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The Effect of Natural Resource Shocks on Violence, Crime, and Drug Cartels Presence in Mexico

by

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Abstract

We examine the effect of natural resource shocks on violence by drug cartels at the municipality level in rural Mexico from 2003 to 2017. For this, we use an Instrumental Variable setup by instrumenting our main explanatory variable vegetation density with rainfall. Vegetation density is an indicator for natural resource shocks and reflects the "greenness" in a particular area which is considered as an indicator of land productivity. Our main finding is that negative shocks in vegetation density increase homicides. This negative shock could imply crop failures resulting in bad economic outcomes for people in rural areas thereby pushing people to engage with violent drug cartels. Additionally, in order to confirm the main results we explore possible effects that natural resource shocks have on drug cartel presence, seizure of illegal drugs and other drug-related criminal activities. These results further confirm the negative relationship between natural resource shocks and violence by drug cartels. Our findings highlight the dynamics in the operation of the drug cartels and are relevant for understanding the determinants of conflict in rural Mexico.

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Introduction

The Mexican Drug Cartels[1] are one of the wealthiest organised criminal groups in the world. They are the largest suppliers of illegal drugs to the United States (U.S.) with about 90 percentage market share (O'Neil, 2009). These cartels are said to make around 35 billion USD annually by supplying contraband to the U.S. and are one of the largest employers in Mexico with a workforce of 500,000 (Dell, 2015). If considered a legitimate business, the Mexican drug cartels would be one of the largest companies in Mexico, second only to Pemex, a state run petroleum company (Stargardter, 2018). Drug lords like Joaquin "El Chapo" Guzman and Rafael Caro Quintero have regularly featured in the world list of billionaires (Estevez, 2013).

A major reason for the rise of these drug cartels is the strong workforce the drug cartels have. These workers are involved in a range of activities including production, processing and smuggling of drugs. Further, they also carry out a range of criminal activities like extortions, kidnappings, thefts and in fights with rival gangs or security forces. A major reason for a large number of people, especially youngsters to get involved in this dangerous industry is due to the lack of adequate livelihood options. This is particularly true for people from rural areas who are dependent on the agriculture sector. The vulnerability of the agriculture sector to climate and price shocks pushes people into the drug trade when their livelihoods in the agriculture sector has been affected. In fact, Dube et al. (2016) and Dell et al. (2019), find that in the Mexican context negative shocks to legitimate jobs pushes workers in search of work in the illegal drug trafficking industry. Further, they claim this to be an important reason and driver for increased violence in Mexico. Given this, in this paper, we explore the effect of natural resource shocks on violence by drug cartels in rural Mexico.

[1] The term drug cartels is a misnomer. In Mexico, it is colloquially used to refer to criminal organizations which are primarily engaged in drug trafficking. These criminal organizations do not collude to set prices and the coordination between them is not strong. These criminal organizations also engage in fights amongst themselves (Dell, 2015)

Increased penetration of drug cartels into rural areas after the 2000s makes it interesting to examine the role natural resource shocks play in influencing violence. That is, after the 2000s, increased military action on drug cartels, popularly known as the "drug war" have led to the increased penetration of these criminal organizations into Mexico's rural areas. Apart from access to the workforce, rural areas are attractive to drug cartels as they can perform their operations more discreetly and can also extort rents from farmers. These rents are referred to as "protection rackets" (Campana and Varese, 2018) and have become common for drug cartels to extort when increased clashes with security forces affect their earnings from drug trafficking. Thus, given that the drug cartels are situated and dependent on rural areas it becomes necessary to understand how shocks to natural resources affect their criminal activity.

It is important to note that natural resources are captured by using satellite imagery on vegetation density. Vegetation density reflects the "greenness" in a particular area and is considered a good indicator of land productivity (Labus et al., 2002; Gawande et al., 2017). With about half of the population in rural areas dependent on the agriculture sector (Instituto Nacional de Estadística y Geografía, 2022), shocks to land productivity can have a decisive effect on the economic outcome. For instance, lower vegetation density can reflect crop failure or droughts and, in general, can be viewed as a bad economic effect. Thus, vegetation density can be a good indicator of the economic conditions in rural areas.

In order to examine the causal relationship between vegetation and violence by drug cartels, we use an Instrumental Variable (IV) setup. For this, we use rainfall as an instrument to overcome the endogeneity problem present in the standard OLS framework. A similar empirical strategy has been followed by Gawande et al. (2017) in their paper exploring the effect of natural resource shocks on left-wing violence in the Indian context. For our empirical analysis, we constructed a unique panel dataset containing data for 2,138 for the period between 2003-2017. As explained before this sample period is relevant as it coincides with the rise of drug cartels in the early 2000s and the dramatic increase in violence after that.

The main conclusion of our study is that a one standard deviation decrease in vegetation density can result in a 15.89 percent increase in homicides. This negative relationship between natural resource shocks and homicides is not only true for the rural areas in entire Mexico, but also for selected states with a large drug cartel presence.

This result is consistent with the opportunity cost effect, which means that a fall in natural resources, results in more violence as income from agriculture is reduced and leads to people switching to employment in the drug sector. Further, a lack of agricultural income can also make it impossible to completely pay the protection rackets to drug cartels and can potentially lead to more violence.

In order to further examine the mechanisms behind this effect, we examine the impact natural resources shocks have on a host of outcome variables like marijuana seizures, cartel presence, and drug-related criminal activities. As before, we find a strong negative relationship as negative natural resource shocks increase marijuana seizures, expansion of cartels, and increase in violent drug-related killings. The soundness of both the results and the validity of the instrument is revised by a series of robustness checks.

Our paper contributes to the literature in the following ways: Firstly, it is one of the first papers to examine the effect of natural resource shocks on violence by drug cartels in rural Mexico. Focusing on non-economic factors like natural resources, it differs from most other papers in the literature as they mainly have examined the role of economic factors like commodity prices or trade policy on violence by drug cartels. It is also uniquely situated by focusing on rural areas as other papers in the literature do not have a special rural focus. Secondly, an advanced micro-empirical strategy using an IV setup has been used in this paper. This helps to strongly describe the relationship between natural resource shocks and violence by drug cartels by circumventing the endogeneity problem. Thirdly, this paper relies on satellite data of vegetation density and is part of the emerging literature which uses geospatial data in economic research.

The remainder of this paper is organized as follows: Section 2 presents the background on the drug cartels and socio-economic conditions in rural Mexico. Section 3 is a literature review of important papers that are referred to. Section 4 explains the theoretical background and the main hypothesis of this paper. Following this is Section 5 and Section 6 which describe the data sources and empirical strategy used in the analysis. Section 7 presents the main results of this paper and is followed by Section 8 which describes the mechanisms behind the main results. Finally, the soundness of the main result is evaluated in Section 9, and concluding remarks are presented in Section 10.

2

Background

This section presents the contextual background on two important aspects of our paper. First, we examine the evolution of the drug cartels throughout our sample period and second discuss socio-economic conditions in rural Mexico.

2.1 Drug Cartels and Rising Violence in Mexico

Illegal drug trade to the United States (U.S.) from Mexico has been in existence since the early 20th century. It increased sharply during the 1960s given the increased demand for marijuana in the U.S. and the lack of adequate supplies from Europe. With the inclusion of cocaine in the 1980s, the illegal drug trade witnessed further growth (Smith, 2021). Initially, the Mexican drug traffickers worked with their Colombian counterparts by smuggling cocaine produced in Colombia via Mexico (Dube et al., 2016). However, by the 2000s, the Mexican drug cartels became stronger and their market share in the illegal drug market in the U.S. increased from 50 percent in the 1990s to around 90 percent in the early 2000s (O'Neil, 2009).

Apart from trafficking cocaine from Colombia, the growth of the Mexican drug trade also involves the production and distribution of marijuana and opium poppies, with the latter being used to manufacture heroin (Smith, 2021). While Mexico is a lead supplier of marijuana, it became an important supplier of heroin by the 1990s and the world's third-largest opium supplier after Myanmar and Afghanistan (United Nations Office on Drugs and Crime, 2010). Currently, the Mexican drug cartels earn around 25 billion USD annually by trafficking drugs to the U.S. (United Nations Office on Drugs and Crime, 2010). These cartels are said to employ around 500,000 people and have a presence in two-thirds of Mexico's municipalities (Dell, 2015).

Prior to the 2000s, drug cartels were operating in Mexico without any large confrontations with the state or rival criminal organizations (Herrera and Martinez-Alvarez, 2022). They enjoyed impunity due to their close relationship with the Institutional Political Party (PRI), which ruled the country continuously for 70 years until the 2000s. Illegal political funding by the drug cartels helped them to establish patron-client relationships with the police and local government officials enabling cartels to operate in locations with relatively low or no impunity (O'Neil, 2009). However, the political dynamics changed in the 2000s when the National Action Party (PAN) won over PRI and the 70 years regime ended. These changes undermined the arrangements made between government officials and drug cartel leaders (O'Neil, 2009), which set the incentives for territorial expansions and infighting among rival drug cartels (Osorio, 2015).

Further two major events are said to have triggered the conflict. The first one was in 2001. The leader of the Sinaloa Cartel, Joaquin "El Chapo" Guzman, escaped prison and tried to take control of important drug points and routes near the U.S. border increasing violence due to competition for production areas and crossing points (Dube et al., 2016). Second, in 2006, President Felipe Calderon launched a military operation against drug cartels, known as the "Mexican Drug War". These operations resulted in dramatic violence throughout the country (Reuters, 2010). For example, since 2006, it is estimated that 150,000 people have been murdered due to violence by drug cartels (Center for Preventive Action, 2022) and this number is suspected to be underestimated (Breslow, 2015). This puts Mexico ahead of war-torn countries like Afghanistan and Iraq, as the total number of deaths in these countries together is 60 percent lesser than that reported in Mexico during the period between 2006 and 2014 (Breslow, 2015).

A key element to the operation of the drug cartels and their resistance to the security forces is their strong workforce. As mentioned before, by maintaining a large presence in about two-thirds of Mexican municipalities, these cartels via their 800 recruitment centers can easily draw in workers to engage in drug cartels (Cruz Santiago et al., 2012). A large proportion of these workers are hired from rural areas due to a lack of adequate livelihood opportunities in the agricultural sector. In fact, according to (Dube et al., 2016) and (Dell et al., 2019), negative shocks to employment opportunities in the legal sector push young workers to engage in drug cartels thereby increasing violence. Given this, it becomes necessary to examine the effect of natural resource shocks to land productivity on violence by drug cartels in rural Mexico.

