How do environmental shocks affect competitors in a supply chain? Evidence from a competitors' weighting matrix

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Abstract

Quantifying the impact of supply shocks on global commodity trade networks is an increasing concern for researchers under the current threats of climate change and the COVID-19 pandemic. This paper proposes a novel methodology to estimate these effects across the entire trade network: we create a weight matrix based on an index that captures the extent to which two coffee-producing countries compete within consumer markets. Using this matrix, we estimate the degree to which an adverse weather shock in a coffee-producing country influences the coffee production of its competitors. Our results show that this adverse shock has a negative direct effect on the country's coffee exports and, importantly, a positive, one-year, lagged effect on the quantities produced by competitors.

Keywords: coffee, droughts, supply shocks, weighting matrix, spatial spillovers.

JEL: E23, F1, Q02, Q17, Q56.

1. Introduction

Quantifying the impact of supply shocks on global commodity trade networks is an increasing concern for researchers under the current threats of climate change and the COVID-19 pandemic in increasingly interconnected supply chains (Anderson, *et al,* 2016). These threats are even more significant in the case of agricultural supply chains, as crops are negatively affected by extreme and erratic weather conditions and agricultural products are perishable. In this paper, we study the case of the coffee supply chain - the second most traded commodity and the most traded agricultural commodity - to empirically identify the effect of weather shocks on trade networks, answering the question: How does a negative weather shock in a competitor country impact the production and exports of coffee in a coffee-producing country?

The negative direct effect of adverse weather conditions has already been shown by several empirical studies. These studies have found that higher-than-usual temperatures negatively affect productivity (Nordhaus, 2006), labor income (Dell, Jones & Olken, 2008; Partridge *et al.,* 2017), and exports (Jones & Olken, 2010; Li *et al.,* 2015) within countries affected by weather shocks. Kuwayama *et al.* (2019) find that droughts reduce crop yields in the U.S. but have no effect on farmers' income, as well as Birthal *et al*. (2015), who find that droughts significantly affect rice yields in India. The indirect effects of adverse weather conditions have been studied in the dyadic relationship between exporter and importer countries. For example, Dallman (2019) finds that temperature variations in the exporting country have a negative impact on bilateral trade and Ayala *et al*. (2022) show that floods and landslides in trading partners can affect local tax revenue. In the case of coffee, adverse weather conditions have been found to have a direct impact on productivity (Ceballos-Sierra & Dall'erba, 2021).

However, the indirect effect on competitor countries has largely been ignored by these studies, which fail to recognize the interdependence between seemingly unrelated countries as they belong to interconnected supply chains (Fold, 2014). This could lead to biased estimates of the impact of climate change on global trade, as negative direct impacts of adverse weather conditions on the dyadic relationship between exporter and importer might be offset by increased production coming from competitor countries as information is transmitted via prices (Lybbert *et al.,* 2014).

Further development in this literature has used shock propagation models to study supply networks beyond dyadic relationships. By simulating shocks across networks based on historical bilateral trade, they have shown that negative economic, environmental, and political shocks propagate through the supply networks singling out developing countries (Distefano, et al., 2021) and countries that are net importers or that import from more regions (Gephart, et al., 2016) as more susceptible to absorb the trade shocks.

We try to fill this gap in the literature by developing a novel weight matrix that captures the extent to which two countries, i and j, are competitors in the same supply network, in this case, the coffee supply network. We start by defining the potential demand of country *i* as the volume of coffee that all its competitors place in those markets where *i* sells coffee in any given year *t*. Then, to construct each competitor index, w_{ijt}, we look at the share of country *j*'s exports of country *i*'s potential demand. If country *j* is a fierce competitor of country *i*, our competitor index will approach 1, and 0 otherwise. We then estimate a spatial model, and through the competitor matrix, explore the spillover effect of adverse weather shocks on a country *j* over the production and export volume of country *i*. The results show that current droughts have a negative effect on local coffee production, while the previous year's drought has no effect on the same variable. However, a drought in a competitor country with a one-year lag has a positive effect on local coffee production and exports.

These results imply that worldwide coffee production self-compensates to an extent, but the process takes about a year. This is consistent with the fact that farmers' decision to ramp up production in competitor countries - because of the market scarcity induced by the adverse shock - will be reflected in the next growing season. We believe that these results extend to other supply chains as anecdotal evidence seems to suggest. For instance, oil production by OPEC members has expanded since Russia's invasion of Ukraine and ensuing sanctions by Western countries[1]. Similar effects have been observed in the wheat market.[2] Future work will investigate how permanent these shifts in the supply chain are.

