Drug Cartels and Deforestation: Investigating the Impact of Heroin Demand Shocks on Mexico's Forests

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Abstract

This paper explores the impact of exogenous heroin demand shocks in the United States on illegal logging and deforestation in Mexico. Mexico, a megadiverse country with approximately 65 million hectares of forested area, has lost five million hectares of forest, and illegal logging is one of the key drivers of deforestation. The involvement of drug trafficking organizations in deforestation, coined as "Narco deforestation," is increasing in Central America and Mexico (McSweeney et al., 2014). The illegal logging activities in Jalisco and Michoacán states are controlled by cartels, and state authorities either stay passive or are not able to stop these illegal activities (García-Jiménez and Vargas-Rodriguez, 2021). The timber industry can be attractive for cartels as a means of diversifying their income and compensating for losses related to decreasing poppy and cannabis prices. This study uses heroin demand shocks in the United States to detect changes in cartel behavior. The findings suggest that lower levels of deforestation are observed in deciduous forests, which are less valuable for timber production, following decreasing poppy prices. In contrast, opposite results are observed in coniferous forests, which are the main timber supply for round wood production in Mexico, when a municipality has cartel presence. In other areas, deforestation levels remain stable or decrease following poppy demand shocks. The results imply that cartels cope with income loss through illegal logging. The identification strategy is based on comparing poppy and cannabis-suitable municipalities, with the former impacted by U.S. heroin demand shocks and the latter not (Daniele et al., 2023). The paper concludes that the U.S. heroin market significantly affects deforestation through Mexican cartels' adaptation strategies. The study highlights the importance of considering the indirect effects of drug demand on the deforestation.

Keywords : Deforestation; Environmental degradation; Organized crime; Poppy cultivation; Mexico

JEL classification : Q23; Q34; Q57 ; L72; O13

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1 Introduction

Mexico is a megadiverse country with approximately 65 million hectares of forested areas, of which 49% are tropical forests and 51% are temperate forests that provide essential ecosystem services to millions of people (Torres-Rojo, 2021). However, during the period 1990-2020, Mexico lost five million hectares of forest, primarily due to agricultural expansion (FAO, 2020; Curtis et al., 2018; Kissinger et al., 2012). Illegal timber extraction is the second major cause of deforestation in Mexico, with a particular impact on the coniferous forests that are home to endemic and rare pine trees (Goldstein et al., 2011; Sáenz-Romero et al., 2003). Despite certification programs, illegal logging continues to be a serious problem, with pine trees representing nearly 70% of the total timber production (Blackman and Villalobos, 2021).

The *"Narco deforestation"*, a term coined to reflect the deforestation caused by drug trafficking organizations, is becoming more widespread in Central America and Mexico (McSweeney et al., 2014). From constructing landing strips and roads to isolated areas of Central America for drug trafficking purposes to hindering States capacity to protect environment and oppressing resisting indigenous groups, cartels activities overlap with deforestation (McSweeney et al., 2014). Protected areas in Central America are under constant pressure from drug trafficking organizations, and recent evidence shows that cartels are clearing forests for cattle ranching as a way to smuggle and launder money (Devine et al., 2020, 2021). According to Sesnie et al. (2017), drug trafficking organizations cause between 15 and 30% of annual forest loss in three Central American countries (Nicaragua, Guatemala, and Honduras). The growing literature on the impact of cartels on deforestation is alarming and necessitates more research in other forest-rich countries. Mexico, home to a large amount of illegal activities and various cartels, is not spared from "Narco-deforestation." Several news outlets and quantitative pieces of evidence point out illegal timber extraction as being highly controlled by cartels (García-Jiménez and Vargas-Rodriguez, 2021).

