_{ij} + \delta_{it} + \gamma_{jt}\right)} u_{ijt} \tag{1}$$

and

$$X_{ijt} = \exp^{\left(\beta_1 \mathrm{PTA}_{ijt} + \beta_2 (\mathrm{GATT/WTO})_{ijt} + \beta_4 \mathrm{event}_{i(j)t} + \sum_{1987}^{2016} \beta_t \mathrm{Glob}_{ijt} + \mu_{ij} + \delta_{it} + \gamma_{jt}\right)} u_{ijt} \tag{2}$$

where X_{ijt} are exports from country '*i*' to country '*j*' in time '*t*', PTA is a dummy for Preferential Trade Agreements, GATT–WTO is a dummy for the GATT/WTO system, Glob measures globalisation and it is made up of a dummy for international trade (which takes the value 1 for international flows and zero for domestic ones, labelled as *int*) interacted with year dummies (except 1986, to avoid multicollinearity), *temp* is the average annual temperatures of countries (implicitly interacted with *int*) and the *event* is the number of *extreme weather* events, and their consequences (implicitly interacted with *int*), μ_{ij} are CPFE and δ_{it} and γ_{jt} are CYFE for the exporter and the importer, respectively.

The data for PTAs and the GATT/WTO system have been taken from the Dynamic Gravity Dataset (DGD) developed by the United States International Trade Commission (USITC; see Gurevich & Herman, 2018). This database was designed to be easily combined with the usual sources of bilateral trade data. In our case, we use a panel dataset built by Thomas Zylkin. The advantage of these data is that they incorporate both domestic (intranational) trade flows and international trade flows for manufacturing trade over the period 1986–2006 for 69 countries which has been extended to 2016.[4] We have selected 67 countries for our analysis because of the lack of enough data for two of the countries included in the aforementioned sample (Argentina and Hong Kong).

As noted earlier, we have chosen two measures that reflect climate change: *temperatures* and *extreme weather events* (or their consequences). On the one hand, the average annual *temperatures* of each country have been extracted from the Climate Change Knowledge Portal (World Bank). On the other hand, *extreme weather events* (or their consequences) are taken from the International Disasters Database (EM–DAT),[5] Center for Research on the Epidemiology of Disasters. In particular, we have considered the following events: Wildfires ($Wildfire_{ijt}$), Floods ($Flood_{ijt}$), Extreme Temperatures (Ext_Temp_{ijt}), Epidemics ($Epidemic_{ijt}$), Insect Infestation ($Insect_{ijt}$), Storms ($Storm_{ijt}$), Droughts ($Drought_{ijt}$) and Landslides ($Landslide_{ijt}$).

[3]We are grateful to an anonymous referee for pointing this out.

[4]One potential caveat of this dataset is that it does not include trade on agricultural products which prevents us from analysing the effects of climate on bilateral trade flows that are probably sizeable. For instance, Klomp and Hoogezand (2018) explore the impact of natural disasters on the degree of agricultural protection. The results obtained are that natural disasters increase agricultural trade controls in high-income countries to favour domestic farmers, while trade barriers in poor countries are reduced in an attempt to diminish food scarcity.

[5]This dataset is used by Felbermayr and Gröschl (2013) to construct IV estimates for openness in order to analyse the effect of trade on income.

4 | RESULTS

4.1 | 'Partial' equilibrium

We estimate Equations (1) and (2) by PPML with CPFE and CYFE. We start with regressions that do not consider the impact of globalisation (columns 1 and 3). Then, we estimate the same specification including the globalisation trend as in Bergstrand et al. (2015).

In addition to the PTAs and the GATT/WTO system dummies, in column (1) we present the countries' temperatures. As shown, PTAs and GATT/WTO membership have a positive and significant impact on bilateral trade flows (relative to domestic ones), as expected, with an especially strong effect in the case of the GATT/WTO system. Note that due to the inclusion of country-pair fixed effects in the regressions, we only identify the impact of those countries that joined the agreements during the sample period. Regarding our variable of interest, we obtain a positive and significant coefficient (0.202). The estimated parameter implies that an increase in one degree Celsius leads to a 22% increase in international flows relative to domestic ones.[6] In the case of events (column 3), the parameter is 0.005, which implies an impact on bilateral trade of around 0.5% for each additional event.

In columns 2 and 4, we introduce the measure of globalisation.[7] As shown, and in line with expectations, the corresponding parameters for the respective *Glob* variables are positive, highly significant and increasing over time (with some exceptions, such as the outset of the financial crisis). The process of world trade integration increases international flows relative to internal ones over time. This means that the omission of a measure of globalisation in the regressions implies that the estimated parameters of the other variables in the model are capturing this phenomenon, overestimating the impact of the corresponding variables. Indeed, this is what we observe in the estimations. The values of the parameters for the PTAs and the GATT/WTO system has been drastically reduced, but they are still highly significant. As expected, the same occurs with our *temp* variable, whose impact has been reduced to around 3.8% though it remains statistically and economically significant. In the case of the *events* variable, the sign of the estimated parameter changes, although it continues to be significant at conventional levels, with an impact of around −0.5%. Once we take into account the significant reduction (statistically and economically) of international trade costs relative to domestic ones, an extreme weather event will have a negative impact on international flows (relative to intranational ones).

We must be cautious with the interpretation of these results. The fact that climate change affects (on average) international flows in relation to domestic ones implies that trade costs are relatively altered in these two dimensions. If we focus on the reasons for the impact of climate change on trade, this will be the result of a different effect on infrastructure for each type of trade (we can include maritime routes) or on labour productivity for international versus domestic tasks within countries. Unfortunately, we do not have data at the within country level to further investigate these mechanisms.[8]

[6][exp (0.202)− 1]*100 = 22%.

[7]Following a referee's recommendation, as a robustness check, we have included (in different regressions) a measure of the Gross Domestic Product and per capita Gross Domestic Product of countries, both interacting with the 'international trade dummy'. Our main findings remain unaltered. For brevity, these results are not reported but are available from the authors.

[8]We thank an anonymous referee for helping to clarify this point.

To dig deeper into our findings, we have carried out additional estimates. First, we have examined country-specific impacts. In Table 2, we present these estimations for temperatures and events in columns (1) and (2), respectively.[9] We have performed a regression for each country by splitting the corresponding variable of interest between the average effect excluding the corresponding country plus the country's own effect. As can be seen, the positive average coefficient for temperatures shown in column 3 of Table 1 is not too generalised, although the positive cases predominate over the negative ones.[10] There are some countries with very high positive impacts (Malawi, Morocco or Hungary, among others) for which domestic flows are strongly negatively affected in relation to international ones. On the other hand, for some countries, the estimated parameter is negative (and significant), which means that the increase in temperatures affects to a greater extent the costs of international trade in relation to internal ones. This is the case of Nepal or Singapore. For 30 countries, we cannot find a significant difference in the relative cost of trade over the type of trade (international or intranational).

Focussing on events, at first sight, it seems that the overall (negative) result is driven by a few countries: only in 13 of 67 cases, we find a negative (and significant) coefficient, in eight a positive (and significant) one with no significant effect for the rest of the countries. However, a remarkable difference arises for the two countries: when China or Japan are excluded from the sample: the estimated average parameter completely loses its statistical significance.[11] Therefore, the impact of these countries is crucial for the average effect observed, although other relevant exporters also present a negative and significant estimated coefficient, such as Germany, France or Italy.

Regarding *events*, we can take one step forward that might shed some light on the cases of China and Japan. As stated above, in our database, we have information about the 'type of event'. Therefore, we have split our *events* variable into the following eight categories according to the type of event: Wildfires ($Wildfire_{ijt}$), Floods ($Flood_{ijt}$), Extreme Temperatures (Ext_Temp_{ijt}), Epidemics ($Epidemic_{ijt}$), Insect Infestation ($Insect_{ijt}$), Storms ($Storm_{ijt}$), Droughts ($Drought_{ijt}$) and Landslides ($Landslide_{ijt}$). The results of estimating Equations (1) and (2) for each of these variables are presented in column 1 of Table 3. Additionally, we have divided each of these variables into the effect on China and the rest of the sample and the effect on Japan and the rest of the sample (columns 2 and 3).[12]

As observed, *Extreme Temperatures* (with an impact of around 6%), *Epidemics* (6%), *Insect Infestation* (23%), *Storms* (1.1%) and *Landslides* (2.1%) decrease international flows relative to domestic ones, *Wildfires* increase them (3.5%) while *Floods* and *Droughts* do no show a differential effect between international and intranational flows. Focusing on the case of China,

[9]To save space, we do not report fixed effects and other estimated coefficients, but they are available from the authors upon request.

[10]We found 26 positive and significant cases (at least at 10% level) and 11 negatives out of 67 cases.

[11]It is important to point out that for the rest of the regressions for each country, the coefficient of the global effect of the *event* variable excluding the corresponding country is always negative and significant with a value not very different from that presented in column 4 of Table 2. Regressions can be provided under request.

[12]It is important to note that there is not any multicollinearity problem in the general regression including the variables for the distinct type of events. However, when considering the variables corresponding to the case of China, we have detected a very high correlation between *Floods* and *Storms*. Therefore, we have eliminated the variable *Floods* for China. In any case, by including this variable, the conclusions reached for *Storms* are exactly the same. With respect to Japan, there is no collinearity problem.