2.2 Socio-Economic Conditions in Rural Mexico

Since our paper is based on the rural context, it becomes necessary to understand the socio-economic conditions of rural areas in Mexico. The rural areas in Mexico are predominantly agricultural. According to Instituto Nacional de Estadística y Geografía (2022), it is estimated that 85 percent of the rural areas in Mexico have agricultural, livestock, or forestry activity. As a result about half of the rural population in Mexico is employed in agriculture-related activities. Most of these people engage in subsistence farming and earn much lower than their counterparts in the urban-nonagricultural sector. It is estimated that about 40 percent of the rural population lives in poverty with a lack of access to jobs in the formal sector (International Fund for Agricultural Development, 2017). In fact, according to (Dube et al., 2016), most agricultural workers earn about 18 percent less than urban non-agricultural workers.

Lack of adequate income and access to financial safety nets makes them particularly vulnerable to natural resource shocks to land productivity. During the El Niño years (recently in 1997-1998 and 2014 to 2016), land productivity has been impacted by changing patterns of rainfall (Cordova Salvador et al., 2016). These changing rainfall patterns can delay sowing, and thus, delay revenue generation for agricultural producers due to smaller crop yields (Granados et al., 2017).

Bad agricultural years especially due to crop failure and droughts can have negative effects on the livelihoods of the people and can push them into engaging in illegal activities with drug cartels (Campana and Varese, 2018). Further, negative shocks can also result in the inability of farmers to pay in full the "protection rackets", which is an illegal fee or a tax charged by drug cartels and thus can result in conflict with them (Campana and Varese, 2018). Thus, it becomes important to examine the effect of natural resource shocks to land productivity on violence by drug cartels in Mexico.

3

Economics of Conflict

There are broadly two kinds of studies that emerge from the literature on the Economics of Conflict. The first category of papers analyses the causes of conflict. In particular, these focus on how various economic and non-economic factors can affect the intensity of a conflict. The second strand of literature examines the consequences of a conflict and deals with issues related to the distribution of resources post-conflict. This paper mainly belongs to the former category which analyzes the factors affecting conflict. It is a micro-empirical study on Mexico, that focuses on how non-economic factors like changes in renewable natural resources affect conflict.

A recent micro-empirical study examining the determinants of conflict is the paper by Dube and Vargas (2013). This study examines the effect of international coffee and crude oil prices on the conflict in Colombia. They find that price shocks perpetuate into conflicts through either the opportunity cost or rapacity effect mechanisms. For instance, the opportunity cost mechanism is in play for labor-intensive commodities like coffee as price increments lead to a reduction in conflict in Colombia. However, for commodities like crude oil, the rapacity effect is dominantly seen as an increase in oil prices resulting in more conflicts.

These mechanisms are further explored in Dube et al. (2016) in a micro-empirical study that examined the role of international maize prices on the conflict in Mexico. Like the earlier paper, the authors find that the opportunity cost effect is dominant as increases in maize prices lead to a drop in conflict in Mexican municipalities. Similar to this, various cross-country studies that examined conflicts arising from agricultural commodity price shocks also indicate the dominance of the opportunity cost effect in labor-intensive agricultural products (Brückner and Ciccone, 2010; Bazzi and Blattman, 2014).

It is important to note that a key difference between cross-country studies and within-country studies like this one is that within-country studies have high internal validity and can depict the causal mechanism at a micro-level and thus can complement arguments from cross-country studies (Do and Iyer, 2010).

Apart from analyzing the role of economic factors like commodity prices or income, various papers also examine the role of non-economic factors like vegetation density, rainfall, geographic conditions, political rallies, etc. on conflict (Do and Iyer, 2010; Iyer and Shrivastava, 2018; Baysan et al., 2019). A notable paper in this strand of literature is a paper by Miguel et al. (2004). This paper examines the impact of exogenous variation in Gross Domestic Product (GDP) caused by rainfall on conflict in the Sub-Saharan African context using an Instrumental Variables setup. As far as our knowledge is concerned, it is one of the first papers to use rainfall as an instrument in studying the impact on conflict. Numerous papers inspired by it used variations in climatic conditions to examine the dynamics of conflict (Burke et al., 2009; Hsiang et al., 2011; Gawande et al., 2017; Baysan et al., 2019). Most of these papers based on developing countries find that local climate shocks have an impact on agriculture and thus influence the dynamics of conflict (Bazzi and Blattman, 2014). Largely, they find that climatic conditions that result in droughts like higher temperature and lower rainfall can increase the incidence of conflict.

Further, studies have also focused on the effect of geography in influencing the intensity of a conflict (Do and Iyer, 2010; Rigterink, 2020). Do and Iyer (2010) in their paper on the conflict in Nepal find that the prevalence of conflict increases in forested and mountainous areas as they serve as ideal hideouts for insurgents. Likewise, the distribution of natural resources also plays an important role in determining conflict. Rigterink (2020) finds that conflict is concentrated in those areas of Africa where diamonds can be easily mined. With a similar theme, various other studies have also focused on the role of the distribution of natural resources like oil fields and mines in conflict in the African context (Sierra, 2013; Arezki et al., 2017; Berman et al., 2017; McGuirk and Burke, 2020). The results from these studies are conflicting as there is no consensus on the channel (opportunity cost or rapacity effect) in which natural resources perpetuate conflict in the African context.

In a similar vein, a paper closely related to our paper is by Gawande et al. (2017). The authors developed a micro-empirical study based on selected states in Central India and they examined how violence due to left-wing extremism (Maoist) increased due to changes in renewable natural resources like vegetation density. To avoid potential issues due to endogeneity, the authors use an Instrument Variable (IV) strategy by using annual rainfall as an instrument for vegetation. The authors find the dominance of the opportunity cost channel as there is a negative relationship between vegetation and conflict as one standard deviation fall in vegetation leads to an increase in conflict by about 60 percent. The economics of conflict literature in the Mexican context is largely qualitative and is based on case studies. Micro-empirical studies are few and mainly focus on the consequences of conflict rather than the determinants of a conflict. For instance, many papers have highlighted the effect of the drug war on homicides, crime against women, and labor force participation (Hoehn-Velasco et al., 2021; Benyishay and Pearlman, 2013; Dube et al., 2016). Some interesting micro-empirical papers that focus on the determinants of conflict in Mexico are the papers by Dube et al. (2016), Dell (2015) and Dell et al. (2019).

As already mentioned Dube et al. (2016) evaluates the role of maize price shocks on violence in Mexico. The study by paper Dell (2015) uses a regression discontinuity design to examine the changes in drug cartel violence by mayors from the anti-drug PAN party during elections. They find a significant increase in violence post the election of PAN mayors as security operations on drug cartels is launched. Another notable paper by Dell et al. (2019) studies how job losses in the urban areas due to increased competition from Chinese manufacturers have led to a spike in drug cartel violence. The paper finds the dominance of the opportunity cost channels as manufacturing workers displaced due to competition from China is drawn into drug cartels, thereby, increasing violence, especially in urban areas. Apart from the above-mentioned papers, the literature on determinants of conflict in Mexico is mainly theoretical and relies on simple models to establish causality (Rios, 2012; Osorio, 2015; Shirk and Wallman, 2015). Studies that focus on the role of non-economic factors in causing conflicts are even rarer.

Given this, our paper aims to extend the micro-empirical literature by examining the relationship between natural resource shocks and violence by drug cartels in Mexico. It seeks to analyze the role of exogenous variations in vegetation density on conflict in rural Mexico. It builds upon earlier analyses by various authors on rural Mexico and offers policy prescriptions that can be effective to contain violence in Mexico.

4

Hypothesis

The relationship between income per capita and conflict is explored by Chassang and Miquel (2009). They argue that poor countries have a higher probability to suffer from internal conflicts, and these exacerbate when there are negative income shocks which can be based on the opportunity cost of fighting. This opportunity cost mechanism considers whether an individual decides to invest their efforts in productive activities or in violent activities like engaging with the drug cartels. This study mostly relates to low GDP economies, where wages are low, and therefore the returns on productive activities are small, and citizens are more likely to turn to lucrative criminal activities. On the same lines, Gawande et al. (2017) argues that conflict occurs if current economic circumstances are bad, independently of expected future situations.

Additionally, Dube et al. (2016) discusses that increments of crop prices such as maize reduces agricultural costs of participating in illicit activities, therefore reducing conflict in Mexican municipalities. They augment their discussions by mentioning that a reduction of agricultural income by municipality increases the possibility of people being employed in the drug sector.

Given this, our econometric strategy considers several points made by the mentioned authors. First, Gawande et al. (2017) and Chassang and Miquel (2009) convey that cross-country literature on conflict has an omitted variable bias due to the exclusion of the repressive capacity of the government in their empirical strategies. Therefore, as was done by Gawande et al. (2017), we conduct our analysis at the municipality level within Mexico, where the capacity to repress drug cartels is in the hands of the state (Truqui, 2021).

Second, according to Chassang and Miquel (2009), we cannot exploit transitory shocks on conflict based on examining within variation, therefore we establish municipality and year fixed effects in all our specifications to control for differences across municipalities and for common events that affect all municipalities in a particular year. Therefore, our main hypothesis is that negative shocks to renewable natural resources are associated with more violence at municipality level in Mexico.

We follow Dube et al. (2016) by investigating vegetation density as an indicator of agricultural and forest-related natural resources on which a large proportion of the rural areas in Mexico depend. Because of these points, we are confident that a negative association between natural resources (vegetation density) and conflict (such as homicides) in municipalities of Mexico could be interpreted as consistent with Dube et al. (2016), Gawande et al. (2017) and Chassang and Miquel (2009), which emphasizes the opportunity cost of fighting. Therefore, we focus on the determinants affecting an ongoing conflict.

5

Data and Descriptive Statistics

The goal is to investigate if there is a causal relationship between natural resources and violence induced by drug cartels in Mexico. Official statistics in Mexico do not collect and publish data on drug-related killings regularly. The last time such data was collected was during the drug war in 2007-2010 when a nationwide crackdown on drug cartels was launched during the Mexican President Felipe Calderon's regime (2006-2012). In order to overcome this problem, researchers usually use crime data on homicides as it is one of the most common crimes committed by the drug cartels in Mexico (Benyishay and Pearlman, 2013; Dell, 2015). There is ample evidence indicating the rise in homicides during episodes of the government crackdown on drug cartels, popularly known as the "drug war". This can be seen in Figure 1 and a sharp increase in homicides can be noticed during the periods between 2007-2010 and 2015 onwards. It is important to note that drug cartels use homicides to inflict fear and intimidate others.