The demand for heroin in the United States experienced two distinct shocks during the period 2010-2020. The first shock occurred in 2010 when OxyContin was reformulated, increasing the demand for heroin in the United States and raising the price of poppies, the raw ingredient of heroin, in Mexico (Daniele et al., 2023; Sobrino, 2020; Evans et al., 2019). The second shock was the gradual introduction of fentanyl to the U.S. market around 2014. Fentanyl is an ingredient that boosts heroin's impact, thus lowering the demand for pure heroin and reducing poppy prices in Mexico (Lopez, 2022; Le Cour Grandmaison et al., 2019). Using these two exogenous shocks, I investigate the cartel's response and their impact on deforestation. To the best of my knowledge, there is no study investigating the impact of heroin demand shocks on deforestation in Mexico. I provide evidence on cartel-induced deforestation following the two opposite demand shocks on a cash crop, poppy.

I adopt the empirical strategy of Daniele et al. (2023) which is used to detect the impact of OxyContin reformulation on the homicide rate and subsequent migration from poppy-growing municipalities to other Mexican cities or the United States. The authors create poppy and cannabis suitability indexes for Mexican municipalities and compare changes occurring in poppy suitable areas with cannabis suitable ones following the heroin demand shock (Daniele et al., 2023). Sobrino (2020), elaborating on a similar but different poppy suitability index based on machine learning, interacts the poppy prices at the retail level (in the United States) with the suitability index to estimate the impact of increasing poppy prices for the same period as Daniele et al. (2023). A similar strategy to Daniele et al. (2023) is employed by Lopez (2022) to analyze the relation between the reduction of poppy prices following the fentanyl introduction, for a different period and an opposite demand shock compared to Daniele et al. (2023) and Sobrino (2020), and cartels' income diversification strategy. She finds increasing homicide rates in avocado production municipalities close to poppy-growing municipalities, implying that the cartel compensates for their income loss by extracting income from avocado production, but she does not find an increased cartel presence in avocado-producing areas Sobrino (2020). There is a growing literature investigating the impact of heroin demand shocks in the United States on the Mexican poppy-growing landscape and cartel adaptation strategies.

My findings indicate lower levels of deforestation in forests less valuable for timber production, while opposite results are observed in coniferous forests, which are the main timber supply for round wood production in Mexico, when the municipality has a cartel presence. Otherwise, deforestation levels remain stable or decrease following the poppy demand shocks. My identification strategy is based on comparing poppy and cannabis-suitable municipalities, following Daniele et al. (2023). The latter has not been impacted by the U.S. heroin demand, while the former has received these shocks.

The paper is organized as follows. Section 2 reviews briefly the role of cartels in illegal logging and forest industry in Mexico followed by recent evolution in U.S. heroin market and its repercussion on Mexican poppy cultivation. Section 3 explains the theory of change by discussing hypothesis in regard of relation between poppy demand shocks and land use. Section 4 presents empirical strategy and data. Section 5 investigates the change in deforestation following two opposite direction poppy demand shock and cartel's role on deforestation. Finally, Section 6 concludes.

2 Background

2.1 Forest industry, illegal logging and the role of cartels

The Mexico boasts a vast array of plant and animal species, thanks to its large and diverse geography (Koleff et al., 2018). Known as a megadiverse country, the forested areas in Mexico cover approximately 65 million hectares, with 49% being tropical forests and 51% being temperate forests (Torres-Rojo, 2021). Both being particularly rich in terms of biodiversity, the latter hosts 50% of pine and 40% of oak species worldwide (Galicia and Zarco-Arista, 2014). The temperate forest, which spans from the Sierra Madre Occidental in northwest Mexico to the Sierra Madre del Sur in the southwest states of Michoacán and Guerrero, provides essential ecosystem services to millions of people. These services include the provision of drinking water, wood, carbon capture, cultural/spiritual services, and eco-tourism, among others (Galicia and Zarco-Arista, 2014).

