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DISCUSSION PAPER

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The Effects of Natural Disasters and Weather Variations on International Trade: a Review of the Empirical Literature

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The Effects of Natural Disasters and Weather Variations on International Trade: a Review of the Empirical Literature

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Abstract

This review summarizes the empirical literature on the effects of natural disasters and weather variations on international trade flows. A first result is that the body of literature is actually not as small as previously suggested. In total, I summarize 19 studies of 18 independent research teams and show that there is a large diversity in terms of motivations, data sets used, methodologies, and results. Still, some overarching conclusions can be drawn. Increases in average temperature seem to have a detrimental effect on export values (less on imports), mainly for manufactured and agricultural products. Given climate change, this is an important finding for projecting long-term developments of trade volumes. Imports seem to be less affected by temperature changes in the importing country. Findings on the effects of natural disasters are more ambiguous, but at least it can be said that exports seem to be affected negatively by occurrence and severity of disasters in the exporting country. Imports may decrease, increase, or remain unaffected by natural disasters. Regarding heterogeneous effects, small, poor, and hot countries with low degrees of institutional quality and political freedom seem to face the most detrimental effects on their trade flows. Possible directions of future research include analyzing spillover effects in-depth (in terms of time, space, and trade networks), considering adaptation, and using more granular data.

Keywords: International Trade; Climate Change, Natural Disasters.

JEL-Classification: Q17, Q54, Q56, F14, F18

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Introduction

This review summarizes the empirical literature on the effects of natural disasters and weather variations on international trade flows. The volume of international trade flows has increased in absolute terms and relative to GDP in the last decades, as illustrated by Figure 1. In 2017, 24 percent of the global production was exported across borders. Nowadays, many production processes are embedded in international supply chain networks and would not be feasible without an intensive transboundary exchange of goods and services (Dietzenbacher et al. 2012, Hummels et al. 2001). Consequently, international trade is perceived as a driver of economic growth, welfare, political freedom, security, and technological innovation.

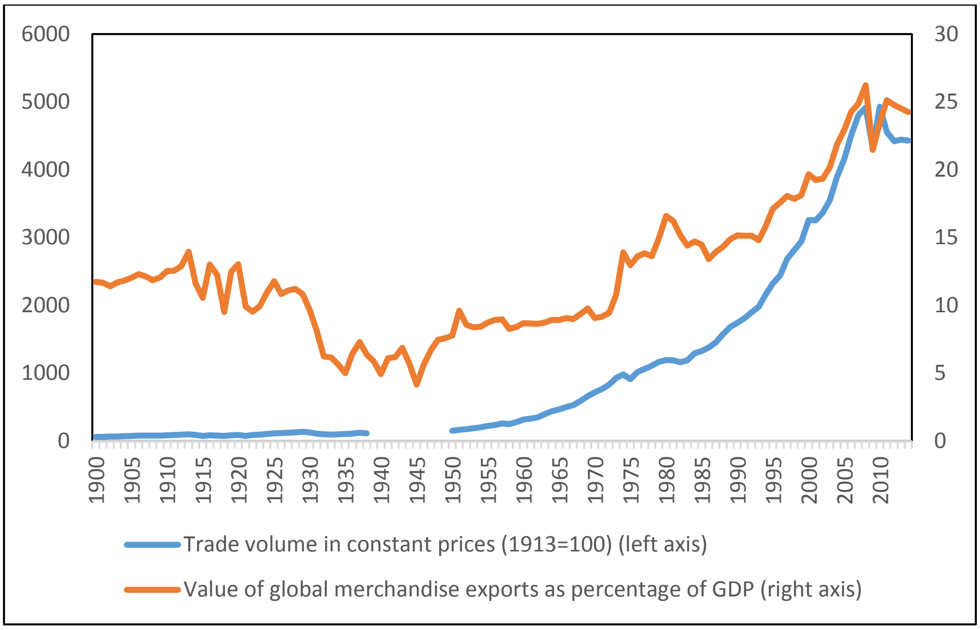

Figure 1: Global trade volume (in absolute terms and relative to GDP) from 1900 to 2014. Source: Ortiz-Ospina et al. 2018 and the data sources cited there.