TABLE 1 Trade and climate change. Period 1986–2016.

Dependent variable	(1) Nominal trade flows in current US dollars	(2) Nominal trade flows in current US dollars	(3) Nominal trade flows in current US dollars	(4) Nominal trade flows in current US dollars
PTA_{ijt}	0.320***	0.122**	0.368***	0.122**
	(0.065)	(0.056)	(0.066)	(0.056)
$GATT/WTO_{ijt}$	1.540***	1.024***	1.620***	1.064***
	(0.092)	(0.116)	(0.086)	(0.109)
$temp_{i(j)t}$	0.202***	0.037***		
	(0.013)	(0.010)		
$event_{i(j)t}$			0.005***	−0.005***
			(0.002)	(0.002)
$Glob_{ij1987}$		0.024***		0.029***
		(0.008)		(0.007)
$Glob_{ij1988}$		0.088***		0.121***
		(0.010)		(0.010)
$Glob_{ij1989}$		0.126***		0.162***
		(0.016)		(0.015)
$Glob_{ij1990}$		0.193***		0.254***
		(0.019)		(0.019)
$Glob_{ij1991}$		0.228***		0.267***
		(0.018)		(0.019)
$Glob_{ij1992}$		0.244***		0.285***
		(0.018)		(0.019)
$Glob_{ij1993}$		0.277***		0.306***
		(0.020)		(0.021)
$Glob_{ij1994}$		0.323***		0.370***
		(0.023)		(0.023)
$Glob_{ij1995}$		0.411***		0.447***
		(0.024)		(0.024)
$Glob_{ij1996}$		0.447***		0.454***
		(0.025)		(0.025)
$Glob_{ij1997}$		0.509***		0.560***
		(0.028)		(0.029)
$Glob_{ij1998}$		0.554***		0.617***
		(0.027)		(0.029)
$Glob_{ij1999}$		0.539***		0.594***
		(0.029)		(0.031)

(Continues)

TABLE 1 (Continued)

Dependent variable	(1) Nominal trade flows in current US dollars	(2) Nominal trade flows in current US dollars	(3) Nominal trade flows in current US dollars	(4) Nominal trade flows in current US dollars
$Glob_{ij2000}$		0.603***		0.668***
		(0.030)		(0.033)
$Glob_{ij2001}$		0.581***		0.634***
		(0.029)		(0.030)
$Glob_{ij2002}$		0.531***		0.601***
		(0.030)		(0.034)
$Glob_{ij2003}$		0.577***		0.629***
		(0.031)		(0.033)
$Glob_{ij2004}$		0.624***		0.670***
		(0.032)		(0.034)
$Glob_{ij2005}$		0.642***		0.691***
		(0.033)		(0.036)
$Glob_{ij2006}$		0.671***		0.739***
		(0.033)		(0.036)
$Glob_{ij2007}$		0.794***		0.855***
		(0.039)		(0.040)
$Glob_{ij2008}$		0.822***		0.869***
		(0.039)		(0.040)
$Glob_{ij2009}$		0.736***		0.785***
		(0.042)		(0.042)
$Glob_{ij2010}$		0.819***		0.853***
		(0.044)		(0.043)
$Glob_{ij2011}$		0.824***		0.873***
		(0.045)		(0.043)
$Glob_{ij2012}$		0.818***		0.869***
		(0.047)		(0.045)
$Glob_{ij2013}$		0.847***		0.907***
		(0.048)		(0.048)
$Glob_{ij2014}$		0.804***		0.876***
		(0.048)		(0.046)
$Glob_{ij2015}$		0.786***		0.865***
		(0.054)		(0.050)
$Glob_{ij2016}$		0.745***		0.821***
		(0.056)		(0.052)

TABLE 1 (Continued)

Dependent variable	(1) Nominal trade flows in current US dollars	(2) Nominal trade flows in current US dollars	(3) Nominal trade flows in current US dollars	(4) Nominal trade flows in current US dollars
Constant	10.946***	11.776***	11.410***	11.835***
	(0.095)	(0.108)	(0.083)	(0.103)
Observations	136,153	136,153	136,153	136,153
Country pair FE	Yes	Yes	Yes	Yes
Importer-year and Exporter year FE	Yes	Yes	Yes	Yes
Intra-national trade	Yes	Yes	Yes	Yes
Pseudo R^2	0.99	0.99	0.99	0.99

Note: Standard errors are clustered by country pair.
*Significant at 10% level, **Significant at 5% level, ***Significant at 1% level.

there is an event in which there is a clear influence of this country with respect to the average of the rest of the countries. As can be seen, when referring to *Storms*, excluding China causes the general average parameter to cease to be significant and the specific impact of this event for China increases to around 3%. So, these types of events (mainly cyclones, tornadoes and convective hail) negatively impact China to a large extent, probably affecting critical infrastructures related to international trade. In the case of Japan, something similar occurs with our *Extreme Temperature* variable (with a negative impact of around 18%), so the exclusion of this country makes the general average close to non-significant (at the 10% level). Rather, we tentatively postulate the differential behaviour of labour productivity between trade 'types' as the likely reason. As in China, the impact of *Storms* in Japan is quite strong (around 2.4%) and also influences the general average, which is halved. Finally, *Landslides* also have a relatively negative impact on Japan's international trade. The rest of the events do not seem to have had any significant impact in this country.

4.2 | General equilibrium

Lastly, we run a General Equilibrium analysis that closely follows the implementation in Baier et al. (2019)[13] and which is based on partial (equilibrium) estimations from column 1 of Table 3. The starting point (see, for instance, Costinot & Rodríguez-Clare, 2014) is a theoretical model for international trade flows based on an Armingon–CES model with a single sector being labour (L) the only factor of production of the (standard) type:

$$X_{\mathrm{ij}} = \frac{A_i w_i^{-\theta} \tau_{\mathrm{ij}}^{-\theta}}{\sum_k A_k w_k^{-\theta} \tau_{\mathrm{kj}}^{-\theta}} E_j \tag{3}$$

[13]To explain the General Equilibrium, we closely follow Baier et al. (2019) and Thomas Zylkin's web page http://www.tomzylkin.com/uploads/4/1/0/4/41048809/help_file.pdf, where the Stata command (ge_gravity) and the methodology are described.

TABLE 2 Trade and climate change. Period 1986–2016.

Country	(1) Coefficient of temperatures (temp)	(2) Coefficient of events (event)
Australia	−0.030 (0.028)	−0.005 (0.004)
Austria	0.107*** (0.018)	0.005 (0.004)
Belgium	−0.097*** (0.018)	0.005 (0.009)
Bolivia	0.187** (0.075)	0.020** (0.009)
Brazil	0.095*** (0.030)	0.003 (0.002)
Bulgaria	0.348*** (0.050)	0.022*** (0.006)
Cameroon	0.053 (0.195)	0.023* (0.014)
Canada	0.021 (0.016)	0.002 (0.003)
Chile	0.107** (0.043)	0.004 (0.003)
China	0.025 (0.018)	−0.010***(0.003)
Colombia	0.104* (0.058)	0.003 (0.006)
Costa Rica	0.202* (0.121)	−0.002 (0.006)
Cyprus	0.382*** (0.090)	−0.005 (0.007)
Denmark	−0.002 (0.014)	−0.014*** (0.003)
Ecuador	0.003 (0.050)	−0.002 (0.005)
Egypt	0.246*** (0.071)	0.004 (0.005)
Finland	−0.042** (0.020)	−0.016**(0.007)
France	0.013 (0.018)	−0.008** (0.003)
Germany	0.058*** (0.019)	−0.007*** (0.002)
Greece	−0.063 (0.049)	−0.008* (0.005)
Hungary	0.491*** (0.043)	0.004 (0.011)
Iceland	0.092 (0.081)	0.001 (0.006)
India	0.287*** (0.077)	−0.003 (0.005)
Indonesia	−0.232*** (0.064)	−0.011 (0.006)
Iran	−0.301*** (0.114)	0.016 (0.011)
Ireland	0.034 (0.027)	−0.004 (0.006)
Israel	0.200*** (0.056)	0.003 (0.006)
Italy	−0.048** (0.023)	−0.013*** (0.003)
Japan	−0.164*** (0.031)	−0.020*** (0.004)
Jordan	−0.027 (0.057)	0.001 (0.008)
Kenya	−0.004 (0.054)	0.013 (0.009)
Korea	−0.016 (0.031)	−0.007*(0.004)
Kuwait	−0.199*** (0.074)	−0.003 (0.007)
Macao	0.277 (0.211)	−0.031 (0.027)
Malawi	0.759*** (0.294)	0.043 (0.034)
Malaysia	−0.193** (0.086)	−0.003 (0.007)

TABLE 2 (Continued)