Even though each region has its own characteristics, the major cause of deforestation in Mexico is, by far, the agricultural expansion and livestock grazing (Figueroa et al., 2021; Goldstein et al., 2011; Monjardín-Armenta et al., 2017). On the other hand, the timber extraction (both legal and illegal), second major driver of deforestation (Goldstein et al., 2011; Kissinger et al., 2012), contributes to the forest loss, particularly in the Sierra Madre Occidental, Trans-Mexican Volcanic Belt and Sierra Madre del Sur (García-Jiménez and Vargas-Rodriguez, 2021).

In 2016, the legal forest industry of Mexico, composed of timber and paper products, contributed 0.23% to the country's GDP and generated 166,664 employments, with 69.6% of those positions being in the timber industry, as reported by the CONAFOR (2019). Mexico primarily exports forest products to the United States and China, while importing a significantly larger quantity from a diverse range of nations. The country's trade deficit in the forest industry sector amounted to 6,165.6 million US dollars in 2017 CONAFOR (2019).

The management and property structure of the Mexican forest landscape diverges from that of other nations with abundant forested areas, due in large part to the emphasis placed on community management (Bray et al., 2003). Specifically, the system of *ejidos* - communal lands utilized for agricultural purposes and established post-Mexican Revolution - and indigenous communities collectively manage nearly 60% of the country's forested regions, comprising a total area of 38 million hectares in 2015 (FAO, 2020). Alongside non-timber products such as eco-toursim, payment for environmental services (PES) (Hernández-Aguilar et al., 2017), in community-managed forests, the production of timber serves as a significant source of income for local communities and has the potential to mitigate poverty (Antinori and Bray, 2005).

In Mexico, the total timber sales currently reaches 17 million m^3 of roundwood as of 2019. However, it is estimated that illegal timber production accounts for over half of this demand, at approximately 9 million m^3 in 2019 (Torres-Rojo, 2021). The coniferous trees such as pines represent nearly 70% of the total timber production followed by oak and fir (García-Jiménez and Vargas-Rodriguez, 2021).

The Mexican government employs forestry permits as a tool to combat illegal logging and deforestation, but with limited success (Blackman and Villalobos, 2021). Conversely, certification and support schemes have been found to have a positive impact on community income and employment (Frey et al., 2019; Cubbage et al., 2015).

Beside timber production and aforementioned ecosystem services, the temperate forest of Mexico provides an atypical service, mentioned rarely in the literature, to cartels. These forests in the mountainous regions of both southern and northern Sierra Madre's provide coverage for drug cultivation such as poppy and cannabis.

The drug cultivation and production mostly concentrated in barely accessible areas with high forest density (UNODC, 2021). The poppy production overlaps with the dense forests of Southern Sierra Madra mountains, particularly Guerrero and Oaxaca, and so called "Golden Triangle" region of Sinaloa, Durango, and Chihuahua. It is likely that in poppy-producing regions, cartels may prioritize preserving the forest in order to preserve poppy cultivation. Additionally, with ongoing drug eradication campaigns, farmers may frequently change their cultivation locations, requiring even larger tree-covered areas. However, in municipalities where drug cultivation is not prevalent or during periods with low drug prices, cartels may adopt different strategies regarding forest preservation. The timber industry in Mexico can be attractive for cartels as a means of diversifying their income and compensating for losses related to decreasing poppy and cannabis prices. Moreover, the fragmentation of cartels following the "war on drugs" policy of Felipe Calderon during 2006-2012 has prompted organized crime to diversify their income sources (Herrera and Martinez-Alvarez, 2022; Magaloni et al., 2020).