Given the high relevance of international trade, the quantitative analysis of possible effects of natural disasters and weather variations on trade is an interesting research question *per se*. Climate change, manifested by higher temperatures, changed precipitation patterns, and more frequent and more severe extreme weather events, will further increase the relevance of the topic (IPCC 2012). Natural disasters and weather variations may affect trade flows via different channels: Disasters can physically destroy transport infrastructure such as ports, container terminals, road or railway connections, thereby raising trade costs. Disasters and weather variations can affect production (mainly of the agricultural and manufacturing sectors), and consequently the supply of tradable goods. If income is affected by weather variations or disasters, the demand for imports may change. Furthermore, imports of small developing countries may increase after a major natural disaster as a result of large inflows of external aid.

In this context, there is an emerging strand of empirical economic literature which aims to identify and quantify the effects of natural disasters, weather and climatic changes on international trade flows.[1] In this review, I report the main conclusions, most important data sets, and empirical methods of

[1] There are related bodies of empirical literature which analyze disaster or climate effects on economic growth (e.g. Cavallo et al. 2013; Noy 2009), migration (Boustan et al. 2012, Marchiori et al. 2012), or conflicts (Slettebak 2012). In this review, I focus on the effects on trade flows.

relevant studies from the grey and peer-reviewed literature. To the best of my knowledge, the review takes account of all publicly available studies that meet the following criteria:

1. The study is an ex-post analysis.
2. The analysis focusses on international trade flows as the dependent variable.
3. The estimation includes dimensions of natural disasters or weather variations as an explaining variable.
4. The analysis is not restricted to a single event.

Many of these studies include brief literature reviews themselves, and mostly it is stated that the empirical literature on the effects on trade in question is extremely sparse. In fact, the number of referenced previous studies ranges from zero to four. In contrast to these assessments and quite surprisingly, the present review shows that the number of studies meeting the abovementioned criteria is actually not that small, but amounts to at least 19 papers published since 2008.[2] These studies can be deemed as reasonably independent from each other, as just one scholar (co-)authored more than one study (Chang Hoon Oh contributed to two papers). The existing literature is relatively diverse in terms of regional and temporal coverage, data sets used, disaster and weather definitions, methodologies, and main conclusions, as shown in the remainder of this review.

The motivations of the summarized papers are just as diverse as their data and methodology. First and foremost, the mere relevance of international trade for modern economies and societies, alongside with ongoing climate change, is the main motivation for the outlined research question. From a climate change perspective, it is well acknowledged that even if the largest and richest economies of the world were relatively resilient towards the direct (domestic) effects of global warming and natural disasters, they could be severely affected by climate change or disaster impacts on their trade partners, and this indirect effect could even exceed direct effects (Freeman & Guzman 2009, Knittel et al. 2018, Schenker 2013, U.S. Global Change Research Program 2018). For the urgently-needed quantitative analysis of this potential channel of climate impacts, it is an interesting question whether trade flow effects of climatic events or changes are indeed already observable in *ex-post* analyses and how large they are.

Furthermore, there is a range of more specific motivations behind the reviewed studies: Some authors focus on developing countries because for many of these small economies exports and imports are crucial for their economic development (Andrada da Silva & Cernat 2012, Cuaresma et al. 2008, El Hadri et al. 2018, Heger et al. 2008, Lee et al. 2018, Pascasio et al. 2014). Another motivation is the usage of trade data (which is often reported by international agencies or customs authorities) as an arguably more reliable and detailed measure of economic activity than national indicators such as GDP, which is reported by the country itself (Hsiang & Jina 2014, Jones & Olken 2010, Li et al. 2015). Moreover, some studies focus on the role of institutions and political indicators for the resilience towards natural disasters (Gassebner et al. 2010, Oh & Reuveny 2010). Cuaresma et al. (2008) and Pelli & Tschopp (2017) raise the question whether natural disasters may induce technological change via a build-back better effect and use product-specific trade data to test their hypotheses. Finally, some more isolated motivational settings include the analysis of temporal and spatial displacement of trade flows and the substitutability of ports in the USA (Sytsma 2018a), the disentangling of the total disaster effect on trade into partial effects (El Hadri et al. 2018), and an analysis of economic impacts of hurricanes in a historical setting (Mohan & Strobl 2013).

In the following review, I first summarize the main characteristics of the 19 studies, present the datasets on trade, weather variations, natural disasters, and other covariates used in these studies, discuss the estimation methods, and synthesize the main conclusions of the reviewed papers. In the

[2] This may partly be explained by the fact that not every author is citing grey literature.

concluding section, I define some common challenges and knowledge gaps of the thematic field and suggest directions for future research.