[1] https://edition.cnn.com/2022/06/02/energy/oil-prices-opec-russia/index.html
[2] https://www.spglobal.com/commodityinsights/en/market-insights/latest-news/agriculture/060722-india-may-allow-up-to-500000-mt-of-wheat-exports-soon-in-second-tranche-since-ban

The outline of the paper is as follows: Section 2 describes the methods used in building the competitor matrix and conducting the empirical estimations. Section 3 defines the data and displays the descriptive statistics. Section 4 presents the results of the estimations. Finally, section 5 concludes and discusses the policy implications and the limitations of this study.

2. The coffee trade network

Coffee is one of the major commodities on the world market with around 75% of the production being exported in the 2018/2019 coffee year. World coffee exports have trended upwards over the period 1980-2009, rising from 3,7 million tons in 1980 to 9,3 million tons in 2009 (FAO, 2022). In 2016, five exporting countries accounted for 63.5% of total world exports from producing countries, with the largest exporters of coffee being Brazil (39.15%), Vietnam (34.22%), Colombia (14.95%), Indonesia (8.23%), and Ethiopia (3.45%). Brazil has increased its export levels during the period 1980-2019, dominating the market and maintaining adequate levels of competitiveness due to low production costs and its specialization in the robusta variety.

Similarly, five countries accounted for 57.7% of the total volume of coffee imports, with the main importers being the United States (20.8%), Germany (17.4%), Italy (7.6%), Japan (6.8%), and Belgium (5.2%). In relation to the imports of coffee in tons, an upward trend is observed between 1980 and 2009: imports surged from 3,713 thousand tons (t) in 1980 to 6,045 thousand tons (t) in 2009 (FAO, 2012). According to the International Coffee Organization (ICO), Europe accounted for 36.0% of world coffee consumption, North America 19.2%, South America 17.5%, Asia and Oceania 15.1%, Mexico and Central America 7.2%, and Africa 5.1%. The United States is the largest consumer with approximately 21.4 million bags per year, followed by Brazil (18.4 million), Germany (8.9 million), Japan (7.1 million), and Italy (5.8 million). The market concentration is also seen across private roasters, in fact, a few transnational corporations control more than three-quarters of the world's coffee trade. These are Neuman Kafee (Germany), Volcafé (Switzerland), Cargill (United States), Esteve (Brazil-Switzerland), Aron (United States), Ed&F Man (United Kingdom), Dreyfus (France), and Mitsubishi (Japan), which control about 56% of the world market (Roldán, González and Salazar, 2003). Table 1 shows the market share of coffee producer countries for the 2019-2020 year.

Table 1. Market share of coffee producer countries. 2019/2020 Coffee year

Country	Species*	Market share (%)	Country	Species	Market share (%)
Brazil	(A/R)	35.27	Burundi	(A/R)	0.17
Viet Nam	(R/A)	18.47	Cameroon	(R/A)	0.16
Colombia	(A)	8.54	Guinea	(R)	0.11
Indonesia	(R/A)	6.93	Cuba	(A)	0.08
Ethiopia	(A)	4.45	Panama	(A)	0.07
Honduras	(A)	3.59	Timor-Leste	(A)	0.06
Uganda	(R/A)	3.34	Yemen	(A)	0.06
India	(R/A)	3.02	Bolivia	(A)	0.05
Mexico	(A/R)	2.41	The Central African Republic	(R)	0.03
Peru	(A)	2.32	Angola	(R/A)	0.03
Guatemala	(A/R)	2.18	Nigeria	(R)	0.03
Nicaragua	(A)	1.75	Togo	(R)	0.02
Côte d'Ivoire	(R)	1.17	Sierra Leone	(R)	0.02
Costa Rica	(A)	0.89	Sri Lanka	(R/A)	0.02
Tanzania	(A/R)	0.56	Jamaica	(A)	0.01
Kenya	(A)	0.51	Paraguay	0	0.01
Papua New Guinea	(A/R)	0.46	Malawi	(A)	0.01
El Salvador	(A)	0.40	Zambia	(A)	0.01
Venezuela	(A)	0.39	Ghana	(R)	0.01
Lao PDR	(R)	0.38	Trinidad & Tobago	(R)	0.01
Ecuador	(A/R)	0.34	Guyana	(R)	0.01
Thailand	(R/A)	0.31	Zimbabwe	(A)	0.01
Dominican Republic	(A/R)	0.24	Liberia	(R)	0.00
Democratic Republic of Congo	(R/A)	0.24	Congo	(R)	0.00
Madagascar	(R)	0.23	Nepal	(A)	0.00
Rwanda	(A)	0.21	Gabon	(R)	0.00
Haiti	(A)	0.21	Equatorial Guinea	(R)	0.00
Philippines	(R/A)	0.19			