Country	(1) Coefficient of temperatures (temp)	(2) Coefficient of events (event)
Malta	0.024 (0.080)	0.002 (0.008)
Mauritius	−0.170** (0.082)	0.003 (0.005)
Mexico	0.378*** (0.094)	0.013*** (0.003)
Morocco	0.510** (0.203)	−0.014* (0.008)
Myanmar	0.424 (0.300)	0.027 (0.027)
Nepal	−0.474*** (0.143)	−0.004 (0.012)
Netherlands	0.081*** (0.020)	−0.002 (0.004)
Niger	−0.117 (0.150)	−0.027** (0.013)
Nigeria	0.030 (0.051)	−0.006 (0.012)
Norway	0.045 (0.031)	−0.013** (0.006)
Panama	0.223*** (0.087)	−0.012 (0.007)
Philippines	0.126** (0.060)	0.003 (0.004)
Poland	0.307*** (0.026)	0.023*** (0.008)
Portugal	0.047 (0.037)	−0.005 (0.005)
Qatar	0.417*** (0.156)	0.002 (0.007)
Romania	0.292*** (0.050)	0.074** (0.037)
Senegal	0.087 (0.104)	0.030** (0.014)
Singapore	−0.323*** (0.110)	−0.021** (0.010)
South Africa	0.049 (0.039)	−0.002 (0.006)
Spain	0.157*** (0.022)	−0.003 (0.003)
Sri Lanka	−0.105 (0.074)	−0.010*(0.006)
Sweden	−0.012 (0.012)	−0.010*** (0.004)
Switzerland	0.202*** (0.037)	−0.009 (0.007)
Tanzania	0.045 (0.072)	0.015 (0.013)
Thailand	0.031 (0.047)	0.002 (0.004)
Trinidad and Tobago	0.101 (0.179)	0.005 (0.007)
Tunisia	0.202*** (0.055)	−0.004 (0.008)
Turkey	0.195*** (0.034)	−0.002 (0.003)
United Kingdom	0.055*** (0.015)	0.002 (0.003)
United States	0.031 (0.023)	−0.002 (0.002)
Uruguay	−0.015 (0.059)	−0.012*** (0.005)

Note: Full estimates are available from the authors upon request. Standard errors are clustered by country pair.
*Significant at 10% level, **Significant at 5% level, ***Significant at 1% level.

where i is origin, j destination, X are trade flows (domestic, when i coincides with j, and international, if it is not the case), A is technology level, w is production cost (wages), τ are iceberg trade costs, θ is the elasticity of substitution across (differentiated) goods, which is also

TABLE 3 Trade and climate change. Period 1986–2016.

Dependent variable	(1) Nominal trade flows in current US dollars	(2) Nominal trade flows in current US dollars	(3) Nominal trade flows in current US dollars
$Wildfire_{ijt}$	0.035***		
	(0.008)		
$Wildfire\text{-}no\text{-}China_{ijt}$		0.032***	
		(0.008)	
$Wildfire\text{-}China_{ijt}$		0.046***	
		(0.008)	
$Wildfire\text{-}no\text{-}Japan_{ijt}$			0.034***
			(0.007)
$Wildfire\text{-}Japan_{ijt}$			−0.007
			(0.011)
$Flood_{ijt}$	0.000		
	(0.002)		
$Flood\text{-}no\text{-}China_{ijt}$		0.000	
		(0.002)	
$Flood\text{-}China_{ijt}$			
$Flood\text{-}no\text{-}Japan_{ijt}$			0.001
			(0.002)
$Flood\text{-}Japan_{ijt}$			−0.008
			(0.007)
Ext_Temp_{ijt}	−0.062***		
	(0.016)		
$Ext\_Temp\text{-}no\text{-}China_{ijt}$		−0.058***	
		(0.017)	
$Ext\_Temp\text{-}China_{ijt}$		−0.062***	
		(0.019)	
$Ext\_Temp\text{-}no\text{-}Japan_{ijt}$			−0.020*
			(0.012)
$Ext\_Temp\text{-}Japan_{ijt}$			−0.203***
			(0.032)
$Epidemic_{ijt}$	−0.062***		
	(0.019)		
$Epidemic\text{-}no\text{-}China_{ijt}$		−0.068***	
		(0.019)	

TABLE 3 (Continued)

Dependent variable	(1) Nominal trade flows in current US dollars	(2) Nominal trade flows in current US dollars	(3) Nominal trade flows in current US dollars
Epidemic-China$_{ijt}$		−0.040*	
		(0.023)	
Epidemic-no-Japan$_{ijt}$			−0.066***
			(0.019)
Epidemic-Japan$_{ijt}$			0.037
			(0.041)
Insect$_{ijt}$	−0.256***		
	(0.068)		
Insect-no-China$_{ijt}$		−0.226***	
		(0.071)	
Insect-China$_{ijt}$		−0.293***	
		(0.107)	
Insect-no-Japan$_{ijt}$			−0.300***
			(0.065)
Insect-Japan$_{ijt}$			−0.014
			(0.092)
Storm$_{ijt}$	−0.011***		
	(0.003)		
Storm-no-China$_{ijt}$		−0.004	
		(0.003)	
Storm-China$_{ijt}$		−0.027***	
		(0.006)	
Storm-no-Japan$_{ijt}$			−0.006**
			(0.003)
Storm-Japan$_{ijt}$			−0.024***
			(0.008)
Drought$_{ijt}$	0.002		
	(0.015)		
Drought-no-China$_{ijt}$		−0.018	
		(0.014)	
Drought-China$_{ijt}$		0.054*	
		(0.029)	
Drought-no-Japan$_{ijt}$			−0.003
			(0.014)
Drought-Japan$_{ijt}$			0.038
			(0.059)

(Continues)

TABLE 3 (Continued)

Dependent variable	(1) Nominal trade flows in current US dollars	(2) Nominal trade flows in current US dollars	(3) Nominal trade flows in current US dollars
Landslide$_{ijt}$	−0.021*** (0.006)		
Landslide-no-China$_{ijt}$		−0.038*** (0.009)	
Landslide-China$_{ijt}$		−0.029*** (0.009)	
Landslide-no-Japan$_{ijt}$			−0.015*** (0.005)
Landslide-Japan$_{ijt}$			−0.050** (0.020)
Observations	136.153	136.153	136.153
Country-pair FE	Yes	Yes	Yes
Importer-year and Exporter-year FE	Yes	Yes	Yes
Intra-national trade	Yes	Yes	Yes
Pseudo R^2	.99	.99	.99

Note: The coefficients for PTAs, GATT-OMC and the constant have been omitted for brevity. Full estimates are available from the authors upon request. Standard errors are clustered by country pair.

*Significant at 10% level, **Significant at 5% level, ***Significant at 1% level.

assumed to be trade elasticity and E is total expenditure. It is the case that $E_j \equiv \sum_i X_{ij}$. In the model, trade unbalances (D, assumed exogenous) are introduced additively to expenditure,[14] $E_j \equiv w_j L_j + D_j$.

As stated, the partial effects of the occurrence of an event in trade (assuming wages as fixed) are the result of estimating our structural gravity equation (column 1 of Table 3). Therefore, the direct trade impact of lowering trade barriers associated with a specific event is $\beta = -\theta \Delta \ln \tau_{ijt}$.

When simulating a general equilibrium, it should be the case that a country's labour income is the result of the value of the country's shipments to all destinations $Y_i \equiv w_i L_i \equiv \sum_i X_{ij}$. Then,

$$w_i L_i = \sum_j \frac{A_i w_i^{-\theta} \tau_{ij}^{-\theta}}{\sum_k A_k w_k^{-\theta} \tau_{kj}^{-\theta}} \left(w_j L_j + D_j \right) \quad \forall i \tag{4}$$

[14]The existence of trade unbalances implies that the change in real wages does not exactly coincide with the change in welfare. However, the changes in real wages and welfare will be the same if the 'multiplicative' alternative is considered, which assumes national expenditure as a fixed multiple of national output. In any case, the differences between the two alternatives are usually quite small and qualitatively similar.

Furthermore, the price levels in each country can be expressed as $P_j \equiv \left[\sum_k A_k w_k^{-\theta} \tau_{kj}^{-\theta} \right]^{-\frac{1}{\theta}}$.

Therefore, wages in a country are a function of its ability both to sell to markets with strong demand and to buy from technologically advanced markets. The system of equations determined by (4) is solved if we consider variations in the variables. Following the notation of Dekle et al. (2007), consider $\hat{w}_i = \frac{w_i''''}{w_i}$, the change in wages (or any other variable) in country 'i'' as a result of the occurrence of an event. Because of $\hat{\tau}_{\text{ij}}^{-\theta} = e^{\beta\ x\ \text{event}_i}$, we have that:

$$Y_i \hat{w}_i = \hat{w}_i^{-\theta} \sum_j \frac{\pi_{\text{ij}} e^{\beta\ x\ \text{event}_i}}{\hat{P}_j^{-\theta}} \left(Y_j \hat{w}_j + D_j \right) \ \ \forall i \tag{5}$$

where $\pi_{\text{ij}} \equiv \frac{X_{\text{ij}}}{E_j}$ are trade shares and $\hat{P}_j \equiv \left[\sum_k \pi_{\text{kj}} \hat{w}_k^{-\theta} e^{\beta\ x\ \text{event}_j} \right]^{-\frac{1}{\theta}}$.