Overview of studies

Since 2008, at least 19 studies have been published assessing *ex-post* the effects of climatic changes or natural disasters on international trade. Eleven of them have been published in peer-reviewed journals, of which eight are associated to economics. Spatially, some papers focus on developing countries, geographical regions, or single countries, while nine studies include all parts of the world (only restricted by data availability). In case of spatially focused studies, the selection of countries is motivated by high trade dependencies or high disaster exposure. Regarding the temporal coverage, all studies but one cover as many and recent time periods as possible. The other one analyzes historical data of the 18th and 19th century. While most analyses rely on annual data, a few recent publications introduce monthly estimations. Table 1 presents an overview of the studies included in this review.

Table 1: Overview of included studies (ordered by publication date)

Study	Spatial coverage	Temporal coverage	Sectoral coverage	Journal
Cuaresma et al. (2008)	Exports from five industrialized countries to 49 developing countries	1976-1990 annual	Manufacturing industry	Economic Inquiry
Heger et al. (2008)	Exports and Imports of 16 Caribbean countries	1970-2005 annual	All sectors	*Not peer-reviewed*
Gassebner et al. (2010)	Bilateral trade of 170 countries	1962-2004 annual	All sectors	Review of International Economics
Jones & Olken (2010)	Global, exports to the USA and to the world	1973-2001 annual	All sectors	American Economic Review: Papers & Proceedings
Oh & Reuveny (2010)	Bilateral trade of 116 countries	1985-2003 annual	All sectors	Global Environmental Change
Andrada da Silva & Cernat (2012)	Exports of 41 developing countries to OECD countries	1988-2010 quarterly	All sectors	*Not peer-reviewed*
Felbermayr & Gröschl (2013)	Bilateral trade of 162 countries	1950-2008 annual	All sectors	European Economic Review
Mohan & Strobl (2013)	Exports of 21 Caribbean colonies/countries	1700-1960 annual	Only sugar	Weather, Climate, and Society
Pascasio et al. (2014)	Trade of the Philippines	1991-2009 annual	All sectors	*Not peer-reviewed*
Hsiang & Jina (2014)	Global, exports to and imports from the world	1950-2008 annual	All sectors	*Not peer-reviewed*
Li et al. (2015)	Exports and imports of 31 Chinese cities	2000-2011 annual	All sectors	Economics Letters
Oh (2017)	Bilateral trade volume of 53 countries	1984-1998 annual	All sectors	Journal of Risk Research
Pelli & Tschopp (2017)	Exports of 46 countries to the USA	1980-2000 annual	Manufacturing industry	Journal of International Economics
Lee et al. (2018)	Trade balance of 12 Pacific island countries	1980-2016 annual	All sectors	*Not peer-reviewed*
Sytsma (2018a)	Trade of 72 ports in Eastern USA	2003-2015 monthly	All sectors	*Not peer-reviewed*
Barua & Valenzuela (2018)	Exports of 67 countries	1962-2014 annual	Agriculture	*Not peer-reviewed*
El Hadri et al. (2018)	Exports of 74 small developing countries	1995-2010 annual	Agriculture	*Not peer-reviewed*
Dallmann (2019)	Bilateral trade of 134 countries, without small and island countries	1992-2014 annual	All sectors	Environmental and Resource Economics
Tembata & Takeuchi (forthcoming)	Exports of four Southeast Asian countries	2004-2016 monthly	All sectors	Economics of Disasters and Climate Change

Data and methods

Trade data

Analyzing quantitative effects on “international trade” is by no means straightforward, as trade may be operationalized in very different ways (see Table 2). Most studies use bilateral trade flows as the dependent variable, hence they differentiate along the exporter *and* importer dimension. However, depending on the concrete research question, it may suffice to look at the aggregate trade flows of a country to “the world”, or to one specific country. Some scholars restrict their analysis to trade flows included in national databases, due to data quality concerns (Jones & Olken 2010). Consequently, they only consider trade flows which are either imports or exports of the given country. Some studies estimate changes in trade variables (Heger et al. 2008, Hsiang & Jina 2014, Jones & Olken 2010, Lee et al. 2018, Pascasio et al. 2014), while the majority uses level data.