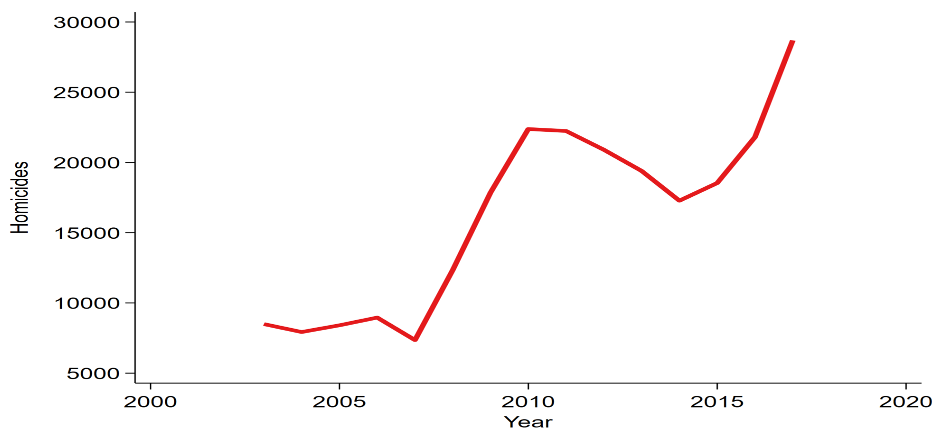

Figure 1: Total Homicides in Mexico (2003-2017). Notes. This figure shows the annual total homicides in Mexico between 2003 and 2017. The data was obtained from INEGI.

The data on municipal level homicides is collected from Mexico's National Institute of Statistics and Geography (INEGI). INEGI database reports a series from 1990 to 2021 based on deaths due to homicide at the state and municipality levels. For this paper, annual homicide data from 2003 to 2017 has been retrieved. The period between 2003 to 2017 is of particular importance as drug cartels gained more power and the Mexican government tried to put a halt to the drug cartels' influence by initiating a war against them. The annual municipal level homicides data was transformed into logarithmic values as they were count variables.

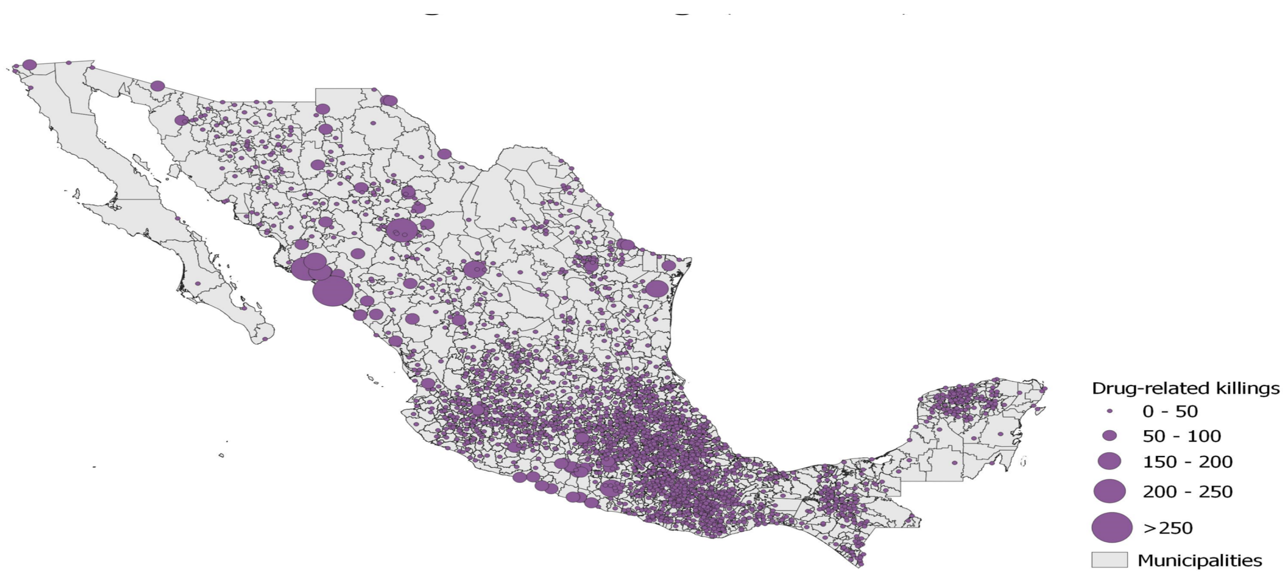

Figure 2: Drug-related Killings by Municipality (2007- 2010). Notes. This figure shows the total drug-related killings in each Mexican municipality between 2007 and 2010. The data were obtained from Mexican National Security Council. Bigger circles denote higher drug-related killings in the municipality. This map does not distinguish between drug-related killings in urban and rural areas.

Data on drug-related killings is available from 2007 to 2010. This data was collected by the government in 2010 to quantify the violence that was caused during the initial phases of the drug war. This data is available at the municipal level and has been collected by the Mexican National Security Council. Three categories of drug-related killings have been characterized by the Security Council. This includes drug-related executions, confrontations, and attacks. Various types of evidence like telltale signs or messages left at the crime scene are used to classify them as drug-related crimes. Drug-related execution as the name suggests accounts for executions such as beheadings carried out by criminals related to drug cartels.

Fights between the security forces and the cartels or fights between cartels are recorded as drug-related confrontations. Drug cartel attacks account for the attacks carried out by drug cartels on the army and police forces (Baysan et al., 2019). All these three categories have been added together to create a fourth category called drug-related killings. As before, these variables have been log-transformed.

Figure 2 depicts the distribution of drug-related killings across Mexico between the years 2007-2010. However, it is important to note that many of the killings were not counted by the Mexican National Security Council. In many cases, it has been impossible to identify bodies and connect them with an investigation folder. Since 2006, 8,200 people have been found in mass graves and remain unidentified (Reina, 2022).

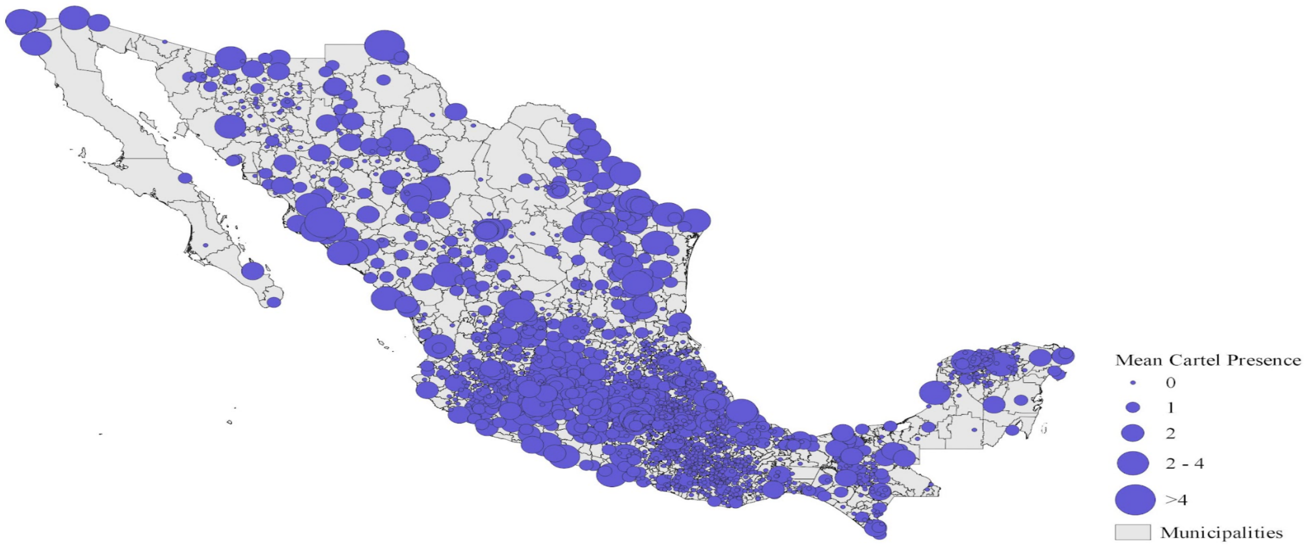

Figure 3: Mean Cartel Presence by Municipality (2003-2010). Notes. This figure shows the mean total drug cartel presence in each Mexican municipality between 2003 and 2010. The data were obtained from Coscia and Rios (2012). Bigger circles denote a higher mean concentration of drug cartels in the municipality. This map does not distinguish between drug cartel presence in urban and rural areas.

To study the causal relationship between natural resources and cartel activity across municipalities, we use the data set constructed by Coscia and Rios (2012). This data set reports the presence of 10 drug cartels at the municipality level from 1991 to 2010. It was constructed using a framework that codes a drug cartel as being present in a municipality in archived publications from Google News. This code reports the drug cartel as being present if the municipality and the name exceed a threshold determined by Coscia and Rios (2012).

Using the data between 2000-2010, we built three variables of cartel presence, as done by Dube et al. (2016): a variable if any cartel is present in the municipality ("Any Cartel"); a variable if the drug cartel was present for the first time in the municipality ("First Cartel"); and, a variable that indicates the operation of multiple cartels in the municipality ("Multiple Cartels").

Data on the seizure and eradication of illegal substances like marijuana and opium poppies is collected to analyze the impact of vegetation density on these measures. We followed Dube et al. (2016) and utilized drug crop eradication as a proxy for cultivation of marijuana and poppy. Municipal level data for this is collected from The Mexican Secretariat of National Defence (SEDENA) for the years 2000 to 2017.