In order to find a solution to Equation (5), we only require information on trade flows (domestic and international),[15] production and expenditure levels of the countries. Additionally, it is necessary to assign a value to the trade elasticity θ. Following Baier et al. (2019) we consider that θ=4.[16] Also, since trade is in nominal terms, the algorithm does the normalisation $\sum_i Y_i \hat{w}_i = \sum_i Y_i$. This implies that world output remains constant under the baseline and counterfactual.

Therefore, changes in welfare are measured as follows[17]:

$$\hat{W}_i = \frac{\hat{E}_i}{\hat{P}_i} \tag{6}$$

where $\hat{E}_i = \frac{Y_i \hat{w}_i}{E_i}$

The estimates based on Equation (6) for each of our eight events are shown in Table 4, in which we present the change in welfare in percentage terms.[18] Table 4 shows the average, maximum and minimum values across countries. We consider the trade balance of the first year of the sample (1986) as the baseline for the counterfactual.

From Table 4 some interesting conclusions stand out. First, *Insect infestation* and *Extreme temperatures* lead to the greatest reduction in average welfare, especially the first one. Second, *Landslides* and *Storms* also reduce welfare, but to a much lesser extent. In all these four cases, the reduction in welfare is generalised. Third, *Floods* and *Droughts* have null (or almost null) impacts on welfare. It is important to bear in mind that these events did not present significant estimated parameters (column 1 of Table 3). Fourth, *Wildfires*, with a positive and significant estimated parameter (which implies that the costs of domestic trade increase with respect to

[15]When explaining the Stata command on his web page, Thomas Zylkin states this clear cautionary note: "One common issue that researchers new to these methods should be aware of is that GE trade models require a "square" data set with information on internal trade flows in addition to data on international trade flows."

[16]They follow the recommendations in Simonovska and Waugh (2014).

[17]We focus on changes in welfare, although the Stata command output also provides us with trade volumes and changes in nominal wages and prices.

[18]The output in Stata is the new welfare level divided by the old welfare level.

TABLE 4 General equilibrium. Welfare effect (% change) of events.

Event	Average impact (%)	Highest impact (%)	Lowest impact (%)
$Wildfire_{ijt}$	0.23	0.67	0.02
$Flood_{ijt}$	0.00	0.00	0.00
Ext_Temp_{ijt}	−0.40	−1.15	−0.04
$Epidemic_{ijt}$	0.56	6.93	−0.08
$Insect_{ijt}$	−1.56	−4.36	−0.17
$Storm_{ijt}$	−0.07	−0.22	−0.01
$Drought_{ijt}$	0.01	0.03	0.00
$Landslide_{ijt}$	−0.14	−0.39	−0.01

international ones) have a positive (and generalised) effect on welfare. Finally, *Epidemics*, although with a positive average welfare effect, have a mixed welfare impact (although in most cases it is positive). In the latter case, two comments are in order. On the one hand, although the estimated average parameter (partial equilibrium) is almost identical to that of *Extreme Temperatures*, the consequences on welfare are very different. On the other hand, and connected with the previous point, the different evolution of nominal wages and prices across countries is what matters for welfare.

5 | CONCLUSIONS

In this article, we have analysed the impact of climate change on international flows through a solid econometric methodology. We have estimated a theory-consistent gravity equation using annual data from a sample of 67 countries over the period 1986–2016. Our main variables of interest are *temperatures* and *extreme weather events* (*wildfire, floods, extreme temperatures, epidemics, insect infestation, storms, droughts and landslides*).

Our results suggest that the increase in temperatures raises trade costs of domestic flows in relation to international ones, while the opposite occurs with events. However, the analysis by country reveals a remarkable degree of heterogeneity across countries (and also across extreme events). In particular, we find that the estimated impact of the events is mainly due to the influence of China and Japan on the estimations. In the first case, *storms* are what matters, while *extreme temperatures* are the relevant phenomenon in the second. In general, extreme weather events have a negative impact on welfare, although there are exceptions.

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DATA AVAILABILITY STATEMENT

Not applicable.

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REFERENCES

Abman, R., Lundberg, C., & Ruta, M. (2021). *"The effectiveness of environmental provisions in regional trade agreements", policy research working paper 9601*. World Bank, Washington, DC.

Anderson, J. E., & van Wincoop, E. (2003). Gravity with gravitas: A solution to the border puzzle. *American Economic Review*, *93*(1), 170–192.

Antweiler, W., Copeland, B., & Taylor, S. (2001). Is free trade good for the environment? *American Economic Review*, *91*(4), 877–908.

Babin, J., Lasserre, F., & Pic, P. (2020). Arctic shipping and polar seaways. In P. A. Maurice (Ed.), *Encyclopedia of water: Science, technology, and society* (pp. 1539–1550). Wiley.

Baghdadi, L., Martinez-Zarzoso, I., & Zitouna, H. (2013). Are RTA agreements with environmental provisions reducing emissions? *Journal of International Economics*, *90*(2), 378–390.

Baier, S. L., & Berstrand, J. H. (2007). Do free trade agreements actually increase members´ international trade? *Journal of International Economics*, *71*, 72–95.

Baier, S. L., Yotov, Y. V., & Zylkin, T. (2019). On the widely differing effects of free trade agreements: Lessons from twenty years of trade integration. *Journal of International Economics*, *116*, 206–226.

Baldwin, R., & Taglioni, D. (2007). Trade effects of the euro: A comparison of estimators. *Journal of Economic Integration*, *22*(4), 780–818.

Bekkers, E., Francois, J. F., & Rojas-Romagosa, H. (2015). Melting ice caps and the economic impact of opening the Northern Sea route. *The Economic Journal*, *128*, 1095–1127.

Bellmann, C., & Bulatnikova, A. (2022). *Incorporating environmental provisions in regional trade agreements*. OECD trade and environment working papers 2022/01.

Bergstrand, J. H., Larch, M., & Yotov, Y. V. (2015). Economic integration agreements, border effects, and distance elasticities in the gravity equation. *European Economic Review*, *78*, 307–327.

Beverelli, C., Keck, A., Larch, M., & Yotov, Y. V. (2018). *Institutions, trade and development: A quantitative analysis*. School of Economics Working Paper Series 2018–3, LeBow College of Business, Drexel University.

Brenton, P., & Chemutai, V. (2021). *The trade and climate change nexus: The urgency and opportunities for developing countries*. World Bank, Washington.

Clive, G., & Shunta, Y. (2018). *Assessing implementation of environmental provisions in regional trade agreements*. OECD trade and environment working papers 2018/01.

Copeland, B., & Taylor, S. (2003). *Trade and environment: Theory and evidence*. Princeton University Press.

Costinot, A., & Rodríguez-Clare, A. (2014). Trade theory with numbers: Quantifying the consequences of globalization. In G. Gopinath, E. Helpman, & K. S. Rogoff (Eds.), *Handbook of international economics* (Vol. IV pp. 197–261). Elsevier Ltd..

Dekle, R., Eaton, J., & Kortum, S. (2007). Unbalanced trade. *American Economic Review*, *97*(2), 351–355.

Dellink, R., Hwang, H., Lanzi, E., & Chateau, J. (2017). *International trade consequences of climate change*. OECD trade and environment working papers 2017/01.

Deryugina, T., & Hsiang, M. (2014). *Does the environment still matter? Daily temperature and income in the United States*. NBER Working Paper 20750.

Federspiel, C. C., Fisk, W. J., Price, P. N., Liu, G., Faulkner, D., Dibartolomeo, D. L., Sullivan, D. P., & Lahiff, M. (2004). Worker performance and ventilation in a call center: analyses of work performance data for registered nurses. *Indoor Air.*, *14*(8), 41–50.

Felbermayr, G., & Gröschl, J. (2013). Natural disasters and the effect of trade on income: A new panel IV approach. *European Economic Review*, *58*, 18–30.

Gassebner, M., Keck, A., & The, R. (2010). Shaken, not stirred: The impact of disasters on international trade. *Review of International Economics*, *18*(2), 351–368.

Gil-Pareja, S., Llorca-Vivero, R., & Martínez-Serrano, J. A. (2008). Assessing the enlargement and deepening of the European Union. *The World Economy*, *31*(9), 1253–1272.

Gosling, S. N., Zaherpour, J., & Ibarreta, D. (2018). *PESETA III: Climate change impacts on labour productivity*. JRC Technical Reports, European Union, https://adaptecca.es/sites/default/files/documentos/2018_jrc_pesetaiii_impact_labour_productivity.pdf

Grossman, G., & Krueger, A. B. (1992). *Environmental impacts of a north American free trade agreement*. CEPR discussion papers 644, London.

Gurevich, T., & Herman, P. (2018). *The Dynamic gravity dataset: 1948:2016*. U.S. International Trade Commission, Economics Working Paper Series, Working Paper 2018-02-A.

Hancock, P. A., Ross, J. M., & Szalma, J. L. (2007). A meta-analysis of performance response under thermal stressors human factors. *The Journal of the Human Factors and Ergonomics Society*, *49*, 851–877.

Klomp, J., & Hoogezand, B. (2018). Natural disasters and agricultural protection: A panel data analysis. *World Development*, *104*, 404–417.