Table 2: Different measures of international trade, studies on weather and natural disasters

Formulation of trade	**Example**	**Studies focusing on effects of …**	
		… slow onset weather effects (temperature and precipitation)	**… natural disasters**
Bilateral trade	Trade volume from exporter *j* to importer *i*	Dallmann 2019	Andrada da Silva & Cernat 2012 El Hadri et al. 2018 Felbermayr & Gröschl 2013 Gassebner et al. 2010 Oh & Reuveny 2010 Tembata & Takeuchi (forthcoming)
Bidirectional bilateral trade	Aggregate trade volume (in both directions) between two countries	---	Oh 2017
Trade to one specific importer	Trade volume from exporter *j* to the USA	Jones & Olken 2010 Pascasio et al. 2014	Pelli & Tschopp 2017
Aggregate exports to the world	Trade volume from exporter *j* to the world	Barua & Valenzuela 2018 Jones & Olken 2010 Li et al. 2015[a]	Heger et al. 2008 Hsiang & Jina 2014 Mohan & Strobl 2013 Sytsma 2018a
Trade from one specific exporter	Trade volume from the Philippines to importer *i*	Pascasio et al. 2014	Cuaresma et al. 2008
Aggregate imports from the world	Trade volume from the world to importer *i*	Li et al. 2015[a]	Heger et al. 2008 Hsiang & Jina 2014
Trade balance relative to GDP	(Exports – imports)/GDP of country *i*	---	Lee et al. 2018

[a)] Li et al. 2015 include also humidity and sunshine.

Given the formulation of trade, the level of observations ranges from very granular observations (e.g. value of product k traded from exporter *j* to importer *i* in time *t*) to more aggregate units (e.g. total imports to country *i* in time *t*).

The data sources of bilateral trade data which are currently maintained are summarized in Table 3. It becomes apparent that most of the available data is based on data collection efforts of the United Nations Statistics Division (UN Comtrade). Some data sources reconcile these original data (e.g., by estimating and deducting freight and insurance costs, adding missing data), or complement it with data from national and regional sources. Beside those data sets, there are national trade statistics (focusing on trade flows of a specific nation), data sets without bilateral resolution, hence only displaying aggregate exports and imports of countries (e.g. IMF World Economic Outlook[3], NBER Trade Data[4], World Development Indicators[5]), and some datasets which are seemingly not updated any more (e.g. Feenstra et al. 2002, Feenstra et al. 2005, World Trade Analyzer).

Table 3: Currently maintained data sources of bilateral international trade flows

Name of the dataset	**Access**	**Temporal coverage and highest resolution**	**Sectoral or product classification**	**Remarks**
UN Comtrade	https://comtrade.un.org/	1900 onwards, monthly	SITC and HS	
IMF Directions of Trade	http://data.imf.org/?sk=9D6028D4-F14A-464C-A2F2-59B2CD424B85	1947 onwards, monthly	No sectoral disaggregation	
CEPII's BACI	http://www.cepii.fr/CEPII/en/bdd_modele/presentation.asp?id=1	1995 onwards, annually	6-digit HS	Based on UN Comtrade
OECD International Trade by Commodity	https://www.oecd-ilibrary.org/trade/data/international-trade-by-commodity-statistics_itcs-data-en	1961 onwards, quarterly	SITC and HS	Based on UN Comtrade
International Trade Centre	http://www.intracen.org/itc/market-info-tools/trade-statistics/	2001 onwards, monthly	6-digit HS	Based on UN Comtrade

Abbreviations for product classifications: HS – Harmonized System; SITC – Standard International Trade Classification

Weather and disaster data

Broadly spoken, the presented studies can be divided into two strands of literature, which are relatively independent from each other: The first one covering slow onset weather effects, the second one focusing on natural disaster effects on trade. Table 2 depicts the focus of the studies, showing that a majority of 14 out of 19 publications analyze trade effects of natural disasters.

Concerning the concrete formulation of weather variables, all authors use the (population-weighted) average annual temperature and precipitation of the trading countries or cities. Dallmann (2019) also studies effects of temperature and precipitation differences between the trade partners, arguing that relative differences between the weather shocks may affect productivity differences, and hence trade flows. The exclusive usage of annual weather data (instead of temporally more disaggregated data) implies that possible intra-annual variations are not yet exploited in this branch of the literature. In contrast, El Hadri et al. (2018) show for the case of natural disasters, that disasters are only harmful for agricultural exports if they hit the exporter during the growing season of its main crop. Concerning temperature and precipitation effects on trade, there no study yet using season-specific weather data. Weather data are available at the grid cell level (mostly 0.5°*0.5°), in different temporal resolutions and downloadable from various climate data repositories (e.g., the University of East Anglia's Climate Research Unit (CRU), CRU TS3.21 database). In general, the operationalization of weather is relatively uniform in this strand of literature.[6]

On the other side, the 14 studies on natural disaster effects come up with more than 14 approaches for measuring natural disasters or their severity, depending on their concrete research question and data availability. These approaches can be grouped into three categories, depending on how much