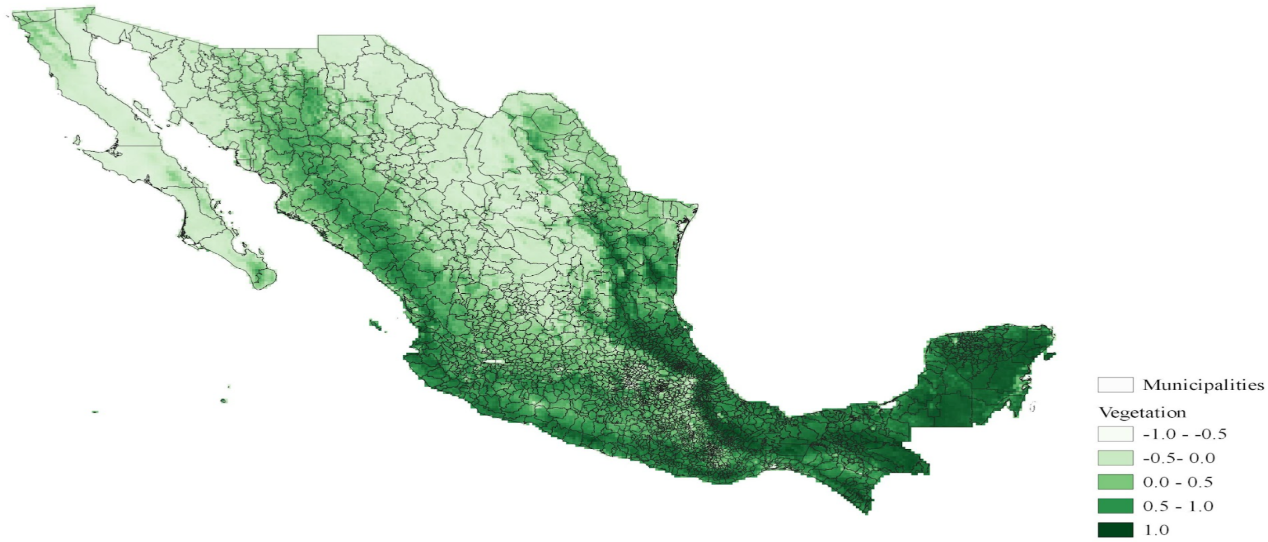

Figure 4: Vegetation Density (NDVI) by Municipality (2000-2020). Notes. This figure shows the average vegetation density in each Mexican municipality between 2000 and 2020. The data were obtained from LP DAAC. Greener areas indicate greater vegetation density in the municipality. This map does not distinguish between urban and rural areas.

For the explanatory variable, vegetation density data is used as the measure of natural resources given that part of the Mexican rural economy is dependent on the agriculture and forestry resources. Vegetation density at the municipality level was computed based on NASA satellite images. This data has been retrieved from the Terra Moderate Resolution Imaging Spectroradiometer (MODIS) Vegetation Indices 16-Day (MOD13A1) Version 6.1 by the LP DAAC from NASA's Earth Observing System Data and Information System (EOSDIS). The product provides an average annual Normalized Difference Vegetation Index (NDVI) value on a per-pixel basis at 500 m spatial resolution. The NDVI index is computed as NDVI = (NIR − VIS) / (NIR + VIS), where NIR is the Near-Infrared Band and VIS is the visible light, which means that unhealthy or sparse vegetation reflects NIR light. NDVI for a given grid ranges from -1 to +1, where values above 0.5 indicate greater vegetation density (Didan and Barreto Munoz, 2019). The NDVI data were extracted and transformed into a panel data set at the municipality level for Mexico from 2003 to 2017 using Google Earth Engine and the municipalities' coordinates were extracted from the Geostatistical Areas Catalog of INEGI in shapefile format.

The rainfall data is extracted from the Center for Climatic Research of the University of Delaware. The dataset contains worldwide monthly total precipitation (in mm) for the years 2003-2017 interpolated to a 0.5 x 0.5-degree grid resolution. This high-resolution data was then matched with the Mexican municipalities' coordinates sourced from the Geostatistical Areas Catalog of INEGI. For the purpose of matching efficiently spatial data analysis was carried out using the R programming language. Annual rainfall for the rainiest months of June to October was collected from this database.

For all outcomes presented in the upcoming sections, we restrict our sample to municipalities that can be classified as rural based on having less than 100,000 inhabitants, following the General Population and Housing Census 2000 (Dube et al., 2016). Rural municipalities are important because we are interested in the impact of vegetation-dense areas on violence, which by definition, is a characteristic of regions of Mexico where agricultural commodities are mostly grown (Granados et al., 2017). Applying this criterion of rurality, we eliminated 271 municipalities resulting in a sample of 2,138 municipalities with 36,135 observations from 2003 to 2017. The summary statistics of our panel dataset is presented in Table 1.

Table 1: Summary Statistics

Variables		Mean	St. Dev.	N
Vegetation	overall	0.4461302	0.1438962	31762
	between		0.1423451	
	within		0.0218015	
Log homicides	overall	0.6106882	0.8674481	27990
	between		0.7050871	
	within		0.5055364	
Any cartel	overall	0.1063354	0.3082755	16984
	between		0.2174509	
	within		0.2185597	
First cartel presence	overall	0.0547574	0.2275128	16984
	between		0.1223989	
	within		0.1917988	
Multiple cartels	overall	0.051578	0.2211799	16984
	between		0.138219	
	within		0.1726961	
Log marijuana eradication	overall	0.2275928	0.7865838	31845
	between		0.651749	
	within		0.4405951	
Log raw marijuana seizures	overall	0.3947931	1.468703	31845
	between		1.055414	
	within		1.021607	
Log poppy eradication	overall	0.1604156	0.7525768	31845
	between		0.6211158	
	within		0.4251548	
Log opium poppy seizures	overall	0.0412659	0.3801768	31845
	between		0.1961878	
	within		0.3256711	
Log total drug-related killings	overall	0.2957543	0.6839075	8364
	between		0.5552261	
	within		0.3994546	
Log drug-related executions	overall	0.2694174	0.6412049	8364
	between		0.5243538	
	within		0.3691822	
Log killings from confrontations	overall	0.509687	0.2897164	8364
	between		0.1739047	
	within		0.2317403	
Log killings from cartel attacks	overall	0.0106169	0.1146102	8364
	between		0.0589024	
	within		0.0983221	
Seasonal Rain (June to October)	overall	0.8308462	0.5227993	31770
	between		0.4852987	
	within		0.1946999	
Non Seasonal Rain (November to May)	overall	0.2676887	0.2969253	28024
	between		0.2719852	
	within		0.1198182	

6

Empirical Strategy

6.1 Model Specification

Our goal is to investigate the effect of natural resources shocks on violence by drug cartels in rural municipalities of Mexico. For this we use vegetation density obtained from satellite data as an indicator for natural resources. As noted earlier, we use vegetation density as the measure of natural resources as a large part of Mexico's rural economy is dependent on the agriculture and forestry sector and is an ideal indicator for natural resources in a given year. For instance, a decrease in vegetation density (NDVI) indicates crop failure and a fall in land productivity, thereby, resulting in loss of income in rural areas during a particular year.

Given this, our empirical strategy attempts to estimate the effect of variations in vegetation density on drug-related violence. For this, we first set up the following OLS regression:

$$y_{i,t} = \beta_0 + \beta_1 Vegetation_{i,t} + \zeta_i + \lambda_t + \epsilon_{i,t} \tag{6.1}$$

Where $y_{i,t}$ is the municipal level log of homicides for municipality i at year t. As described earlier in Section 5, homicide is widely used as a proxy for violence by drug cartels in the Mexican context as data on drug related killings is not collected regularly by the government (Benyishay and Pearlman, 2013). It is important to note that homicide is a count variable and hence its logarithmic value has been considered. In the explanatory side, the municipal level contemporaneous vegetation density is included as the main explanatory variable. Municipality fixed effects ζ_i are included to control for time invariant differences across municipalities. Additionally, year fixed effects λ_t are included to control for common events that affect all municipalities in a particular year. Finally, β_0 is the constant and $\epsilon_{i,t}$ is the error term. Standard errors are clustered at the municipality level.

The OLS estimates may suffer from endogeneity and can be biased. Two possible reasons for this could be that: Firstly, the conflict between drug cartels and the government can plausibly make it difficult for producers to carry out agricultural activities (Miguel et al., 2004). Various studies have pointed out that during the drug war average working hours dropped significantly due to fear. According to Benyishay and Pearlman (2013) fear induced behaviour change is profound in rural areas especially among self-employed and farmers, due to lack of adequate security arrangements in towns. Secondly, military forces clear the forests and agricultural land in the presumption that marijuana or poppies are being cultivated and this could possibly lead to reverse causality as during an increased period of violence vegetation density is reduced.

In order to address this, we use rainfall variation as an instrumental variable. Seasonal rainfall from the the rainiest months of June to October is used as a source of exogenous variation for vegetation density (The World Bank, 2021). The validity of the instrument is discussed in detail in the next subsection.

To identify the causal effect of natural resources shocks on violence by drug cartels, we use an Instrumental Variables (IV) setup with rainfall as the instrument. We use a two stage least squares (2SLS) to estimate the relationship between the vegetation density and homicides for municipality i in year t. The first and second-stage regressions are of the following form:

$$Vegetation_{i,t} = \beta_1 Rain_{i,t} + \beta_2 Rain_{i,t-1} + \beta_3 Rain_{i,t-2} + \lambda_t + \zeta_i + \epsilon_{i,t} \tag{6.2}$$

$$y_{i,t} = \beta_0 + \beta_1 Vegetation_{i,t} + \zeta_i + \lambda_t + \epsilon_{i,t} \tag{6.3}$$

In the above equations Equation 6.2 and Equation 6.3, $y_{i,t}$ is the municipal level log of homicides at year t and municipality i. Equation 6.2 represents the first stage as the effect of rainfall on vegetation density is determined here. Equation 6.2 is the second stage equation depicting the effect of exogenous variations in vegetation density on homicides. Its important to note that in Section 8, we consider different outcome variables $y_{i,t}$ such as log of drug-related killings, cartel presence and log of marijuana and poppy seizures to explain the mechanisms of the main results. Finally, in both equations, municipality fixed effects ζ_i and year fixed effects λ_t are included t. $\epsilon_{i,t}$ is the error term and the standard errors are clustered at the municipality level.