According to a Global Initiative Report, in the state of Chihuahua, the cartels are highly involved at illegal logging activities (Wagner et al., 2020). Moreover, the report indicates that the cartels increased their involvement since 2014 corresponding to decrease of raw heroin demand (Wagner et al., 2020). The local mafias are also linked with illegal logging, however, their capacity is much lower than cartels (Wagner et al., 2020). These groups work with cartels, asking their protection and they use violent means in a much lesser extent compared to cartels (Wagner et al., 2020). An example presented by Wagner et al. (2020) from Insight Crime report[1], which also attributes the rise of cartels interest on illegal logging to fall of poppy and cannabis price shows, the stunning capacity of cartels:

> "...about 40 young, armed men (all of whom were under 20 years of age) arrived in dozens of trucks and started cutting down pine trees just outside of the town. Without fearing any interruption by government officials, they were able to continue in this way for a month, removing about 40 truckloads of wood each day." (Wagner et al., 2020)

A recent study shades light on cartel's participation on deforestation activities by illegally extracting timber in the Western Mexico mountains (García-Jiménez and Vargas-Rodriguez, 2021). According to authors, since 2016, the illegal logging activities in Jalisco and Michoacán states are controlled by cartels and state authorities either stay passive or are not able to stop these illegal activities (García-Jiménez and Vargas-Rodriguez, 2021). Moreover, they imply that the community-managed forestry systems are in decline due to cartels intimidation and extortion policies (García-Jiménez and Vargas-Rodriguez, 2021). According to the InsightCrime report, the testimonies of local residents in Chihuahua provide evidence supporting the notion that there is a rise in violence as a result of competition among cartels for control over timber sources.[2] Overall, an important amount of anectodical evidence supports the claim that cartels are benefiting from lucrative timber market in spite of forest preservation and local development.

2.2 Poppy cultivation and heroin trade in Mexico

Mexico is the third largest opium poppy cultivator country in the world after Myanmar and Afghanistan. Three particular regions come out as important poppy producers: first one is the so-called "Golden Triangle" region, encompassing northern Sierra Madre mountains in Chihuahua, Sinaloa and Durango, second on the is the southern Sierra Madre mountains in Guerero and Michoacan states while the third region is the mountains of Oaxaca.[3] This section starts by briefly explaining the history of poppy cultivation and opium production before discussing the recent dynamics of heroin industry in Mexico and United States.

2.2.1 The beginning of poppy cultivation in Mexico

The poppy cultivation in Mexico begins in the following decade of the great Chinese migration around 1910s in the north-western states of Mexico such as Sonora, Sinaloa, Chihuahua and Nayarit (Velázquez

[1] https://insightcrime.org/news/analysis/illegal-logging-chihuahua-mexico-cartel/

[2] https://insightcrime.org/investigations/drug-cartels-illegal-logging-mexico/

[3] https://noria-research.com/chapter-1-the-reddest-flower-in-the-field-how-does-the-opium-poppy-fit-in-the-mexican-agricultural-scene/

and Smith, 2022; Martinez, 2021). This migration was driven by economic opportunities in Mexico, including railway construction near the U.S. border, as well as the American Exclusion Act of 1882, which aimed to limit Chinese immigration to the United States due to Anti-Chinese racism, and thus redirected the flow of migrants to Mexico (Murphy and Rossi, 2020; Martinez, 2021).

Being a long-term tradition in Asia and China, consuming opium in its smoking form, a cultural habit for socialisation has been imported to Mexico with Chinese migrants as well as the poppy seeds and the know-how of poppy cultivation. (Murphy and Rossi, 2020; Velázquez and Smith, 2022). Overtime, the migrants with access to land cultivate poppy and produce smoking opium at small scale (Velázquez and Smith, 2022). Moreover, separated by U.S. - Mexico border, Chinese migrants become an important actor of smuggling activities (Murphy and Rossi, 2020). Following the Harrison Narcotics Tax Act of 1914, the opium prices in the North side of the border increased, increasing the incentives for drug trafficking (Murphy and Rossi, 2020). According to Murphy and Rossi (2020), the importation of opium related know-how and establishment of smuggling networks had long term impact on Mexican organised crime and contributed to socioeconomic development at local level.