Martínez-Zarzoso, I. (2018). *Assessing the effectiveness of environmental provisions in regional trade agreements: An empirical analysis*, OECD trade and environment working papers 2018/02.

Monteiro, J. A. (2016). *Provisions on Small and Medium-Sized Enterprises in Regional Trade Agreements, WTO Working Paper ERSD-2016-12*.

Nizalova, O. Y., & Murtazashvili, I. (2016). Exogenous treatment and endogenous factors: Vanishing of omitted variable bias on the interaction term. *Journal of Econometric Methods*, *5*(1), 71–77.

Onder, H. (2012). *Trade and climate change: An analytical review of key issues*. Economic Premise, 86, the World Bank, Washington, DC.

Santos Silva, J. M. C., & Tenreyro, S. (2006). The log of gravity. *The Review of Economics and Statistics.*, *88*(4), 641–658.

Simonovska, I., & Waugh, M. E. (2014). The elasticity of trade: Estimates and evidence. *Journal of International Economics*, *92*(1), 34–50.

Tinbergen, J. (1962). *Shaping the world economy*. Twentieth Century Fund.

Van Hassel, H. (2017). *Climate change and trade policy interaction: Implications of regionalism*. OECD trade and environment working papers 2017/03.

World Bank. (2010). *World development report: Development and climate change*. Washington, DC.

WTO and UNEP report. (2009). *Trade and climate change*. WTO Publications.

Yamaguchi, S. (2020a). *Greening regional trade agreements – Subsidies related to energy and environmental goods*. OECD trade and environment working papers 2020/01.

Yamaguchi, S. (2020b). *Greening regional trade agreements on investment*. OECD trade and environment working papers 2020/03.

Yamaguchi, S. (2021). *International trade and circular economy–Policy alignment*. OECD trade and environment working papers 2021/02.

Yotov, Y. V. (2012). A simple solution to the distance puzzle in international trade. *Economic Letters*, *117*(3), 794–798.

Yotov, Y. V., Piermartini, R., Monteiro, J. A., & Larch, M. (2016). *An advanced guide to trade policy analysis: The structural gravity model*. United Nations and World Trade Organization. http://vi.unctad.org/tpa/index.html

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APPENDIX A

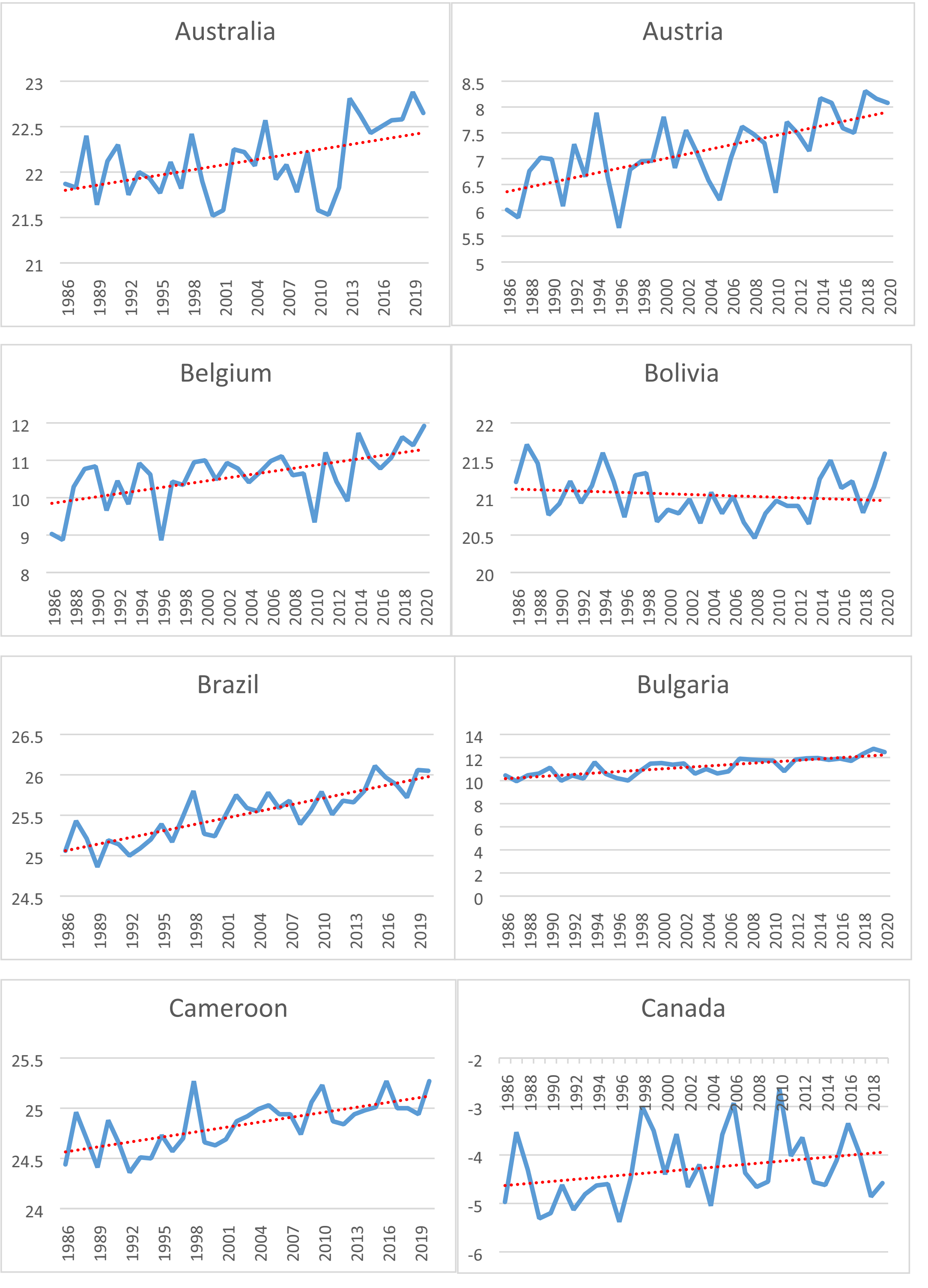
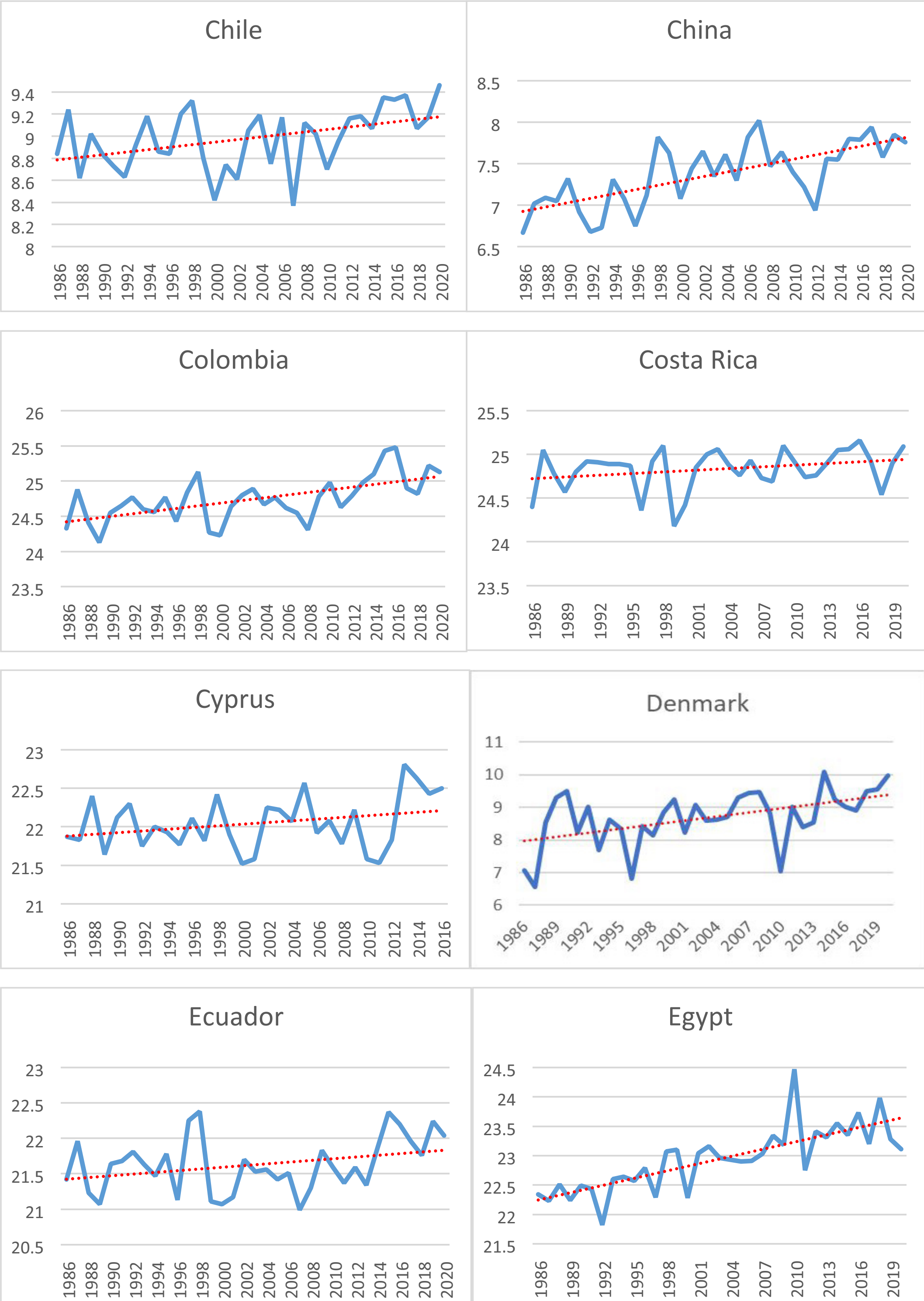