6.2 Validity of IV approach

Four assumptions need to be fulfilled for an instrument to be suitable for an IV setup. We consider these assumptions for our instrument, rainfall, below:

Firstly, the exclusion restriction should hold as causality can be only established if the instrument rainfall affects homicides via vegetation density and not through other channels. It is of concern that the exclusion restriction assumption is violated while using rainfall as an instrument due to the presence of modern irrigation platforms and dams (Sarsons, 2015). However, there is ample evidence that a large part of Mexican agriculture is rain-fed (Conde et al., 2006), and further lack of affordability amongst small farmers prevent them from investing in modern irrigation techniques (Granados et al., 2017). This assumption of exclusion restriction is however not possible to test.

Secondly, the instrument must be independent of potential outcomes. Rainfall meets this assumption as it is provided by nature, however, it is correlated spatially given that weather is not limited to the political boundaries of municipalities. Therefore, each municipality in the sample is treated as independent and the rainfall data is extracted at coordinate points, as each municipality's rain is independent of its neighbor's rain quantity (Cooperman, 2017).

Thirdly, the instrument, rainfall, must fulfill the monotonicity assumption. Angrist and Pischke (2009) discuss that while the treatment might not affect everyone, the ones treated should be affected in the same way. This assumption has been discussed as potentially being violated if areas, where different crops are sown, have opposite responses to increased rainfall (Mellon, 2021). However, rainfall affects satellite vegetation data in a broadly similar way for different types of plants (for example avocado trees versus bushes) and across different climatic zones within Mexico (Gawande et al., 2017).

Finally, the instrument must be relevant, rainfall must have a clear effect on the causal variable of interest. If the instrument and the endogenous variable, vegetation density, are correlated, there will be a strong first stage. This is important for estimating accurate estimators (Angrist and Pischke, 2009), which are consistent, efficient, and provide variation in homicides that is as good as random.

7

Results

In this section, the results of the analysis between natural resource shocks and homicides are presented. For this, the first stage and the reduced form estimates are presented to revise for the instrument relevance assumption. Following this, the main IV results between vegetation density and homicides are presented. The final subsection performs the same analysis for selected states which are vegetation dense and have significant cartel presence.

7.1 First Stage and Reduced Form Results

Instrument relevance is a key assumption that is required to be satisfied in an Instrumental Variable approach. In order to check this, the first stage relationship between rainfall and vegetation is presented in Table 2. Here, it can be noted that there exists a strong positive effect of rainfall on vegetation density in rural Mexico. The positive effect is statistically significant and is robust to the inclusion of both municipality and year fixed effects. This effect is the strongest for the contemporaneous rainfall coefficients as the effect gradually declines with lags. The first stage of our instrument is strong as the First stage F-Statistic is above the thumb rule of 10. The results also reject the null hypothesis that the instrument is weakly identified as the Kleibergen-Paap rk LM statistic is significant at around 258.5. The overidentification test of Hansen J statistics, which has the null hypothesis that the instruments are uncorrelated with the error term is not rejected.

Further the results from the reduced form depicting the direct relationship between homicides and rainfall are also explored. Here, the reduced form coefficients are significant as the contemporaneous rain and its lag have a statistically significant negative effect on homicides.

Table 2: Results From First Stage and Reduced Form Regressions

	First Stage	Reduced Form
	Vegetation	ln(Homicides)
Rain	0.0188***	-0.0985***
	(0.00119)	(0.0261)
L.Rain	0.0122***	-0.163***
	(0.00118)	(0.0276)
L2.Rain	0.0027**	-0.016
	(0.0009)	(0.0217)
N	24,187	24,193
Municipality FE	yes	yes
Year fixed FE	yes	yes
R-squared		0.111
First Stage F	96.31	

Notes. This figure shows in the first column the first stage and in the second column, the reduced-form regression estimated coefficients. Standard errors are clustered at the municipality level and are shown in parentheses. *** is significant at the 1%, ** is significant at the 5% level, and * is significant at the 10% level. FE stands for fixed effects.

7.2 Main Results: Vegetation Effect on Homicides

Table 3 depicts the relationship between vegetation density and homicides using the IV-2SLS estimation method and the OLS model. As described in Section 5, it is important to note that these estimations only consider rural municipalities in Mexico. Following this, in both these models, there exists a negative relationship between vegetation density and homicides. The negative effect of vegetation density on homicides indicates that a decrease in vegetation due to a natural resource shocks can lead to an increase in homicides. According to the IV model, a decrease in vegetation by one within standard deviation (0.0216) can lead to a increase in homicides by 15.89 percent[1].

The negative effect of vegetation on homicides is expected and highlights the dominance of the opportunity cost mechanism. This is similar to the results obtained by Dube et al. (2016). They also highlight the dominance of an opportunity cost mechanism in their study on the relationship between maize price shocks and drug cartel violence in Mexico. A decrease in vegetation density could imply a fall in land productivity and can thus lead to crop failures. This could harshly affect the livelihood of farmers and farm laborers

[1]The results in Table 3 are interpreted in terms of standard deviations. For this the product of the coefficient and the one standard deviation is computed (here it is 0.021*-7.57=-0.1589). This is because the coefficients in Table 3 represent the change of a unit increase in vegetation, so in order to get this in terms of standard deviation we compute the product.

Table 3: *Vegetation and Homicides for Rural Mexico. Results from OLS and IV Regressions*

	OLS	IV
	ln(Homicides)	ln(Homicides)
Vegetation	-0.730***	-7.577***
	(0.167)	(1.393)
Constant	0.914***	
	(0.0752)	
N	27,907	24,187
Municipality FE	yes	yes
Year fixed FE	yes	yes
R-squared	0.0984	

Notes. This figure shows in the first column the OLS and, in the second column, the IV 2SLS regression estimated coefficients. Standard errors are clustered at the municipality level, and are shown in parentheses. *** is significant at the 1% level, ** is significant at the 5% level, and * is significant at the 10% level. FE stands for fixed effects.

as they will not be able to meet their crop production targets (Granados et al., 2017). This lack of livelihood opportunities in the agricultural sector pushes people to work for drug cartels in risky activities like smuggling and the production of narcotics substances resulting in greater violence. Further, a bad crop harvesting season may also lead to conflicts between cartels and farmers, as the latter will be unable to pay the protection rackets which are set by the cartels (Campana and Varese, 2018).

This negative effect of vegetation density on homicides is greater in the IV model compared to the OLS estimates. This was also observed by Gawande et al. (2017) in their study examining the relationship between vegetation density and violence in India. A possible reason for this could be that the OLS estimates may be biased due to the presence of measurement errors in vegetation or due to reverse causality as discussed in Section 6. For example, the conflict between drug cartels and the government can plausibly make it difficult for producers to carry out agricultural activities due to fear (Miguel et al., 2004; Benyishay and Pearlman, 2013). Another reason could be that military forces clear the forests and agricultural land in the presumption that marijuana or poppies are being cultivated in municipalities with cartel presence thus leading to reverse causality.

7.3 Selection of States: Dense Vegetation and High Cartel Presence

In this section the effect of vegetation density on homicides is analyzed for municipalities in selected states which are both vegetation dense and heavily reliant on natural resources (Servicio de Información Agroalimentaria y Pesquera, 2022). The people living in these states are reliant on the cultivation of crops such as maize, lime, and avocados. Earlier studies and reports have pointed out how shifts in prices of crops such as maize and avocados lead to an increase in violence in these regions (Dube et al., 2016). Thus, this makes it ideal to explore the dynamics between homicides and natural resource shocks in this region.

The states which have been considered are Jalisco, Colima, Guanajuato, Michoacan, Guerrero, Chiapas, Quintana Roo, and Mexico. These states are located in the south and eastern parts of the country. As seen in Figure 5, the municipalities in these states have denser vegetation and also a large number of homicides has been recorded in this region. There is the exception that border municipalities with the U.S. as well have larger homicide rates per 100,000 people.

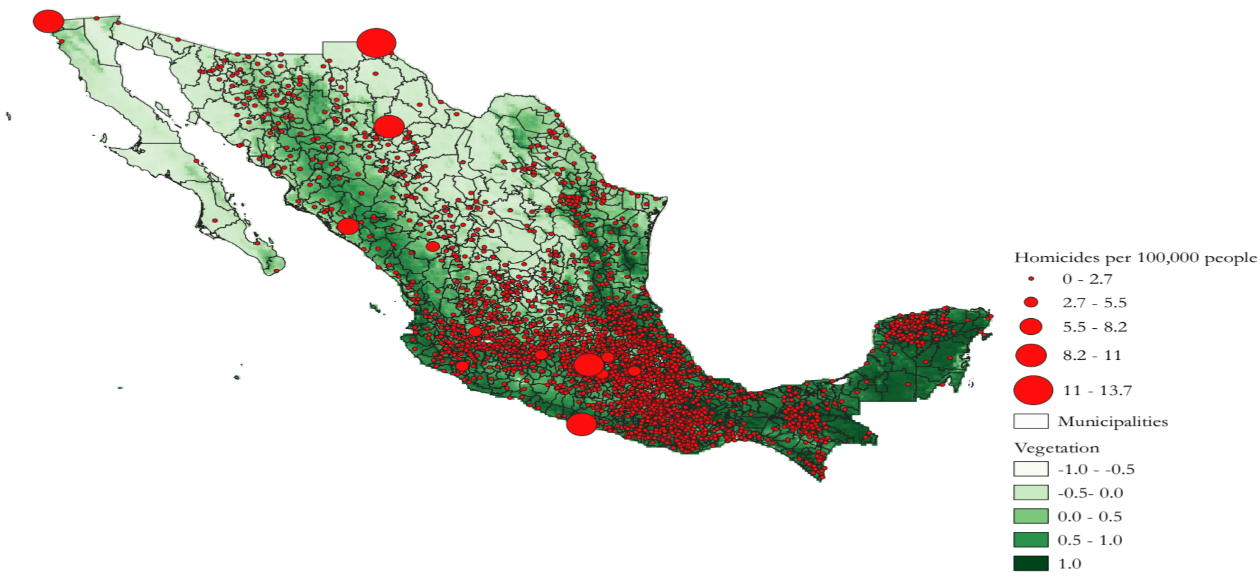

Figure 5: Homicide Rate and Vegetation Density by Municipality. Notes. This figure shows the total homicide rate per 100,000 people in each Mexican municipality between 2003 and 2017 and the average vegetation density in each Mexican municipality between 2000 and 2020. The data were obtained from INEGI and LP DAAC, respectively. Greener areas indicate greater vegetation density and bigger circles denote a higher homicide rate in the municipality. This map does not distinguish between urban and rural areas.