Source: Authors' calculations based on the International Coffee Organization. Historical Data on the Global Coffee Trade. Total production. Retrieved from: https://www.ico.org/new_historical.asp.
*A=Arabicas, R= Robustas.

In terms of per capita coffee consumption, The U.S. Food and Drug Administration shows relatively low domestic consumption of 4 to 6 Kg/person/year. In Europe, the largest consumers of coffee, in per capita terms, are in the Nordic countries with consumption ranging between 10 and 12 kg/person/year. They are followed by the Netherlands and Austria (8 to 10 kg/person/year) and Belgium and Germany (6 to 8 Kg/person/year). The influence of the West on Asian coffee consumption has been important; long-term trends show an increase in consumption in the market of Japan, Asian tigers (especially Hong Kong and Singapore), and China, despite competition from tea (J.Ganes Consulting, 2010).

In general, the increase in coffee consumption is not believed to be caused by decreases in price, given that the price elasticity of coffee demand is low and changes in coffee demand are mostly explained by changes in the population structure and preferences (Durevall, 2007; Grabs and Ponte, 2019). In addition, it has been shown that there is a close relationship between the growth in the income of OECD (Organization for Economic Development and Cooperation) countries and the increase in coffee imports. Coffee consumption is insensitive to income differences between individuals in the same country (Cartay and Ghérsi, 1996).

The world price of coffee is established in accordance with the conditions of supply and demand of the item on the world market; like other commodities, it is characterized by its volatility. Since there are different types of coffee, the ICO established a price system in 1965 to reflect the general or compound price of the different types of coffee, namely: soft Colombian Arabicas; other soft Arabicas; Brazilian Arabicas; other natural and robust Arabicas. Since 2000, the price of coffee is calculated with the average of the indicative prices of the groups, weighted according to their relative participation in international trade: Colombian softs: 12%; other softs: 23%; Brazilian naturals: 31%; robustas: 34% (OIC, 2012). In addition to the supply and demand factors, there are other adverse to coffee cultivation, such as climatic variations, and the presence of diseases and pests, among others.

The two main markets for coffee beans are in the New York and London Stock Exchanges. These operate under two modalities: current or physical markets and futures contracts. The latter do not involve physical transactions, since purchase and sale contracts are made specifying the aspects related to the quantities, the qualities required, and the delivery times. Historically, it has been important to stabilize prices in the world market for this item, limiting fluctuations in supply and their negative effects on coffee producing and exporting economies, through negotiations arising from the International Coffee Agreement created in 1962, made up of producer and consumer countries, its most recent renewal being in 2007, in which sustainable development was incorporated as a goal to be achieved in the world coffee economy.

From 2001 to 2011, the average price of coffee in real terms on the world market showed an increasing trend with an average growth annual rate of 14%. The strongest increase was observed in Colombian soft Arabicas, the other soft arabicas, and Brazilian natural Arabicas which increased by 12.0%, 13.1%, and 14.4%, respectively. For the same period, a more modest increase was observed in the robustas, of an average of 12.1% per year; these reached the highest price level in 2011 (US$ 109.21 cents per pound). According to the National Federation of Coffee Growers of Colombia (2010), the increase in coffee prices was based on excess demand or scarcity, which affected stocks. In addition, in 2010 and 2011, the prices of this item were linked to the expectations of the climate in the producing countries, especially the drought in the central zone of Brazil, the phenomenon of La Niña in Colombia, and Hurricane Karl in Mexico. The weather altered the quality and volumes of coffee from Brazil, as well as the slow marketing of the crop, which pushed coffee prices to levels above US$ 160 cents per pound.