On the other hand, known as red mountains - first because of its communist political leaning in 1980s and then due to the color of opium poppy flower - the south-western state of Guerrero has a completely different story (Gaussens, 2018). The poppy cultivation in Guerrero is associated with economic crises, military oppression neoliberal policies and North American Free Trade Agreement (NAFTA) (Gaussens, 2018; Fuentes and Ortiz-Rojas, 2021). Starting around mid-1970s, opium gum production become an important income source for farmers around this region. Today, Guerrero state is the leader at opium production and is being faced with high level of eradication activities (Gaussens, 2018).

2.2.2 Recent dynamics of heroin industry in Mexico and United States

At the beginning of 2000s, the Colombian sourced heroin was dominating the US market (DEA, 2020). Mexican cartels were rather transporters instead of being producers. The United States Drug Enforcement Administration (DEA) follows the origin country of heroin with two distinct programs: Heroin signature program (HSP) and heroin domestic monitor program (HDMP). The HSP conducts analyses to subset of samples from heroin seizures made at borders (Finklea, 2019). It is an indicator for geographic origins of heroin and it allows to detect the changes in trends. However, the sample size is not representative and it does not provide information at retail level (Finklea, 2019). On the other hand, the HDMP aims to monitor the heroin at retail level. The DEA agents buy heroin from retail sellers in 27 cities across the USA. Both programs provide information on purity level and geographical origin.

According to HSP data, four particular period can be defined by the primary supplier region (DEA, 2020): (1) Mexico from 1920 to 1970s, (2) Asia (including Turkey) (1979-1993), (3) South America (mostly Colombia) (1994-2013), (4) Mexico. Since 2003, market share of Mexican heroin increases constantly. The Mexican cartels supply more than 90 % of US heroin since 2015 according to HSP (DEA, 2020).

The Colombian heroin (or more generally South American) had higher purity compared to Mexico-sourced heroin until mid-2010s and was destined to East coast while Mexican heroin was going to West coast of U.S. (Ospina et al., 2018). Since adaptation of South American method by Mexican cartels, Mexican sourced heroin has similar purity level with their Colombian counterparts. Subsequently, the heroin supply in East coast of U.S. passed from Colombia to Mexico-sourced heroin. For Mexican cartels, sourcing opium in Mexico is more lucrative than buying it from Colombia. In just one year, the Mexico-sourced heroin share is increased from 47% (in 2013) to 82% (in 2014) (DEA, 2020).

In 2010, the FDA changed the reformulation of OxyContin, to combat with opiate epidemic. The restricted access to OxyContin through legal markets increased the heroin demand on the streets (Daniele et al., 2023; Lopez, 2022; Sobrino, 2020; Powell and Pacula, 2021; Evans et al., 2019). The OxyContin, an opioid based on oxycodone, released to market in 1996 by Purdue Pharma as a non-addictive pain killer. It has been a great success for its producer due to an aggressive advertising campaign on its less addictive characteristic. However, the opiod crisis linked heavily to OxyContin usage. According to Kenan et al. (2012), the oxycodone prescription increased by 70% between 2000 and 2010.

The extended-release properties of OxyContin facilitated its abuse. During normal usage, OxyContin releases oxycodone slowly over a period of 12 hours. However, individuals can easily crush these pills to obtain the full impact with a single snort (Evans et al., 2019). In response to the increasing incidence of oxycodone addiction, the Food and Drug Administration (FDA) reformulated OxyContin in 2010 to make it more difficult to abuse. However, the unintended consequence of this reformulation was a shift from oxycodone to easily available street heroin. According to the study of Evans et al. (2019), the OxyContin reformulation, in the short-term, reduced opioid deaths but concurrently led to an increase in heroin deaths by the same amount.