FIGURE A1 Evolution of average yearly temperature by countries. [Colour figure can be viewed at wileyonlinelibrary.com]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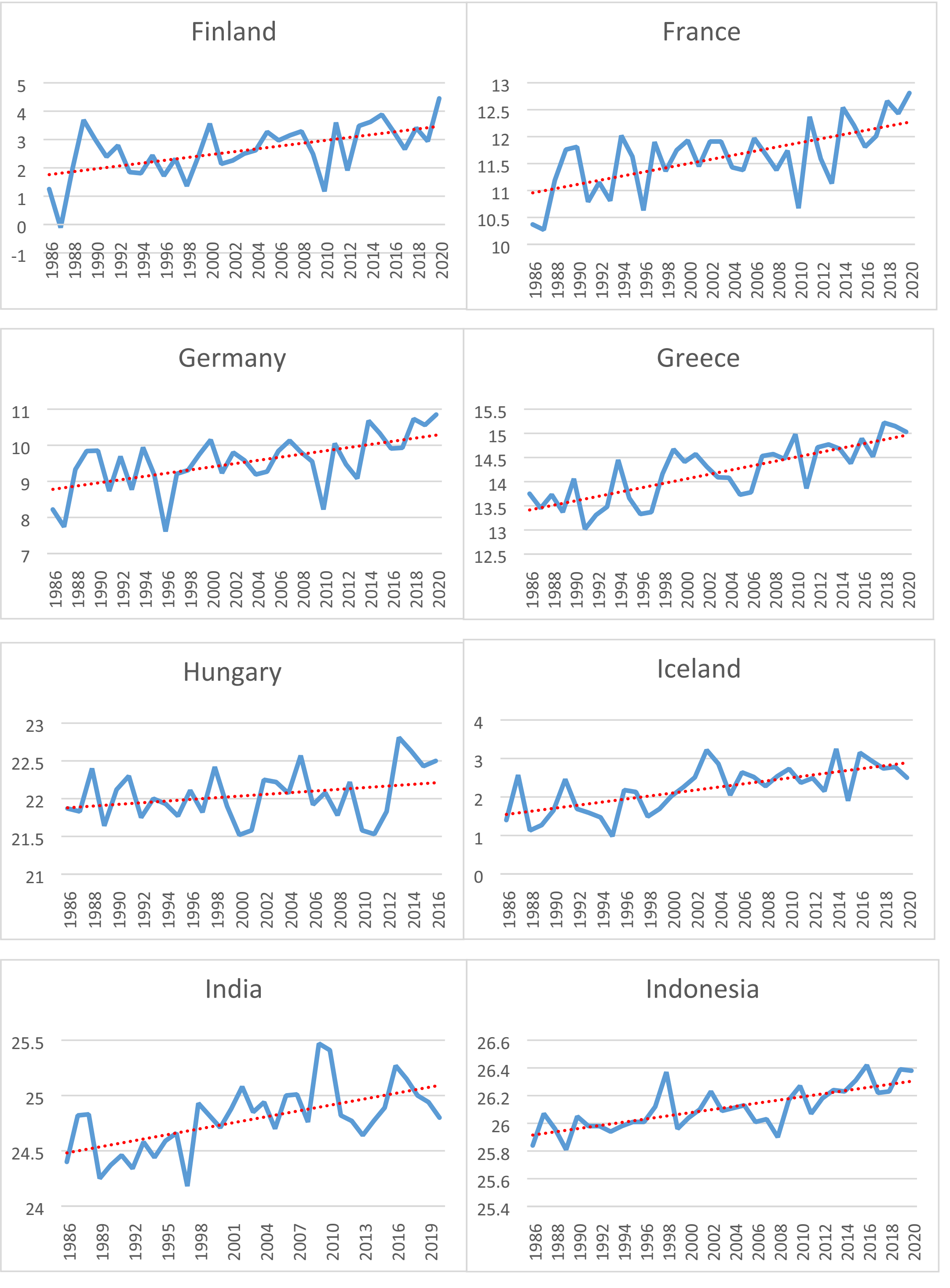
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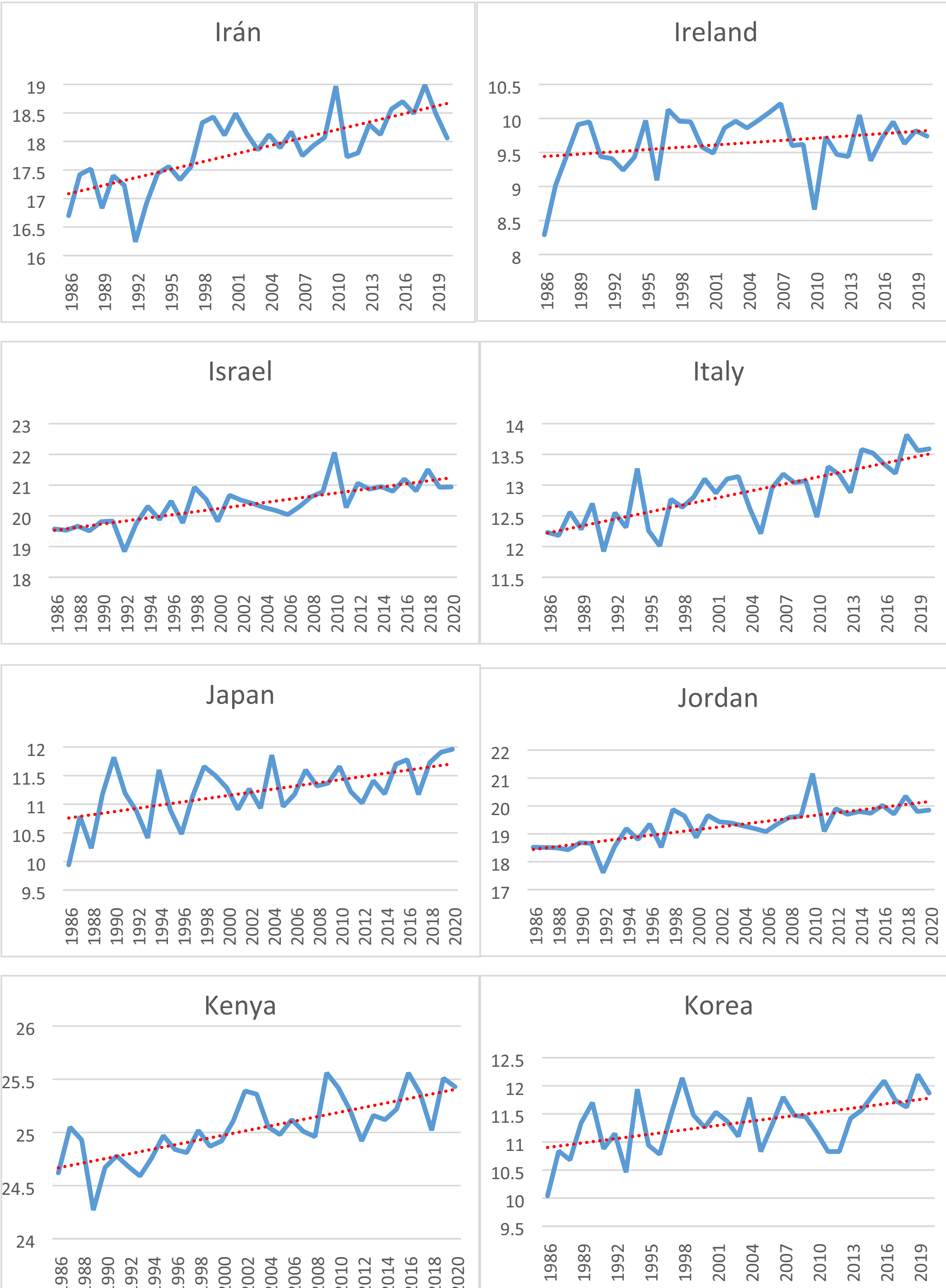