[3] https://www.imf.org/external/pubs/ft/weo/2018/01/weodata/download.aspx
[4] http://www.nber.org/data/
[5] https://datacatalog.worldbank.org/dataset/world-development-indicators
[6] Applications, opportunities and methodological challenges of the estimation of climate variables on economic outcomes are also summarized in two survey articles (Auffhammer et al. 2013, Dell et al. 2014).

importance the authors place on the exogenous character of the disaster variable. The first group of studies uses purely physical measures of disasters such as hurricane wind speeds or earthquake magnitudes (El Hadri et al. 2018, Hsiang & Jina 2014, Pelli & Tschopp 2017, Sytsma 2018a). The second group is a relatively large body of literature which bases its research on the widely-used international disaster database of the Centre for Research on the Epidemiology of Disasters (EM-DAT). EM-DAT includes information on occurrence and impacts of natural and man-made disasters since 1900. Despite its unquestioned strengths in terms of temporal and regional coverage, the data set implies some methodological challenges, in particular for economic analyses. An event is classified as a disaster and enters the database if its socioeconomic impacts surpass certain thresholds. This was criticized because the probability that an event is acknowledged as a disaster depends on a country's socioeconomic variables (Felbermayr & Gröschl 2014). Hence there is a selection bias, and the events are not completely exogenous. Some authors try to mitigate this problem by focusing on severe disasters (Andrada da Silva & Cernat 2012, Gassebner et al. 2010, Lee et al. 2018), disaster measures which are apparently orthogonal to economic activities (Felbermayr & Gröschl 2013), and the mere occurrences and number of disasters instead of severity measures (El Hadri et al. 2018, Mohan & Strobl 2013, Oh 2017, Oh & Reuveny 2010, Tembata and Takeuchi (forthcoming)). Several authors argue that the physical size of the country should be taken into account and estimate the effects of disasters per km^2 (Cuaresma et al. 2008, Gassebner et al. 2010). Finally, Heger et al. (2008) is the only study in the third category, using economic impacts (damage) of natural disasters in the main analysis. Since the economic damage of disasters and their effects on trade may be affected by the same characteristics of a country – e.g. degree of resilience – this approach should be subject to endogeneity concerns.

Besides EM-DAT, the sources for natural disaster data include the ifo GAME dataset[7], including intensity scores of geological and meteorological events (Felbermayr & Gröschl 2014), and several sources for locations and wind speed of tropical storms (Hsiang & Jina 2014, Yang 2008, National Hurricane Center's ''best track'' dataset[8]).

Control variables and heterogeneous effects

Depending on the empirical strategy, different covariates may be included in the estimation. First let us consider data on the country-year level. Most gravity regressions include the GDP or the GDP per capita of the trading countries. Focusing on agricultural trade, Barua & Valenzuela (2018) and El Hadri et al. (2018) extend the usual gravity equation with measures of productivity in the agricultural sector. A number of studies includes indicators of institutional quality or political freedom (Gassebner et al. 2010, Oh & Reuveny 2010). Time-invariant characteristics such as latitude or geographical size are normally controlled for by country-fixed effects. The second set of covariates captures variables at the country-pair-level. These include free trade agreements and other trade policy indicators, the geographical or economic distance between trade partners, the product of both countries' GDPs, adjacency, common historical relationships, common culture and language, and multilateral remoteness[9] indicators. However, instead of including numerous time-invariant characteristics of country-pairs, many studies use the panel dimension and estimate fixed effects for country-pairs.

Many authors are interested in heterogeneities in the effects of weather or natural disasters on trade flows and include interaction terms or divide the sample into subsamples. Twelve out of 19 studies mention heterogeneous results as part of their baseline results, sometimes as the central result (the

[7] https://www.cesifo-group.de/ifoHome/facts/EBDC/Ifo-Research-Data/Ifo_GAME_Dataset.html.
[8] https://www.nhc.noaa.gov/data/#hurdat
[9] The concept of multilateral remoteness takes into account that not only the simple trade costs between trade partners matters, but also the relative trade costs compared to other potential partners.

section "Results" summarizes some of these conclusions). Typical sources of heterogeneity are geographical and economic preconditions of the affected country or city, and the quality of institutions.