The Mexican cartels, which supplied 91% of US heroin in 2017 (Daniele et al., 2023), increased the poppy producing to be able respond this demand shock. Moreover, they compete for control over poppy-growing municipalities which resulted with an increasing violence and out-migration in municipalities suitable for poppy production (Daniele et al., 2023). Moreover, Sobrino (2020) finds an increased cartel presence after 2010 in poppy suitable municipalities by exploiting the exogenous demand shock due to OxyContin reformulation and change in heroin prices.

The last decade has been stamped with the fentanly's introduction to drug market. The fentanyl is a synthetic drug that has become a major concern in the United States due to its high potential for overdose and its association with the opioid epidemic. When mixed with heroin or cocaine, the fentanyl increases the drug's potency and allows dealers to make more profit with less pure heroin (Lopez, 2022). This practice has led to a significant increase in overdose risk, particularly in the United States. According to the Centers for Disease Control and Prevention (CDC), 80997 opioid-related overdoses were reported in 2021, with more than 85% of these deaths being related to synthetic opioids such as fentanyl.[4]

The use of fentanyl by drug dealers in the United States has also led to a reduction of demand of pure heroin from Mexico (Felbab-Brown, 2019; Lopez, 2022; Le Cour Grandmaison et al., 2019). In New York City, for example, the availability of pure heroin has become increasingly scarce, and many long-time users are finding it difficult to obtain the drug without fentanyl adulteration.[5]

The origins of fentanyl have also evolved over time. Initially, the drug was primarily produced and shipped from China to U.S. through the conventional postal services until 2018, when US government and China reached an agreement to reduce the fentanly shipments (Le Cour Grandmaison et al., 2019). Afterwards fentanly smuggled into the United States through Mexico or ordered through the darkweb by drug dealers in United States. However, in recent years, there have been reports of low quality fentanyl production in Mexico by cartels. Furthermore, the origin country of the drug has diversified over time, with recent shipments intercepted by U.S. border agents coming from countries such as South Africa.[6] Despite the agreement between U.S. and China on restrictions and control over fentanyl shipments, there is no sign of reduction of fentanly related overdoses which implies a long-termed change in heroin adulteration habits.

Overall, during the period 2005-2020, it is possible to observe three distinct phenomenons impacting the poppy demand in Mexico: (1) Increased market share of Mexican-sourced heroin, (2) Higher heroin demand due to OxyContin reformulation between 2010 and 2013, (3) Fentanly introduction to drug market reducing the pure heroin demand since 2014. This study takes into account particularly the two opposite demand-side shocks and analyse its impact on land use decision and cartel's income diversification strategy.

2.2.3 Eradication activities

The eradication of poppy and cannabis crops is conducted by the Mexican Secretary of Defence (SEDENA). According to Dube et al. (2016), the army searches for and detects areas with illegal crop cultivation for subsequent eradication. The most commonly used method is manual eradication, which involves the manual harvesting and destruction, primarily by burning, of poppy and cannabis plants. The second method employed is aerial spraying, utilizing an herbicide called Paraquat.[7] The impact of this kind of herbicide usage, such as glyphosate, has been showed to have detrimental effect on health in Colombia, cocaine eradication context (Camacho and Mejia, 2017).