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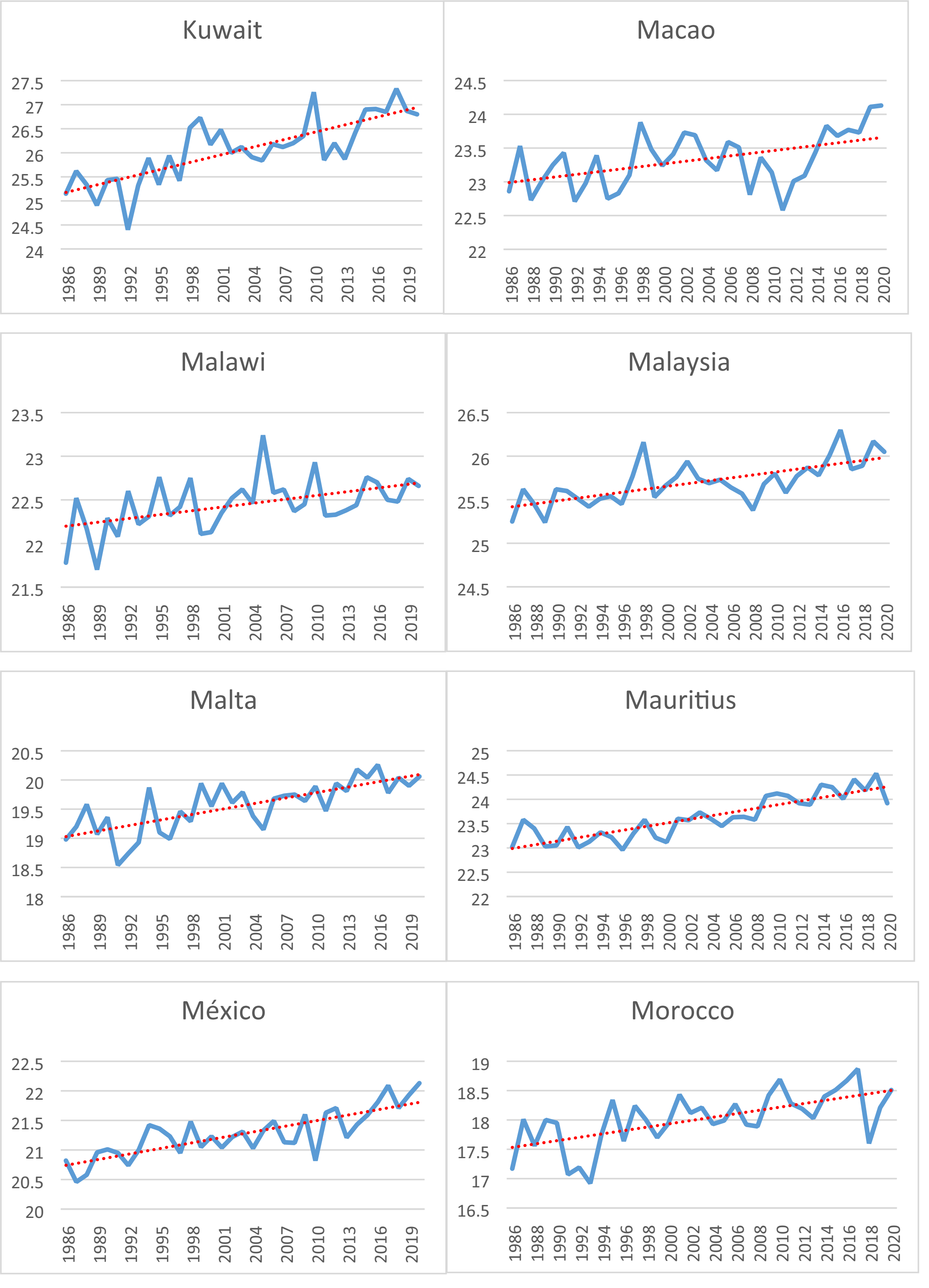
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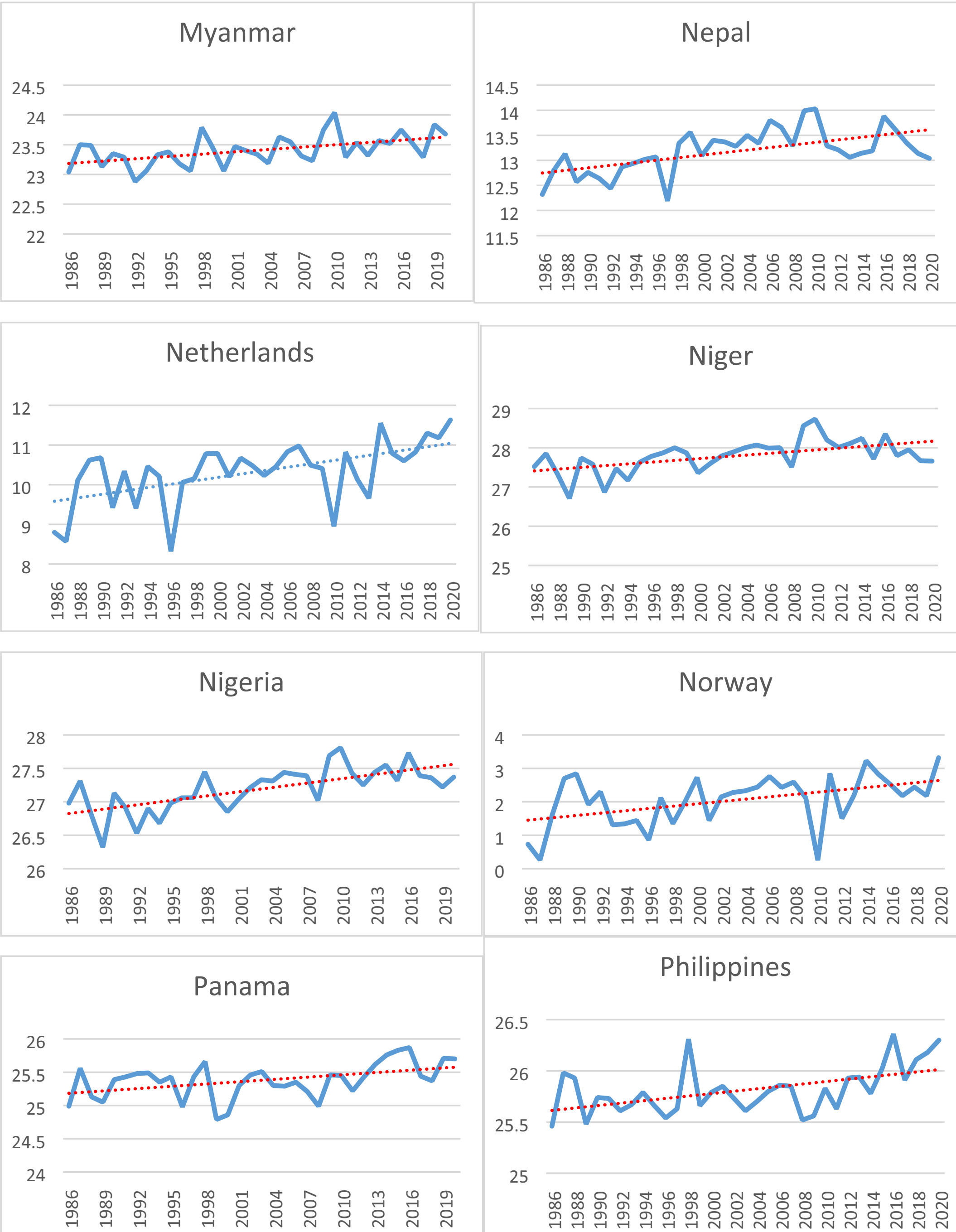
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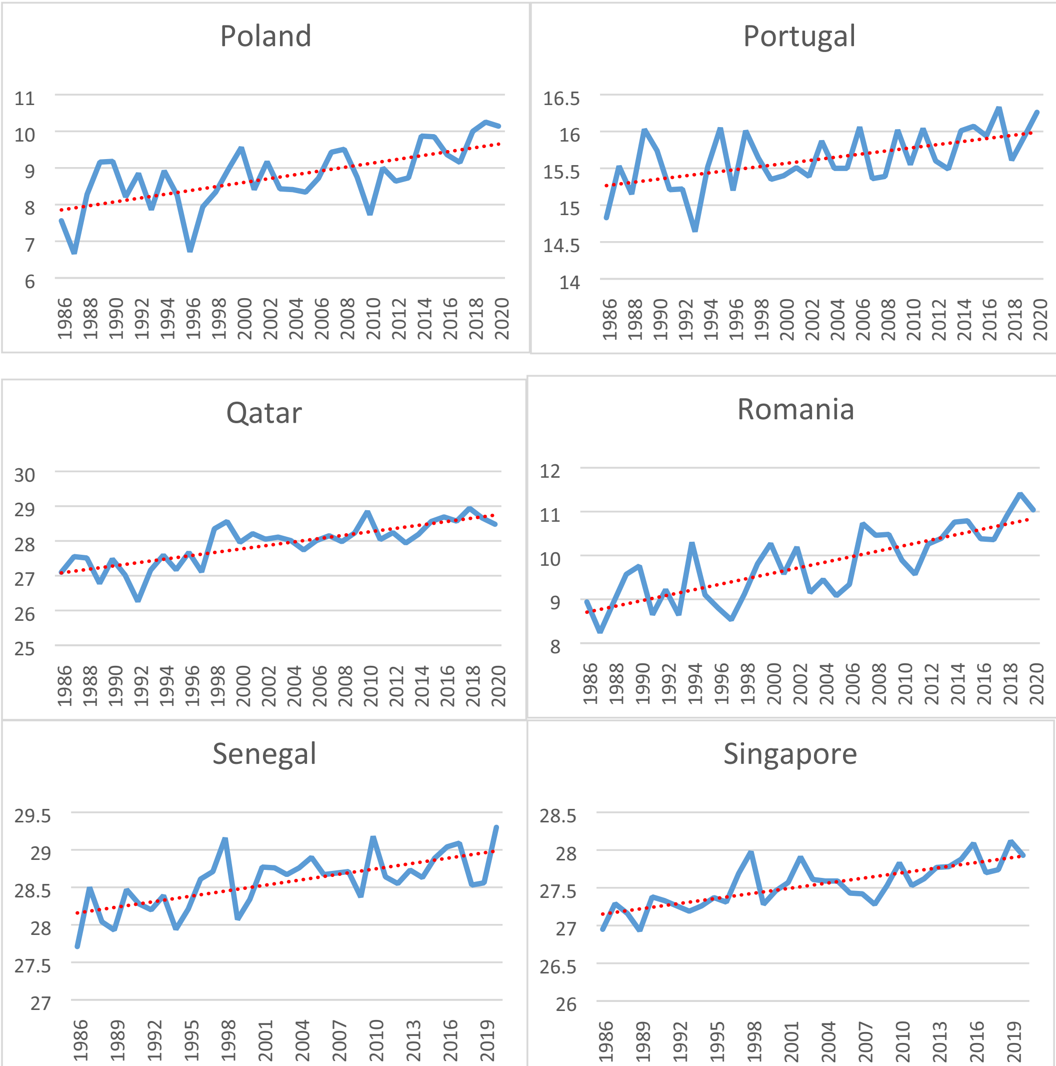