Table 4: Vegetation and Homicides for Selected States

	OLS	IV
	ln(Homicides)	ln(Homicides)
Vegetation	-1.022**	-10.98***
	(0.412)	(4.069)
Constant	1.341***	
	(0.183)	
N	7,432	6,442
Municipality FE	yes	yes
Year FE	yes	yes
R-squared	0.203	
First Stage F		22.87

Notes. This figure shows in the first column the OLS and, in the second column, the IV 2SLS regression estimated coefficients. Standard errors are clustered at the municipality level and are shown in parentheses. *** is significant at the 1% level, ** is significant at the 5% level, and * is significant at the 10% level.FE stands for fixed effects.

Table 4 presents the results of OLS and IV estimates for these selected states. Similar to the above, there is a strong negative effect of vegetation density on homicides. The effect is even more pronounced as a decrease in the vegetation of one standard deviation (0.0210) can lead to an increase in homicides by 23.05 percent in the IV model. The reason for a stronger effect in these selected states can be due to close interactions between the agriculture sector and drug cartels in these areas.

According to Rios (2012), the states in southeast Mexico especially Michoacan, Guanajuato, and Guerrero have been the hotbed of drug cartels since the 1980s. La Familia and Los Zetas drug cartels are heavily present in these states and are known for their notorious criminal activities including smuggling of drugs, weapons, sex trafficking, and kidnappings. Dense vegetation in these selected states makes it easy for drug cartels to carry out their activities discreetly. Various cartel activities such as labs for the production of methamphetamine and the creation of cocaine smuggling routes from Colombia to the U.S. were established. The presence of a large agriculture-based population in these areas led the cartels to easily recruit young adults into their illegal activities. Thus, drop in land productivity and crop failures can push agriculture workers into more illegal activities and result in more homicides. Also, protection rackets were also collected from farmers and various conflicts associated with it also could rise especially during agricultural distress when farmers are unable to pay the obligated protection rackets (Moncada, 2019). The statistically significant results for the selected states also support the robustness of the IV estimates in Table 3.

8

Mechanisms

This section attempts to analyze the mechanisms by which natural resource shocks affect violence in Mexico. We take a deeper look into possible channels by which natural resource shocks affect homicides. We consider the effect vegetation density has on cartel entrance and expansion, seizure of marijuana and opium poppy, and criminal activity of drug cartels. This analysis can potentially help us in understanding and confirming the results in Section 7.

It is important to note that the IV setup is used for all the analyses as already mentioned in Section 6. The same approach as in Equation 6.2 and Equation 6.3 is used by replacing the log of homicides with different outcome variables. All the analyses in this section are done using annual municipal level data.

8.1 Criminal Activity

First, the results of the impact of vegetation on various criminal activities by drug cartels are presented. As already mentioned in Section 5, the data on drug-related criminal activities were collected by the Mexican authorities for a brief period between 2007-2010. This is highly helpful as crimes committed by drug cartels can be divided into various categories like executions, confrontations, and attacks on security forces. These details can help better understand the main results of homicides in Section 7.

The results on the effect of natural resource shocks on criminal activity are presented in Table 5. Here, we can see that there exists a negative relationship between vegetation density and various drug-related crimes. A decrease in vegetation density by one standard deviation (0.016) can lead to an increase in drug-related killings by 46.52 percent. Similar results can be seen with other categories as a decrease in vegetation density by one standard deviation leads to a rise in drug-related executions and confrontations by 38.6 and 24.43 percent, respectively. However, it can be noted that the effect of vegetation density

Table 5: Drug Related Killings and Vegetation

	(1) Log total killings	(2) Log executions	(3) Log confrontations killings	(4) Log cartel activity killings
Vegetation	-29.08***	-24.13***	-15.27***	-1.308
	(6.409)	(5.594)	(3.487)	(1.035)
			First Stage F: 11.51	
N	8,342	8,342	8,342	8,342
Municipality FE	yes	yes	yes	yes
Year FE	yes	yes	yes	yes

Notes. This figure shows the IV 2SLS regression estimated coefficients for rural areas. Standard errors are clustered at the municipality level and are shown in parentheses. *** is significant at the 1% level, ** is significant at the 5% level, and * is significant at the 10% level. FE stands for fixed effects.

on drug cartel attacks, i.e. drug cartels attacking security forces is not significant. This shows that the increase in total drug-related killings is mainly driven by executions and confrontations.

These results are similar to those by Dube et al. (2016) and, in fact, according to them executions and confrontations were the major criminal activity during the drug war post-2006. Thus, this is an important observation as we can potentially conclude that homicides are largely driven by factors such as executions and confrontations amongst drug cartels.

8.2 Drug Cartel Presence

In the 2000s, increasing confrontations with the federal government affected the operations of drug cartels and resulted in difficulties. This led to a breakup of drug cartels into various factions and also fuelled the search for newer territory. These smaller factions in search of new territory entered various new municipalities in order to increase agricultural-related revenue (Herrera and Martinez-Alvarez, 2022). This was part of their diversification strategy as their traditional sources of income through drug trafficking were strained due to the drug war with the Mexican government.

In this pursuit of newer territory, cartels found regions with crop failure or droughts to be attractive. As noted by Dube et al. (2016), people in municipalities with failed crops did not have alternative livelihood options which led them to join drug cartels and aid their smuggling operations.

Further, regions with a crop failure were easy targets for these newer cartels as they could disburse the money which they accumulated from illegal activities in order to win over the people of the municipality (Smith, 2021). This helped them to strengthen their foothold in an area.

To examine the effect natural resource shocks have on drug cartel presence, we use the data set by Coscia and Rios (2012). As mentioned, the data set monitors the presence of cartels in municipalities using Google News for the period between 2000-2010.

Table 6: Drug Cartel Presence and Vegetation

	(1) Any Cartel	(2) First Cartel	(3) Multiple Cartels
Vegetation	-4.358**	1.337	-5.695***
	(1.974)	(1.9)	(1.809)
		First Stage F: 10.34	
N	12,705	12,705	12,705
Municipality FE	yes	yes	yes
Year FE	yes	yes	yes

Notes. This figure shows the IV 2SLS regression estimated coefficients for rural areas by Any Cartel in the first column, which is an indicator if any cartel is present in the municipality; First Cartel in the second column, an indicator of the drug cartel was present for the first time in the municipality; and, Multiple Cartels in the third column, an indicator that indicates the operation of multiple cartels in the third column. Standard errors are clustered at the municipality level and are shown in parentheses. *** is significant at the 1% level, ** is significant at the 5% level, and * is significant at the 10% level. FE stands for fixed effects.

The results analyzing the effect of vegetation on cartel activity are presented in Table 6. The results are in line with the other results discussed previously as a positive vegetation shock can result in a fall in the cartel presence across rural areas in Mexico. A decrease in vegetation density by one standard deviation (0.018) can lead to an increase in any cartel presence by about 7.83 percent. Likewise, a drop in vegetation density also leads to an increase in the presence of multiple cartels in the area. However, the results of the first cartel presence are not significant. Further, these results suggest that homicides could be driven by the presence of multiple cartels and associated confrontations due to that.

8.3 Seizures of Marijuana and Opium Poppy

In this subsection, the effect of vegetation density on the seizure of illegal drugs, such as marijuana and opium poppy, is explored. Mexico is located strategically close to the U.S. and serves as the transport corridor for illegal drugs from other South American countries like Colombia. These illegal drugs are transported mostly via road to the U.S. and are stored in warehouses in various parts of Mexico (Buch, 2022).

In Table 7, the effect of vegetation density on the seizure of illegal substances is presented for the period between 2003 to 2017. There is a strong negative relationship between vegetation density and seizure of illegal drugs. As mentioned before, a drop in vegetation can result in more people switching to drug smuggling and, eventually, this could potentially increase the seizure of illegal drugs. Additionally, this could possibly increase homicides as confrontations between the security forces and drug cartels or within drug cartels can increase.

Table 7: Seizures of Marijuana and Opium Poppies

	(1) log marijuana seizures	(2) log poppy seizures
Vegetation	-4.301* (2.258)	-2.518*** (0.932)
	First Stage F: 117.33	
N	27,528	27,528
Municipality FE	yes	yes
Year FE	yes	yes

Notes. This figure shows the IV 2SLS estimated effects. In the first column, the effect on the seizure of kilograms of marijuana is shown, and in the second column the effect on the seizure of kilograms of opium poppy for rural areas. Standard errors are clustered at the municipality level and are shown in parentheses. *** is significant at the 1% level, ** is significant at the 5% level, and * is significant at the 10% level. FE stands for fixed effects.

9

Robustness Checks

9.1 Lagging Homicides on the Explanatory Side

In order to revise the robustness of the IV model, the lag of the dependent variable (log of homicides) is included in the model to account for the dynamics in the dependent variable. This helps control for serial correlation, especially, when the dependent variable is an AR(1) process. A similar approach has been used by Gawande et al. (2017). The results of this estimate are presented in Table 8.

Table 8: Results from Regression with Lagged Dependent Variable

	OLS	IV
	ln(Homicides)	ln(Homicides)
L.ln(Homicides)	0.230***	0.223***
	(0.0131)	(0.0136)
Vegetation	-0.642***	-6.219***
	(0.155)	(1.245)
Constant	0.584***	
	(0.0705)	
N	26,047	24,187
Municipality FE	yes	yes
Year fixed FE	yes	yes
R-squared	0.15	
First Stage F		95.51

Notes. This figure shows in the first column the OLS and, in the second column, the IV 2SLS regression estimated coefficients. Standard errors are clustered at the municipality level and are shown in parentheses. *** is significant at the 1% level, ** is significant at the 5% level, and * is significant at the 10% level. FE stands for fixed effects.

Here again, the negative effect can be seen and there are no major differences in the estimates in comparison with Table 3. This indicates the robustness of our main regression estimates. Furthermore, Nickell Bias is a common cause of concern for short panels (T less than 15) when both the lagged dependent variable and fixed effects are included. In order to check this, we compare the OLS estimates without lagged dependent variable in Table 3 with the OLS estimates with the lagged dependent variable in Table 8. There are no major differences as the negative relationship between homicides and vegetation density continues without a large change in the coefficient estimates, thus indicating the absence of Nickell Bias in these estimated coefficients.