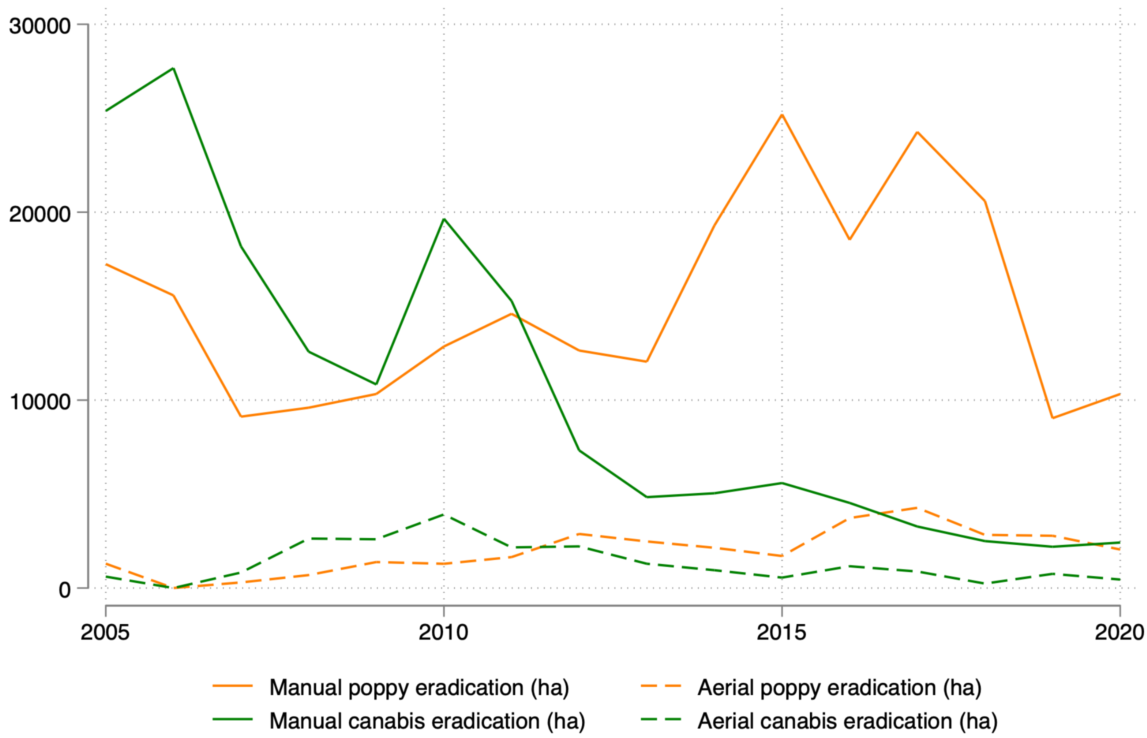
[4] https://www.cdc.gov/nchs/nvss/vsrr/drug-overdose-data.htm

[5] https://www.nytimes.com/2023/01/13/nyregion/new-york-overdose-record.html

[6] https://www.cbp.gov/newsroom/local-media-release/over-220k-lethal-doses-fentanyl-intercepted-cbp-louisville

[7] https://noria-research.com/es-violenta-la-amapola-en-mexico/

Figure 1: Aerial and manual illegal crop eradication amount in Mexico during 2005-2020



Source: Mexican Secretary of Defence (SEDENA)

During the "war on drugs" period (2006-2011), eradication activities were to a lesser extent due to a strategic change in the Mexican government's approach, which allocated more resources towards arresting the leaders of drug trafficking organizations, known as the "kingpin strategy" (Martinez, 2021). However, eradication gradually increased over time, reaching its peak for poppy in 2015 before declining to its lowest level in 2019 since 2005 (see Figure 1).

Despite the fact that the annual amount of poppy eradication reaches 75% of annual poppy cultivation (Dube et al., 2016), there have been doubts about its efficiency and its true goal. Firstly, the amount of eradication does not reduce the smuggled heroin to the U.S. (Martinez, 2021), which raises questions about its effectiveness. Secondly, the poppy eradication campaign has been criticized for being used as a pretext for military presence, particularly in Southern Mexico (Alvarez et al., 2022). According to Alvarez et al. (2022), two particular municipalities targeted by eradication activities were producing a minimal amount of poppy. Thus, it is difficult to justify the use of poppy eradication data as a proxy for poppy cultivation. The motivations behind the eradication activities are not clear and may lead to erroneous conclusions if one wants to proximate the poppy cultivation.