Estimation methodologies

The regression models employed in the reviewed studies are as diverse as the formulation of dependent variables and levels of observation. Mostly, the underlying estimation method is a fixed effects panel estimator. However, the source of fixed effects differs dramatically (time, country, country-pair, industry, industry-by-time, country-by-time, country-by-industry, country- or industry-specific time trends …). The same applies to the estimation of standard errors, which are clustered at various units. Another aspect is the treatment of zero-trade flows, which becomes particularly relevant for very granular observations on the product level, and for large panel data of bilateral trade flows. Depending on the level of observation, the majority of trade flows in the data may actually be zero. However, if trade flows are log-transformed for the estimation, the zero-trade flows are omitted. Indeed, most available studies seem to omit this considerable data portion, and do not use the full information available in the data (Helpman et al. 2008). The only two exceptions which explicitly tackle this issue employ versions of the Pseudo Poisson Maximum Likelihood (PPML) Estimator proposed by Santos Silva & Tenreyro (2006) to account for zero-trade flows (Dallmann 2019, Felbermayr & Gröschl 2013).

Regarding the estimation of heterogeneity across economic sectors or product categories, there are three broad categories describing how sector-specific results are obtained. First, authors restrict the total analysis on the sector(s) of interest (Barua & Valenzuela 2018, Cuaresma et al. 2008, El Hadri et al. 2018, Mohan & Strobl 2013). Second, they repeat the baseline estimation for different subsamples defined by sectoral trade (Barua & Valenzuela 2018, Dallmann 2019, Jones & Olken 2010, Oh 2017[10], Pascasio et al. 2014, Tembata & Takeuchi (forthcoming)). Third, they employ estimations at a level of observation which includes sector or product categories (e.g., at the sector-countrypair-year-level) (El Hadri et al. 2018, Jones & Olken 2010, Li et al. 2015, Pascasio et al. 2014, Pelli & Tschopp 2017).

The diversity regarding dependent variables, covariates, and estimation methods suggests that there is currently no methodology which is widely-accepted as the state-of-the-art for estimating gravity style regressions related to natural disaster or weather effects. There are also no clear differences between peer-reviewed papers and the grey literature in this regard. For bilateral trade flows, however, the PPML approach is definitely a step forward, at least if zero-trade flows are important.

Results

General effects (no interaction effects)

Given the diversity of the concrete formulation of trade flows, disaster variables and estimation methodologies, a summary of the main findings of the reviewed studies is not straightforward. Table 4 summarizes the baseline results. It is important to note that only results for the full samples, without any subsample analyses or interaction effects, are included.

By tendency, the literature finds negative effects of temperature increases on exports. A very robust result is that agricultural exports are particularly affected. Apparently, high temperature shocks are detrimental to economic activity (mainly in the agricultural sector), and ultimately decreases the supply of tradable goods. Imports, however, seem to be less responsive to temperature shocks. Regarding precipitation, there are ambiguous results ranging from negative effects on both kinds of trade flows to positive effects on exports. While higher precipitation may be beneficial for the growing

[10] The study of Oh (2017) is unique in using the BEA (Bureau of Economic Analysis) industry classification. Other studies use SITC or HS product classifications.

of some agricultural products, intensive rainfall may also result in flood events which can affect production processes negatively.

Turning to the effects of natural disasters, the body of literature yields partly contradicting results as well. What can be concluded is that total exports do not seem to benefit from natural disaster occurrence.[11] The decline of exports is mostly reasoned by the production losses caused by the disaster, while some authors also mention destroyed transport infrastructure as a possible impact channel. Imports, however, may decrease, be unaffected, or increase after a natural disaster struck the importer. Decreases are reasoned by income effects: If available income declines after a natural disaster, the demand for imported goods follows (Hsiang & Jina 2014). Obviously, interruptions of transport networks may be relevant for the decline of imports as well. Increases of imports are partly interpreted as the inflow of external aid after the disaster – this notion is supported by some of the interaction effects presented in the next sub-section.

Sector-specific results are only reported in a minority of the natural disaster studies. El Hadri et al. (2018) and Mohan & Strobl (2013) focus on exports of agricultural goods, and find mixed results. Tembata and Takeuchi (forthcoming) report relatively larger effects of floods and storms on agricultural exports than on manufactured exports. In contrast, Oh (2017) finds significant positive effects on agricultural trade if both trade partners experience a natural disaster, while most other industries are negatively affected. Also Pelli & Tschopp (2017) differentiate between economic sectors, focusing on their comparative advantage. These results are presented in the next sub-section.

[11] If positive effects are obtained, they refer to export per GDP ratios. However, the GDP may be negatively affected by natural disasters, resulting in a positive effect on the export per GDP ratio (Heger et al. 2008).