9.2 Marijuana and Opium Poppy Cultivation

In this section, marijuana and poppies cultivation is added as control variables in the main IV regression. The main idea is that, since vegetation can encompass the growth of illegal drugs like marijuana and opium poppy, it is necessary to add them as controls and see how the main results change. This is important because an increase in vegetation could also mean an increase in the cultivation of marijuana which in turn results in more homicides. This violates our argument which connects an increase in vegetation to the agriculture sector rather than the growth of illegal substances.

Table 9: With Controls: Marijuana and Opium Poppy Cultivation

	(1) ln(Homicides)	(2) ln(Homicides)	(3) ln(Homicides)
Vegetation	-7.590***	-7.541***	-7.577***
	(1.393)	(1.389)	(1.389)
Log marijuana eradication	0.0296***		0.0282**
	(0.0097)		(0.0123)
Log poppy eradication		0.0164*	0.00282
		(0.00967)	(0.0124)
N	24,187	24,187	24,187
Municipality FE	yes	yes	yes
Year FE	yes	yes	yes

Notes. This figure shows in the IV 2SLS regression estimated coefficients. In column (1) log marijuana eradication is added as control, (2) log poppy eradication is added as control, and (3) both are added as controls. Standard errors are clustered at the municipality level and are shown in parentheses. *** is significant at the 1% level, ** is significant at the 5% level, and * is significant at the 10% level. FE stands for fixed effects.

The Mexican government does not record the growth of marijuana and opium poppy, hence, eradication data must be used. As mentioned in the data section, the number of hectares of land that was destroyed in a particular municipality annually is recorded by the official statistics, as mentioned in Section 5. This is widely used as a proxy for cultivation (Dube et al., 2016). It is also important to note that marijuana seizures used in the previous Section 8 is different from cultivation as seizures are the drugs that were confiscated during smuggling or when they were hidden.

The results indicate that the cultivation of marijuana or poppies does not affect the effect of vegetation on homicides as the results remain similar to those presented in Table 9. In fact, as expected, the cultivation of marijuana and poppy increases homicides, which could be due to the increment in drug cartel activity within municipalities (and associated violence), as discussed in Section 8.

9.3 Placebo Test: Evaluating the impact of Non-Seasonal Rainfall

Placebo tests are used to identify problems with research designs such as model misspecification, measurement errors, or estimators being biased by confounders (Eggers et al., 2021). In this section, we estimated a placebo test utilizing rainfall of non-rainy season months between November to May as the instrument. This test should check for an association that should be absent if the research design in this thesis is sound (Eggers et al., 2021). Therefore, non-seasonal rainfall should not influence homicides when instrumented. Table 10 contains the results of the placebo test.

Table 10: Placebo Test: Non-Seasonal Rainfall as Instrument

	IV	OLS
	ln(Homicides)	ln(Homicides)
Vegetation	1.256	
	(2.429)	
Non-season Rain		0.0456
		(0.0587)
L.Non-season Rain		0.0769
		(0.0477)
L2.Non-season Rain		0.0804**
		(0.0343)
Constant		0.280***
		(0.0311)
N	20,306	20,335
Municipality FE	yes	yes
Year FE	yes	yes
R-squared		0.0953
First Stage F	30.93	

Notes. This figure shows in the first column the IV 2SLS regression estimated coefficients and, in the second column,the OLS estimated coefficients. Standard errors are clustered at the municipality level and are shown in parentheses. *** is significant at the 1% level, ** is significant at the 5% level, and * is significant at the 10% level. FE stands for fixed effects.

From the results in Table 10, it can be seen that the non-seasonal rainfall during the months of November to May does not significantly affect homicides. There are several reasons for this. Firstly, the amount of rainfall outside the rainy season is limited especially during the winter (García Amaro de Miranda, 2003). This period also is when crops like maize are sown. Similarly, cash crops like avocado and lime are largely harvested in the months of September to December (Alexander, 2013).

The reduced form estimates are also revised to see the impact of rainfall on homicides. It can be noted that there is no significant effect for the contemporaneous and lagged rainfall. However, the second lagged rainfall exhibits significant and positive coefficients, which is counterintuitive to the main results. In the main results, we find that the effect of rainfall gradually declines with lags.

10

Conclusion

In this paper, we examine the effect natural resource shocks have on violence by drug cartels at the municipality level in rural Mexico from 2003 to 2017. The focus is on rural areas given our interest is in the impact of vegetation-dense areas on violence, which is a characteristic of regions where agricultural commodities are mostly grown.

We instrument our main explanatory variable, vegetation density, with rainfall. Vegetation density is obtained from satellite data and is an indicator for natural resources. It reflects the "greenness" in a particular area and is considered a good indicator of land productivity.

It is demonstrated that negative shocks to vegetation density increases homicides at the municipality level. This negative shock could imply crop failures which could result in lower land productivity and can negatively affect the livelihood of farmers. Consequently, they will not be able to meet their crop production targets and will push them to work for drug cartels in risky activities like smuggling and producing narcotics substances. Further, a bad crop harvesting season may lead to violent conflicts, as farmers will be unable to pay protection rackets which are set by the drug cartels.

Additionally, we perform the analysis only on 8 selected states which are vegetation dense and have significant cartel presence. We find similar results as there is a strong negative effect of vegetation density on homicides. The reason for a stronger effect can be due to close interactions between the agriculture sector and drug cartels.

Moreover, we explore possible mechanisms by which natural resource shocks affect homicide occurrences in rural municipalities, such as drug cartel entrance and expansion, seizure of marijuana and opium poppy, and drug-related criminal activities. We find that homicides are largely driven by factors such as executions and confrontations amongst drug cartels. A drop in vegetation density can result in more people switching to drug smuggling and, eventually, increasing the seizure of illegal drugs by military operations. Our findings are relevant for understanding the dynamics of drug cartels in rural Mexico and highlight the importance of better understanding the economic determinants of drug cartel expansion.

Furthermore, our results suggest that policies influencing the income, such as crop insurance can be useful in preventing the rural population from suffering during natural resources shocks. Other income boosting measures like job opportunities or transfer payment to the impoverished can also be useful in limiting their participation in drug cartels. We also propose that the policy makers take into consideration the negative effects changing patterns of rainfall can have on agricultural activities and thereby on conflict in rural areas (SAGARPA and FAO, 2012).

Our paper has some limitations that could be addressed in future research. If more recent data on drug cartel presence were available, it would have been interesting to understand how the ongoing drug war might lead to the entrance of newly created drug cartels into areas where only big drug cartels are dominant. Secondly, it will be also important to explore how the dynamics of conflict are affected by political parties as the local political parties in power have changed since the drug war started in 2006. Finally, a further extension of this paper can be to include Conley standard errors in the Instrumental Variable estimations to recognize potential spatial dependence in rainfall across neighboring municipalities.

Bibliography

Alexander, L. M. (2013). Industria de aguacate mexicano fuerte y floreciente. Available at: https://www.hortalizas.com/cultivos/industria-de-aguacate-mexicano-fuerte-y-floreciente/ [Accessed on 10 April 2022].

Angrist, J. and Pischke, J.-S. (2009). *Mostly Harmless Econometrics: An Empiricist's Companion*. Princeton University Press, Oxford.

Arezki, R., Ramey, V. A., and Sheng, L. (2017). News Shocks in Open Economies: Evidence from Giant Oil Discoveries. *The Quarterly Journal of Economics*, 132(1):103–155.

Baysan, C., Burke, M., González, F., Hsiang, S., and Miguel, E. (2019). Non-economic factors in violence: Evidence from organized crime, suicides and climate in Mexico. *Journal of Economic Behavior & Organization*, 168:434–452.

Bazzi, S. and Blattman, C. (2014). Economic Shocks and Conflict: Evidence from Commodity Prices. *American Economic Journal: Macroeconomics*, 6(4):1–38.

Benyishay, A. and Pearlman, S. (2013). Homicide and Work: The Impact of Mexico's Drug War on Labor Market Participation. *SSRN Electronic Journal*. Available at: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2302437 [Accessed on 15 May 2022].

Berman, N., Couttenier, M., Rohner, D., and Thoenig, M. (2017). This Mine Is Mine! How Minerals Fuel Conflicts in Africa. *American Economic Review*, 107(6):1564–1610.

Breslow, J. M. (2015). The Staggering Death Toll of Mexico's Drug War. Available at: https://www.pbs.org/wgbh/frontline/article/the-staggering-death-toll-of-mexicos-drug-war [Accessed on 15 May 2022].

Brückner, M. and Ciccone, A. (2010). International Commodity Prices, Growth and the Outbreak of Civil War in Sub-Saharan Africa. *The Economic Journal*, 120(544):519–534.

Buch, J. (2022). Mom-and-Pop Stores: Perfect Money Laundering Vehicles on US-Mexico Border. *InSight Crime*. Available at: https://insightcrime.org/news/mom-pop-stores-money-laundering-us-mexico-border/ [Accessed on 10 April 2022].

Burke, M., Satyanath, S., Dykema, J., and Lobell, D. (2009). Warming Increases the Risk of Civil War in Africa. *Proceedings of the National Academy of Sciences of the United States of America*, 106:20670–4.

Campana, P. and Varese, F. (2018). Organized Crime in the United Kingdom: Illegal Governance of Markets and Communities. *The British Journal of Criminology*, 58(6):1381–1400.

Center for Preventive Action (2022). Criminal Violence in Mexico. Available at: https://cfr.org/global-conflict-tracker/conflict/criminal-violence-mexico [Accessed on 15 May 2022].

Chassang, S. and Miquel, G. P. i. (2009). Economic Shocks and Civil War. *Quarterly Journal of Political Science*, 4(3):211–228.

Conde, C., R, F., and S, O. (2006). Climate change and climate variability impacts on rainfed agricultural activities and possible adaptation measures. A Mexican case study. *Atmósfera*, 19. Available at: http://www.scielo.org.mx/scielo.php?pid=S0187-62362006000300003&script=sci_abstract&tlng=en [Accessed on 10 April 2022].

Cooperman, A. D. (2017). Randomization Inference with Rainfall Data: Using Historical Weather Patterns for Variance Estimation. *Cambridge University Press*. Available at: {https://www.cambridge.org/core/journals/political-analysis/article/abs/randomization-inference-with-rainfall-data-using-historical-weather-patterns-for-variance-estimation/2F86BE9EB79FDFF9FF97C8C5CC4A2ED3}[Accessedon10April2022],.