3. Methodology and data

This paper follows a dynamic estimation to study how coffee production and exports are affected not only by droughts happening locally but also by those happening in trading competitors. First, to be able to capture this effect, we construct a time-varying weighting matrix, $\boldsymbol{W_t}$, where every w_{ijt} represents the degree of competition between countries i and j at time t. To the knowledge of the authors, there is no previous evidence of a weighting matrix measuring the degree of competition between countries that produce an arguably homogeneous product. In this case, geographical distance fails to be a correct way to assign weights that represent the strength of the relationship. The degree of competition between any pair of countries i and j is measured based on the potential coffee demand from country i, PD_{it}. We define PD_{it} as the difference between the total coffee demand of the buyers of country i and the total coffee sold by country i at year t, that is, $PD_{it} = D_t - D_{it}$. The competitor countries of i are the set of producers that also sell coffee to buyers from country i. In other words, we assume that coffee is a homogeneous product that can be easily substituted between producer countries. As a result, in the event of a negative shock that reduces the coffee production in country i, the buyer countries could get the coffee from competitor countries. The degree of competition, w_{ijt} is defined as follows:

$$w_{ijt} = \frac{D_{jt}}{PD_{it}},$$

Where D_{jt} is the total coffee sold by country j to all the buyers of country i at time t. As an example, Table 1 presents a subset of the weighting matrix, $\boldsymbol{W_{1995}}$, showing the competitor index for the five largest coffee producers:

Table 2. Snippet of the $\mathbf{W_{1995}}$ matrix

Origin/Competitor	Brazil	Indonesia	Viet Nam	Colombia	Ethiopia
Brazil	0.000	0.076	0.085	0.189	0.027
Indonesia	0.195	0.000	0.074	0.164	0.023
Viet Nam	0.166	0.069	0.000	0.177	0.022
Colombia	0.232	0.064	0.078	0.000	0.026
Ethiopia	0.185	0.055	0.068	0.164	0.000

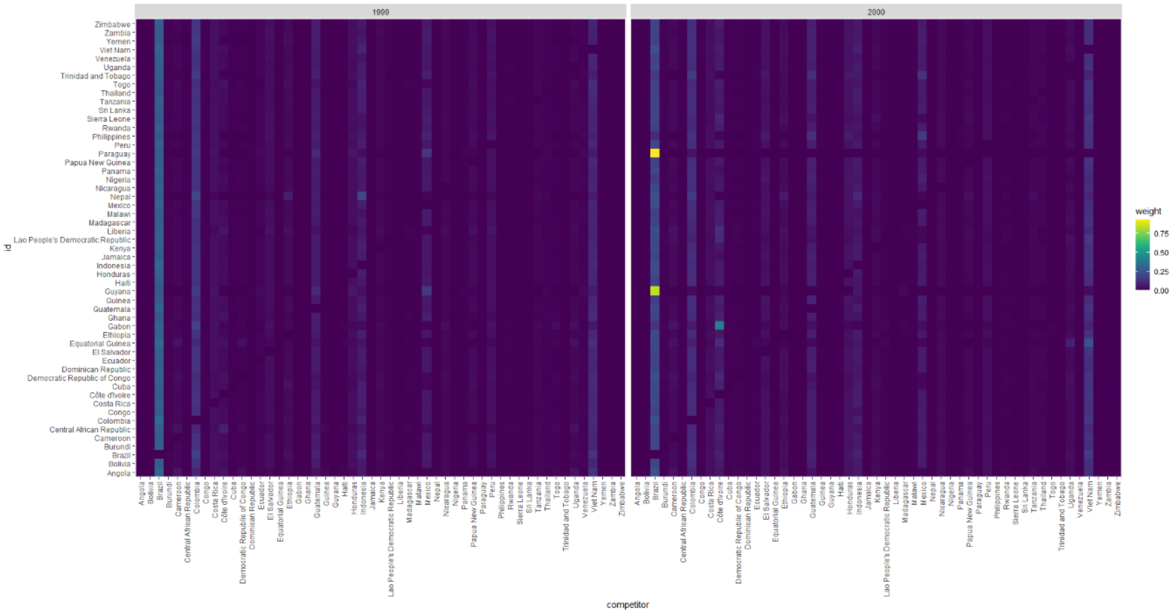
For instance, the value of $w_{Brazil,Colombia,1995}$ is roughly 0.189, meaning that Colombia supplied 18.9 percent of Brazil's potential market in 2005, $PD_{Brazil,1995}$. In comparison, Ethiopia supplied only 2.7 percent of Brazil's potential market for that year. We argue that, were Colombia to have a hypothetical production setback in 1995, Brazil is better poised to fill in Colombia's deficit given its already strong competing relationship with Brazil. The dynamic nature of these matrices is of utmost importance to this study, as it captures the constantly changing strengths of the trading relationships of international supply chains. Figure 1 shows a heatmap plot of matrices $\boldsymbol{W_{1999}}$ **and** $\boldsymbol{W_{2000}}$ with lighter colors representing higher competitor indices. Among other things, Brazil became a stronger competitor of Paraguay and Guyana in 2000 than it was in 1999.