*Table 4: Baseline findings of the reviewed studies (without interaction effects, without sectoral or regional subsamples, etc.). Red shaded cells signal negative effects, green-shaded cells mark positive effects. The stars *, **, *** refer to significance levels of 10, 5, and 1 percent, respectively. Studies notated in bold letters are peer-reviewed.*

Weather or natural disaster	Definition of weather or disaster variable [a]	Effect on exports	Effect on imports	Study
Temperature	Temperature increase (+1°C)	-1.6%**		Barua & Valenzuela 2018
		-3.0%** [b, d]	n.s.	**Dallmann 2019**
		-5.7%*** [d]		**Jones & Olken 2010** (only poor countries)
		-12.6%**	n.s.	**Li et al. 2015**
		-10.5%*** [d]	-3.7%** [d]	Pascasio et al. 2014
Precipitation	Precipitation increase (+100 mm)	n.s.		Barua & Valenzuela 2018
		-10.3%**	-11.7%***	**Dallmann 2019**
		n.s.		**Jones & Olken 2010**
		+1.8*	n.s.	**Li et al. 2015**
		n.s.	n.s.	Pascasio et al. 2014
Sunshine	Sunshine duration in h	n.s.	n.s.	**Li et al. 2015**
Humidity	Relative humidity in %	n.s.	n.s.	**Li et al. 2015**
Occurrence or severity of natural disaster	Number of disasters	n.s.	+2.0**	**Felbermayr & Gröschl 2013**
		Relative to GDP: +1.1 percentage points * [c]	Relative to GDP: +2.0 percentage points ***	Heger et al. 2008
		-68.1% [b]		**Mohan & Strobl 2013** (only sugar)
		-0.6%**	-2.7***	**Oh & Reuveny 2010**
	ln(number of disasters + 1)	n.s.		El Hadri et al. 2018
	Number of disasters per km²		-0.7%** [b]	**Cuaresma et al. 2008**
		-2.1%***	n.s.	**Gassebner et al. 2010**
	Disaster occurrence (binary)	-9.0%*** [b]		Andrada da Silva & Cernat 2012
		n.s.	Relative to GDP: +4.5 percentage points *	Lee et al. 2018
		-5.0%** [b, d]		**Tembata & Takeuchi (forthcoming)**
	Disaster occurrence in one of the trading countries (binary)	Total bilateral trade: -4.1%**		**Oh 2017**
	Wind speed of tropical cyclones in m/second	n.s.	0 to -0.5% * [b]	Hsiang & Jina 2014
		-0.6%** [b]	n.s.	Sytsma 2018a
	Hurricane destruction index	n.s.		**Pelli & Tschopp 2017**

a) Especially for disaster variables, the exact definitions used in the studies may deviate strongly from each other.

b) Effect is persistent over several time periods.

c) Effect is reversed in the following time periods.

d) Especially for agricultural and manufacturing sectors.

Interaction effects

The wide variance of qualitative results, not to speak of quantitative estimates, calls for a deeper investigation of the heterogeneities behind these results. This is often done via the estimation of interaction effects and subsamples. Many studies assess potential sources of heterogeneity, and some quite robust relationships emerge:

Trade flows (imports and exports) are more negatively affected if the disaster hits countries with low-quality institutions or low levels of political freedom (Dallmann 2019, Gassebner et al. 2010, Oh & Reuveny 2010). The reason given for this is resilience or a lack of it. Well-functioning institutions may be conducive to an economy which is relatively resilient towards natural disasters and climatic changes. Relatedly, effects on imports and exports are more negative in relatively poor economies (Barua & Valenzuela 2018, Cuaresma et al. 2008, Jones & Olken 2010, Li et al. 2015), although Pascasio et al. (2014) do not find this effect. Furthermore, geographically small countries and exporters which are located close to the equator or in relatively hot climate face more negative effects on trade flows (Andrada da Silva & Cernat 2012, Dallmann 2019, Gassebner et al. 2010, Li et al. 2015). Some studies suggest that negative effects of high temperature are more pronounced for trade pairs with high initial trade costs (Dallmann 2019, Li et al. 2015), but for natural disasters this interaction effect is not confirmed (Felbermayr & Gröschl 2013).

Beside these relatively robust interaction effects, some studies introduce quite unique interaction effects, motivated by their particular research questions. Pelli & Tschopp (2017) show that hurricanes decrease exports only for industries with low comparative advantage, while they may even increase exports of very competitive industries. The authors conclude that hurricanes, by destroying capital of partly non-competitive industries, induce firms to invest in new technologies in the reconstruction process after hurricanes. In a sense, hurricanes unexpectedly reduce the costs of technological transformation. El Hadri et al. (2018) show that natural disasters only affect agricultural exports negatively if they hit rural areas and occur during the respective growing seasons. Moreover, they suggest that exports to culturally close trade partners do not decline but even increase after natural disasters hitting the exporter – a finding which is interpreted as "solidarity-consistent effect".