Cordova Salvador, D., Núñez Flores, E., Romero, J. C., and García Ramírez, R. (2016). El Niño afecta a los sectores agrícola y pesquero en México. *Ciencia UNAM*. Available at: http://ciencia.unam.mx/leer/562/El_Nino_afecta_a_los_sectores_agricola_y_pesquero_en_Mexico [Accessed on 15 May 2022].

Coscia, M. and Rios, V. (2012). Knowing where and how criminal organizations operate using web content. In *Proceedings of the 21st ACM international conference on Information and knowledge management -CIKM '12*, page 1412. ACM Press. Available at: http://dl.acm.org/citation.cfm?doid=2396761.2398446 [Accessed on 10 April 2022].

Cruz Santiago, C., Cruz Santiago, C., Fumarulo, S., Ruggiero, P., Poscetti, G., and Dell'Olio, T. (2012). *México: la guerra invisible. historias, cifras y negocios de los carteles criminales y la impunidad de las mafias mexicanas*. Libera.

Dell, M. (2015). Trafficking Networks and the Mexican Drug War. *American Economic Review*, 105(6):1738–1779.

Dell, M., Feigenberg, B., and Teshima, K. (2019). The Violent Consequences of Trade-Induced Worker Displacement in Mexico. *American Economic Review: Insights*, 1(1):43–58.

Didan, K. and Barreto Munoz, A. (2019). MODIS Collection 6.1 (C61) VegetationIndex Product User Guide. Available at: https://lpdaac.usgs.gov/documents/621/MOD13_User_Guide_V61.pdf [Accessed on 10 April 2022].

Do, Q.-T. and Iyer, L. (2010). Geography, poverty and conflict in Nepal. *Journal of Peace Research*, 47(6):735–748.

Dube, O., García-Ponce, O., and Thom, K. (2016). From Maize to Haze: Agricultural Shocks and the Growth of the Mexican Drug Sector. *Journal of the European Economic Association*, 14(5):1181–1224.

Dube, O. and Vargas, J. F. (2013). Commodity Price Shocks and Civil Conflict: Evidence from Colombia. *The Review of Economic Studies*, 80(4 (285)):1384–1421.

Eggers, A. C., Tuñón, G., and Dafoe, A. (2021). Placebo Tests for Causal Inference. Available at: https://www.semanticscholar.org/paper/Placebo-Tests-for-Causal-Inference-Eggers-Tu%C3%B1%C3%B3n/c4f3e54a0908fc1efa89d149c606fac150ed5c50 [Accessed on 10 April 2021].

Estevez, D. (2013). Was Mexican Fugitive Caro Quintero The First Billionaire Drug Lord? Available at: https://www.forbes.com/sites/doliaestevez/2013/10/01/was-mexican-fugitive-caro-quintero-the-first-billionaire-drug-lord/ [Accessed on 10 April 2022].

García Amaro de Miranda, E. (2003). Distribución de la precipitación en la República Mexicana. *Investigaciones geográficas*, (50):67–76.

Gawande, K., Kapur, D., and Satyanath, S. (2017). Renewable Natural Resource Shocks and Conflict Intensity: Findings from India's Ongoing Maoist Insurgency. *Journal of Conflict Resolution*, 61(1):140–172.

Granados, R., Soria-Ruiz, J., and Cortina, M. (2017). Rainfall variability, rainfed agriculture and degree of human marginality in North Guanajuato, Mexico. *Singapore Journal of Tropical Geography*, 38:153–166.

Herrera, J. S. and Martinez-Alvarez, C. B. (2022). Diversifying violence: Mining, export-agriculture, and criminal governance in Mexico. *World Development*, 151(C).

Hoehn-Velasco, L., Silverio-Murillo, A., and de la Miyar, J. R. B. (2021). The great crime recovery: Crimes against women during, and after, the COVID-19 lockdown in Mexico. *Economics & Human Biology*, 41:100991.

Hsiang, S., Meng, K., and Cane, M. (2011). Civil Conflicts Are Associated with the Global Climate. *Nature*, 476:438–41.

Instituto Nacional de Estad ıstica y Geografia (2022). Marco geoestadístico - Catálogo único de claves de áreas geoestadísticas estatales, municipales y localidades. Available at: https://www.inegi.org.mx/app/ageeml/ [Accessed on 10 April 2022].

Instituto Nacional de Estadística y Geografía (2022). Censo Agropecuario 2022. Available at: https://www.inegi.org.mx/contenidos/app/consultapublica/doc/descarga/CA2022/proyecto/Presn_ConsultaCA22.pdf [Accessed on 15 May 2022].

Instituto Nacional de Estadística y Geografía (INEGI) (2017). Defunciones por homicidios. Available at: https://www.inegi.org.mx/sistemas/olap/proyectos/bd/continuas/mortalidad/defuncioneshom.asp?s=est [Accessed on 10 April 2022].

International Fund for Agricultural Development (2017). Investing in rural people in Mexico. Available at: https://www.ifad.org/documents/38714170/39972349/mexico_e.pdf/458074c3-ed5a-4675-979c-a2535ec5477b [Accessed on 15 May 2022].

Iyer, S. and Shrivastava, A. (2018). Religious riots and electoral politics in India. *Journal of Development Economics*, 131(C):104–122.

Labus, M., Nielsen, G., Lawrence, R., Engel, R., and Long, D. (2002). Wheat yield estimates using multi-temporal NDVI satellite imagery. *International Journal of Remote Sensing - INT J REMOTE SENS*, 23:4169–4180.

McGuirk, E. and Burke, M. (2020). The Economic Origins of Conflict in Africa. *Journal of Political Economy*, 128(10):3940–3997.

Mellon, J. (2021). Rain, Rain, Go Away: Potential Exclusion-Restriction Violations for Studies Using Weather as an Instrumental Variable. Available at: https://papers.ssrn.com/abstract=3715610 [Accessed on 10 April 2022].

Miguel, E., Satyanath, S., and Sergenti, E. (2004). Economic Shocks and Civil Conflict: An Instrumental Variables Approach. *Journal of Political Economy*, 112(4):725–753.

Moncada, E. (2019). Resisting Protection: Rackets, Resistance, and State Building. *Comparative Politics*, 51(3):321–339.

Osorio, J. (2015). The Contagion of Drug Violence: Spatiotemporal Dynamics of the Mexican War on Drugs. *Journal of Conflict Resolution*, 59(8).

O'Neil, S. (2009). The Real War in Mexico. *Foreign Affairs.* Available Online: https://www.foreignaffairs.com/articles/mexico/2009-07-01/real-war-mexico [Accessed on 15 May 2022].

Reina, E. (2022). Los agujeros negros de México: cada rincón tomado por el narco. *El País México*. Available at: https://elpais.com/mexico/2022-05-08/los-agujeros-negros-de-mexico-cada-rincon-tomado-por-el-narco.html [Accessed on 10 April 2022].

Reuters (2010). Timeline: Key events in Mexico's drug war. Available at: https://www.reuters.com/article/us-mexico-drugs-timeline-idUSTRE69545H20101006 [Accessed on 15 May 2022].

Rigterink, A. S. (2020). Diamonds, Rebel's and Farmer's Best Friend: Impact of Variation in the Price of a Lootable, Labor-intensive Natural Resource on the Intensity of Violent Conflict. *Journal of Conflict Resolution*, 64(1):90–126.

Rios, V. (2012). Why did Mexico become so violent? A self-reinforcing violent equilibrium caused by competition and enforcement. *Trends in Organized Crime*, 16(2):138–155.

SAGARPA and FAO (2012). México: El sector agropecuario ante el desafío del cambio climático. Available at: `https://www.agricultura.gob.mx/sites/default/files/sagarpa/document/2019/01/28/1608/01022019-cambio-climatico.pdf` [Accessed on 10 April 2022].

Sarsons, H. (2015). Rainfall and Conflict: A Cautionary Tale. *Journal of Development Economics*, 115(July):62–72.

Secretariado Ejecutivo del Sistema Nacional de Seguridad Pública (2022). Incidencia delictiva. Available at: `https://www.gob.mx/sesnsp/es/articulos/incidencia-delictiva` [Accessed on 10 April 2022].

Secretaría de la Defensa Nacional (SEDENA) (2022). Datos abiertos sobre acciones antidrogas – México Unido Contra la Delincuencia. Available at: https://www.mucd.org.mx/datos-abiertos-sobre-acciones-antidrogas/ [Accessed on 10 April 2022].

Servicio de Información Agroalimentaria y Pesquera (2022). Estadística de Producción Agrícola. Available at: `http://infosiap.siap.gob.mx/gobmx/datosAbiertos.php` [Accessed on 10 April 2022].

Shirk, D. and Wallman, J. (2015). Understanding Mexico's Drug Violence. *The Journal of Conflict Resolution*, 59(8):1348–1376.

Sierra, R. (2013). On the Origin of States: Stationary Bandits and Taxation in Eastern Congo. *SSRN Electronic Journal*. Available Online: http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2358701 [Accessed on 14 May 2022].

Smith, B. T. (2021). *The Dope: The Real History of the Mexican Drug Trade*. W. W. Norton & Company, New York.

Stargardter, G. (2018). Violentos cárteles de droga paralizan refinerías de México con robo de combustible. *Reuters*. Available at: https://www.reuters.com/article/delito-mexico-combustible-idARL1N1O61KP [Accessed on 10 April 2022].

The World Bank (2021). Mexico - Climatology. Available at: https://climateknowledgeportal.worldbank.org/country/mexico/climate-data-historical [Accessed on 10 April 2022].

Truqui, E. (2021). Drug Cartels, Politics, and Violence in Mexico. Available at: https://chicagopolicyreview.org/2021/06/04/drug-cartels-politics-and-violence-in-mexico/ [Accessed on 15 May 2022].

United Nations Office on Drugs and Crime (2010). World Drug Report 2010. Available at: https://www.unodc.org/unodc/en/data-and-analysis/wdr-2021—previous-reports.html [Accessed on 15 May 2022].

University of Delaware (2022). Air Temperature and Precipitation. Available at: https://psl.noaa.gov/data/gridded/data.UDel_AirT_Precip.html [Accessed on 10 April 2022].

USGS-NASA (2022). The Terra Moderate Resolution Imaging Spectroradiometer (MODIS) Vegetation Indices (MOD13Q1) Version 6. Available at: https://lpdaac.usgs.gov/products/mod13q1v006/ [Accessed on 10 April 2022].