Second, after obtaining our **W** matrix, we estimate the following spatial lag of X (SLX) regression model:

$$Y_{it} = \alpha_i + \gamma_t + \beta_1 Y_{i,t-1} + \beta_2 D_{it} + \beta_3 D_{i,t-1} + \beta_4 \sum_j w_{ijt}\, ED_{jt} + \beta_5 \sum_j w_{ijt}\, ED_{i,t-1} + \boldsymbol{\lambda X_{it}} + \mu_{it}.$$

Y represents the volume of coffee produced, or the volume of exports, ED is a dummy variable equal to one if there was a drought in the country. We include current droughts and one-year lag droughts, as well as their spatial lag to capture the plausible lagged and spatial effects on coffee production. Every w_{ijt} represents the share of exports of country j on the potential demand of buyers of country i defined earlier. $\boldsymbol{X}$ is a matrix of control variables that includes demand and supply factors such as the GDP per capita, population size, and measures of weather conditions such as temperature and precipitation. Standard errors, u, are clustered at the country level to allow for arbitrary serial correlations within countries.

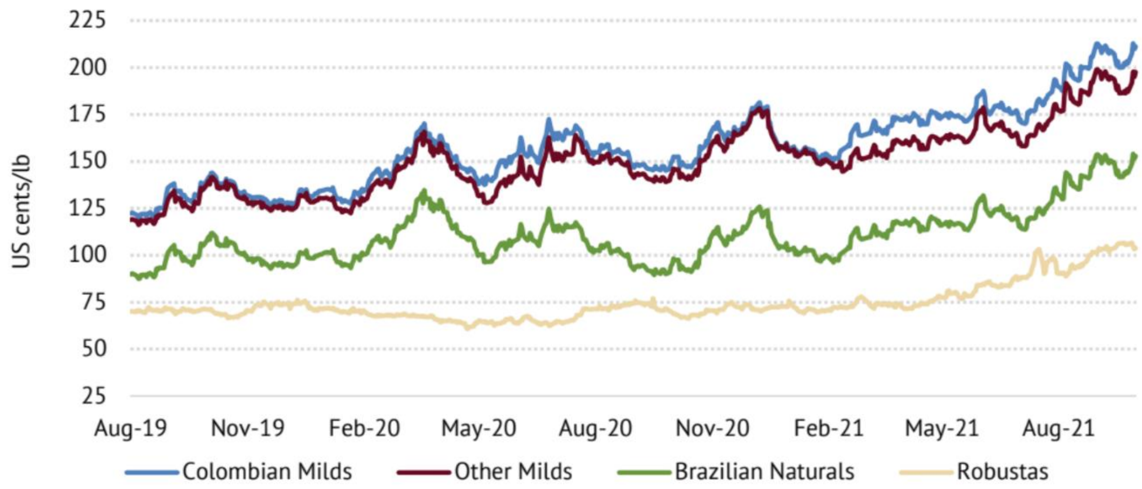
Figure 1. Comparison of the W_{1999} and W_{2000} matrices.



As in Jones and Olken (2010), we consider an estimation with country fixed effects (α_i) that control for the fixed differences in the coffee production across countries as well as time fixed effects (γ_t) that account for the changes in coffee prices as well as common world time effects. Figure 2 presents the trends of prices for different coffee groups as they are traded in major commodity exchanges showing that the prices closely trace each other.

We take advantage of the exogeneity of the occurrence of droughts across countries to arguably interpret the coefficients β_2 and β_3 as the impact of droughts happening locally on coffee production, and β_4 is the average effect of droughts in trading competitors on local coffee production and exports. Since we estimate a dynamic panel model, there is a plausible concern of endogeneity in our estimation because of the correlation in the error term that results from the inclusion of the lagged dependent variable as a regressor. However, this bias becomes negligible when the number of years increases, and we have a 25-year panel from 1995 to 2019, which should eliminate the concerns about the possibility that our results are suffering from this type of endogeneity.