Conclusions and research gaps

This review of empirical literature on trade effects of natural disasters and weather variations demonstrates that the body of literature is actually not as small as suggested by existing reviews. In total, I summarize 19 studies of 18 independent researcher teams and show that there is a large diversity in terms of motivations, data sets used, methodologies, and results.

Still, some overarching conclusions can be drawn which are at least not contradictory to most of the studies. First, increases in average temperature seem to have a detrimental effect on export values, mainly in case of manufactured and agricultural products. Given climate change, this is an important finding for projecting long-term developments of trade volumes. Findings on the effects of natural disasters are more ambiguous, but at least it can be said that exports seem to be affected negatively by occurrence and severity of disasters in the exporting country. Imports may decrease, increase, or be unaffected by natural disasters. Regarding heterogeneous effects, apparently small, poor, and hot countries with low degrees of institutional quality and political freedom face the most detrimental effects on their trade flows.

This review offers some directions for further research. Few studies (Dallmann 2019, Jones & Olken 2010) deliberately raise the issue of price effects. While weather variations or natural disasters may affect the production and supply of sensitive products, their prices may increase after the negative supply shock. As most studies measure trade in monetary terms (the only exception being Mohan &

Strobl (2012) who use lbs of sugar), the price effect may mask possible supply effects. Dallmann (2019) controls for this by integrating national inflation rates as a robustness check. This takes account of national macroeconomic price changes, but does not capture global price shocks of certain products. The latter are included as product-year-fixed effects by Jones & Olken (2010). Future research could – as a first step – follow these approaches to control for possible price effects, or – going beyond existing approaches – develop estimation models which explicitly estimate and include price shocks.

Another topic which has been addressed by some of the existing studies is the temporal persistence of the measured effects. By and large, if lagged effects are estimated, they prove to be significant for considerably long time spans (up to 20 years after a temperature shock as in Dallmann (2019)). Given the variety of results regarding the temporal persistence, more theoretical and empirical studies on the dynamic behavior of trade flows after external shocks may be needed.

On a different note, beside the temporal dimension there may also be spatial spillovers of natural disasters or weather shocks. So far, the shocks were modelled as if they affected only the trade of countries in which they occurred. Future works could try to include possible spillover effects on trade of adjacent countries. Beside this geographical dimension, spillover effects may also occur via supply chains. If country A, due to a natural disaster, cannot export crucial raw materials to country B, the trade flow of processed goods from country B to country C may be affected as well. Such spillover effects on international trade flows have not yet been analyzed empirically, although there is an emerging strand of literature on similar spillover effects on consumption, output and welfare via trade channels (Barrot & Sauvagnat 2016, Costinot et al. 2016, Sytsma 2018b).

Furthermore, the issue of adaptation deserves higher attention. Dallmann (2019) has suggested to use cross-sectional data to analyze long-term effects of weather variations, implicitly including adaptation behavior. Notwithstanding the methodological challenges of this approach, her finding is that there may be adaptation regarding precipitation shocks (e.g., irrigation technologies), but seemingly no effective adaptation to temperature shocks. Hsiang & Jina (2014) find that the effect of cyclones on imports is larger in countries with less historical cyclone experience, and interpret this finding as an evidence of adaptation. Beside these two – quite generic – formulations of adaptation, this issue is rarely raised in the literature.

Finally, some recent studies demonstrate strategies to use more granular data to refine empirical estimates: The use of trade data with higher temporal and spatial resolution. Monthly trade data become increasingly available (e.g., at UN Comtrade), and are used in an increasing number of studies (see Table 1). However, a global analysis of monthly trade is still missing. Furthermore, available monthly weather data could be used in trade analyses, which would allow analyzing the effects of temperature and precipitation during growing seasons of specific agricultural goods (as done by El Hadri et al. 2018 for the case of natural disasters). Regarding the spatial dimension, Sytsma (2018a, 2018b) introduces estimates at the port level. Thereby he tackles the problem that countries with the highest economic relevance (USA, China) are also geographically large countries, implying that the exact locations of external shocks are particularly important, but not depicted in many data sets. Consequently, the next step in this literature may be to estimate trade flows on the firm level, accounting for firm heterogeneities and eventually exact locations of the production sites.

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