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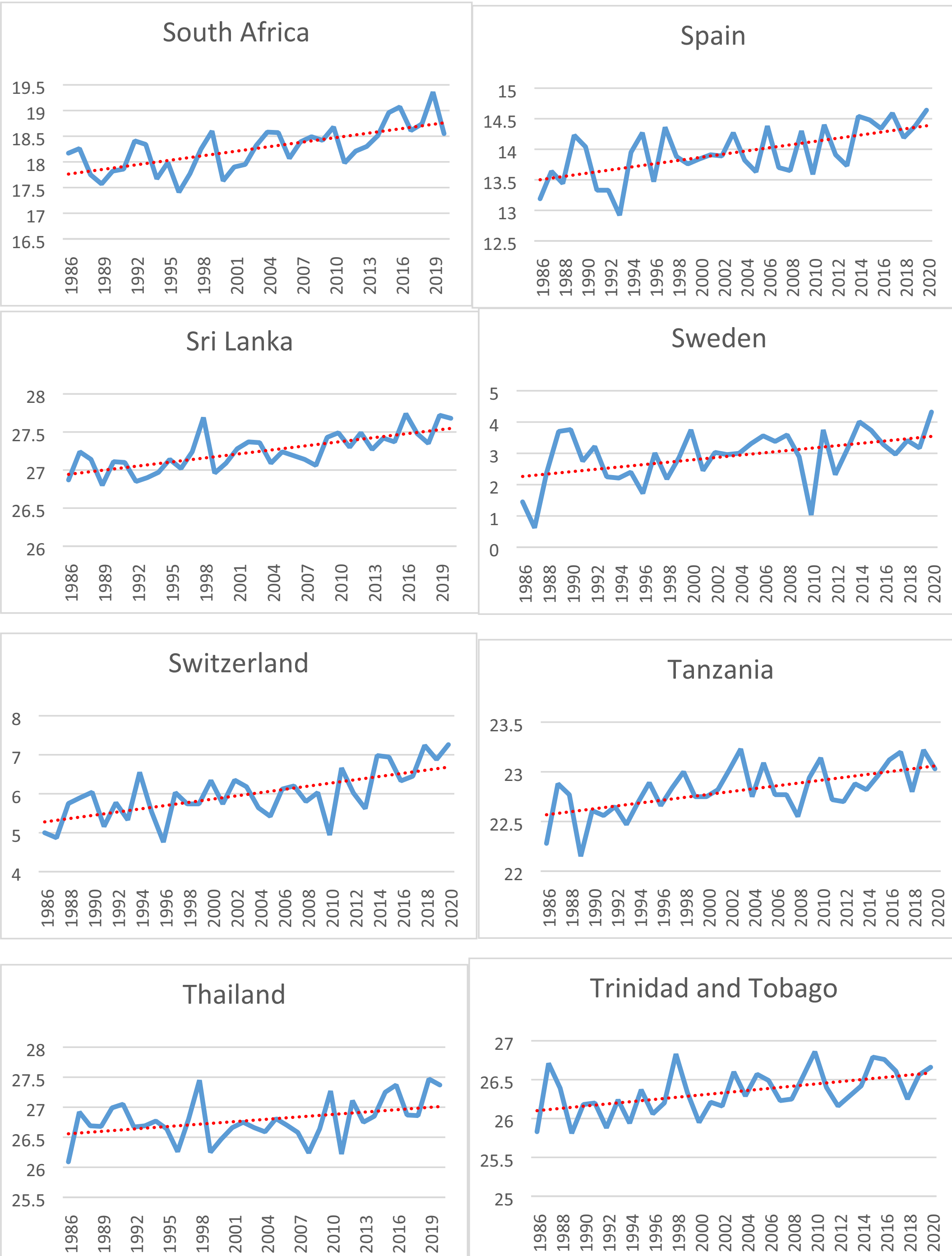
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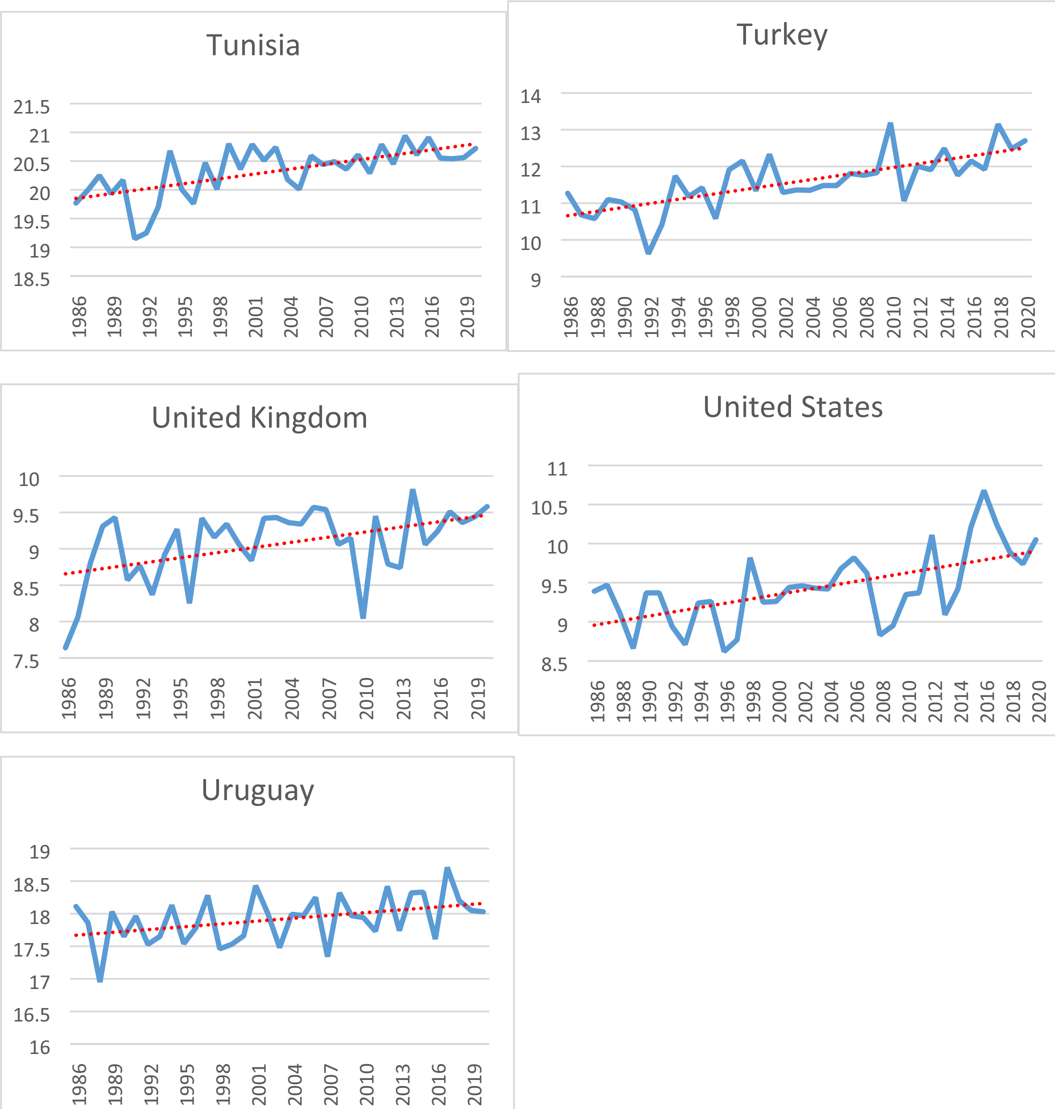
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