Figure 2. Trends in coffee prices for different groups, August 2019-August 2021

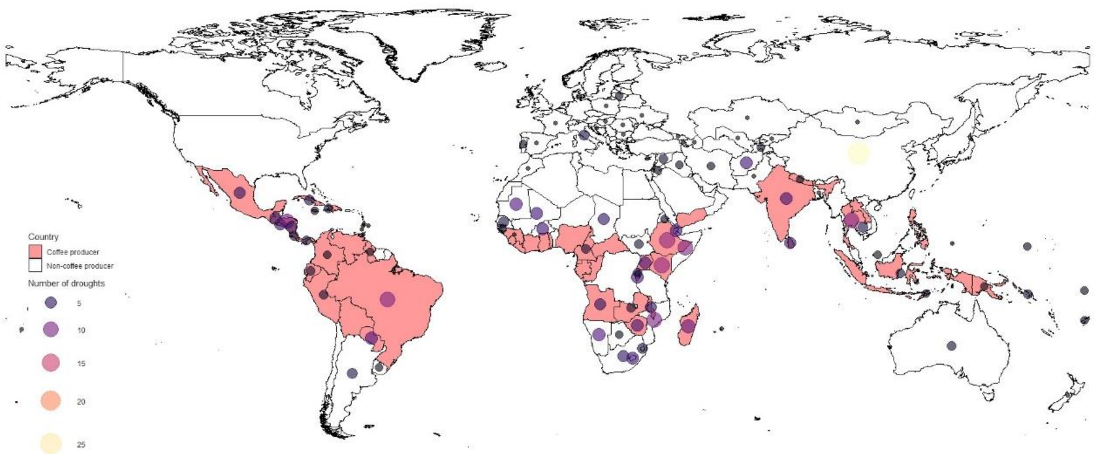


Source: adapted from The International ICO's August Coffee Market Report, retrieved from: https://www.ico.org/documents/cy2020-21/cmr-0821-e.pdf

Our data comes from different sources. We obtained the drought information for every country from the EM-DAT database of the Centre for Research on the Epidemiology of Disasters – CRED of the *Université Catholique de Louvain*. The Gross Domestic Product (GDP) and population information come from the World Bank, the weather information such as precipitation and temperature come from Harris *et al.* (2020), and coffee production and exports come from the International Coffee Organization.

Figure 3 shows the number of droughts per country highlighting those that are classified as coffee producers. The most affected countries by droughts for the period 1995-2019 were Peru with 12 events, Thailand and Mexico (11), and Paraguay, Ethiopia and Brazil (10), while Equatorial Guinea, the Democratic Republic of Congo, Togo, Sierra Leone, and Ghana did not experience any drought event for the same period. The complete list of coffee producer countries considered in this study is displayed in Appendix 1.

Figure 3. The number of drought events per country, 1995-2019.



Source: the authors with data from the EM-DAT database

4. Results

Table 3 shows the descriptive statistics of the variables used in our estimation for the 49 countries of our sample. We consider droughts happening locally and those occurring in competitor countries, a relationship that is captured by our competitors' weight matrix $\boldsymbol{W}$. Competitors are countries that sell coffee to the same set of countries each year. This is possible under the assumption that coffee is a homogeneous product that can be easily substituted between producer countries. It is expected that local production is not only affected by extreme weather events happening locally but also by those that occur in competitor coffee producer countries. It can be seen in Table 3 that, on average, 18% of the country-year sample and 27% of competitors experienced a drought.

Table 3. Descriptive statistics

Variable	Observations	Mean	Std. Dev.	Min	Max
Drought	1,171	0.18	0.38	0	1
W*Drought	1,171	0.27	0.19	0	1
Production (tons)	1,171	152,799	441,982	0	3,907,860
Exports (tons)	1,171	116,962	307,703	0	2,430,643
GDP per capita (USD)	1,171	6,893	6,535	691.2	41,249
Temperature (°C)	1,171	23.91	1.98	18.0	28.2
Precipitation (mm)	1,171	141.40	51.01	42.9	301.9

Source: The authors with information from The World Bank, the BACI trade data, the International Disasters Database – EM-DAT, and Harris *et al*. (2020).

Table 4 shows the main results of our estimation. We regress coffee production and exports on current and one-year lag drought happening locally and in competitor countries, given that coffee production may take some time to adjust after a drought. We also consider a set of control covariates that include previous coffee production to capture the tradition of coffee producer countries, other weather measures such as average temperature and precipitation, and GDP per capita (in logs) to control for economic activity and development. We use the lagged GDP per capita to avoid the reverse causality problem with coffee production. In addition, we consider country-specific fixed effects and time fixed effects.

Table 4. Droughts and coffee production

	ln(production)	ln(exports)
ln(production) (t-1)	0.596***	
	(0.077)	
ln(exports) (t-1)		0.808***
		(0.018)
Drought	-0.064***	0.030
	(0.022)	(0.072)
Drought (t-1)	0.027	0.010
	(0.023)	(0.080)
W*Drought	-0.222	0.202
	(0.140)	(0.279)
W*Drought (t-1)	0.245**	1.932***
	(0.099)	(0.661)
Temperature	0.034	-0.062
	(0.052)	(0.107)
Precipitation	0.000	-0.000
	(0.000)	(0.001)
Ln(GDP per capita) (t-1)	0.320**	0.271**
	(0.143)	(0.135)
Constant	0.631	1.060
	(1.679)	(3.025)
Observations	1,125	1,119
Country fixed effects	YES	YES
Time fixed effects	YES	YES
Adjusted R-squared	0.456	0.725
Number of countries	49	49

Notes: Robust standard errors in parentheses. *** p<0.01, ** p<0.05, * p<0.1.
Source: The authors with information from The World Bank, the BACI trade data, the International Disasters Database – EM-DAT, and Harris *et al*. (2020).

The results show that current droughts have a negative effect on local coffee production. Specifically, a drought can reduce local coffee production by 6.2% but it does not affect total exports. One possible explanation can be that countries decrease their stock after a negative production shock. The previous year's drought has no effect on production or exports, but a drought in a competitor country with a one-year lag has a positive effect on local coffee production, which is consistent with a decrease in the coffee production in the affected countries. A drought in 10% of the competitors can increase local coffee production by 2.5%, and exports by 21.3%. This spillover effects of droughts on coffee exports are of a significant magnitude given the relationship between local droughts and local production. Ignoring this indirect effect would lead us to incorrect conclusions about the effect of natural disasters on coffee production and exports. The fact that a current drought in competitor countries does not affect production or exports can be explained by the time needed to adjust local production given the shock in competitor countries.

The control variables included show the expected sign. Current production is positively correlated with past production, and current exports are strongly associated with past exports, which is consistent with having a sample of coffee production countries. In addition, we find that there is no significant correlation between coffee output and temperature and precipitation. These results are not expected to change if we consider measurements of precipitation or temperature shocks given that we consider countries fixed effects in our regressions. Finally, GDP per capita is positively correlated to coffee production with a point estimated elasticity of 0.32 for coffee production and 0.27 for coffee exports.

5. Conclusion

Coffee is one of the major commodities traded in the international markets, where the largest exporters for 2016 were Brazil (39.15%), Vietnam (34.22%), Colombia (14.95%) and the main importers being the United States (20.8%), Germany (17.4%), Italy (7.6%). This paper studies the impact of droughts on coffee production and exports considering droughts happening locally and in competitor countries. We develop a method of estimation that allows us to consider producer countries and competitor countries in the same regression, avoiding the omitted variable problem that can be a source of endogeneity.

Our approach consists of creating a row standardized weighting matrix of competitor countries, where the weights represent the market share of producer countries among all the producers facing the same international demand for the product each year. It is expected that a negative weather shock in a producer country that reduces local coffee production will also reduce the market segment of the same country in the international market. That segment will be captured by the closest competitors. As a result, this paper contributes to the literature by proposing a method for estimating this indirect effect of weather shocks applied to the coffee trade network.

We found that Brazil is the largest competitor for all countries, followed by Vietnam and Colombia, with small changes throughout the period 1995-2019. The results show that droughts reduce local coffee production, although no direct effect on exports was found. In addition, droughts in competitor countries increase local production and exports with a one-year lag, given the time needed for adjusting the growing seasonal production. Our findings are robust to the inclusion of country and time fixed effects, as well as other control variables such as temperature, precipitation, and GDP. These results contribute to the literature studying the mitigating effect of international trade to negative weather shocks. Ignoring the indirect impacts of natural disasters could lead to incorrect conclusions about the impact of extreme weather conditions.

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