2.3 Similar works

Four articles are particularly aligned with this work and investigating the impact of poppy demand shocks on various outcomes by proposing a causal identification strategy. Daniele et al. (2023) and Sobrino (2020) explore the impact of OxyContin reformulation on poppy suitable municipalities. Daniele et al. (2023) create a poppy suitability index based on temperature, rainfall and soil pH to determine the poppy and marijuana suitable municipalities. They compare migration and violence rate before and after the OxyContin reformulation (i.e. 2010). Their results indicates an increase of violence in poppy producing municipalities. The authors explain this by the higher value of poppy suitable areas in the eyes of cartels after 2010. Furthermore, they find that people are migrating from poppy producing municipalities within country and to USA. Their identification strategy is based on the exogenous demand shock caused by OxyContin reformulation (Daniele et al., 2023).

Sobrino (2020), on the other hand, investigates the same shock but with some methodological differences and a novel data set. The author constructs a cartel presence data at municipality level by employing natural language processing and Google News. Author interacts a poppy suitability index, constructed by employing machine learning algorithm, with annual heroin retail price in United States. The findings indicate an increase of the probability of having at least one cartel in a municipality as well as the cartel number between 2010 and 2016.

The study of Lopez (2022), on the other hand, exploits the fentanyl introduction in 2013 as an exogenous negative demand shock for opium. The author tries to understand the cartels reaction and strategy and argues that the homicides increased in avocado producing municipalities but cartel presence did not. Her identification strategy is based on comparing the poppy suitable municipalities with avocado suitable ones in a difference-in-differences methodology. This study implies that cartels trying to compensate their lost related to low heroin demand by diversifying their incomes in other sectors, in this case avocado production.

The Dube et al. (2016) study the relation between fluctuation of corn price and drug cultivation. They instrument the municipality level corn prices with fluctuations in corn production of biggest four corn exporters – China, France, Argentina, and USA. Their finding suggest that farmers' respond to the income shocks caused by crop prices increases the poppy and cannabis production as well as causes an escalation of violence in municipalities suitable to corn cultivation over the period 2007-2010.

I contribute to this literature by analysing impact of two opposite poppy demand shocks on land use decision, specifically on deforestation. I contribute to the literature on determinants of deforestation, on impact of crop demand shocks and on cartels diversification strategy. Specifically, I establish a connection between cartels income diversification strategy and deforestation.

3 Theory of change

This section explains plausible causal mechanisms behind the impact of demand-side shocks of poppy crop on deforestation. The conceptual framework presented below is based on scientific literature and anectodical evidences acquired from several news outlets as well as from field interviews. I define two actors determining the land use decisions in poppy-growing municipalities: the poppy farmers and cartels.

The reformulation of OxyContin in the United States in 2010 leads to an increase in demand for heroin in following years, as demonstrated by Evans et al. (2019). This subsequently causes a rise in poppy prices and heightens the value of poppy-growing municipalities for drug trafficking organisations (Daniele et al., 2023; Sobrino, 2020). The literature indicates an increase of violence and cartel presence during this period in poppy-growing municipalities as well as increase of poppy prices. (Daniele et al., 2023; Sobrino, 2020).

The impact of increasing price of a cash crop, such as poppy, on deforestation remains ambiguous.

(1) It may push farmers in poppy-growing regions to produce more poppy (without enlarging poppy fields) and to reduce their other economic activities with less economic returns such as timber production or maize cultivation. Thus, a reduction of legal crop cultivation may reduce the pressure on forest. Even though this hypothesis is theoretically possible, it is hard to find supporting evidences.

(2) In contrast, a growing body of literature suggests a positive relationship between cash crop prices and deforestation (Berman et al., 2021; Cisneros et al., 2021; Harding et al., 2021; Guye and Kraus, 2022). This literature, which focuses on legal crops such as soybeans and palm oil, suggests that variations in prices incentivize farmers to expand their agricultural fields. An essential point to keep in mind when considering illegal crop cultivation is its requirement for concealment and the persistent eradication efforts. These two factors restrict expansion in a similar manner as that seen in palm oil or

soybean cultivation. Therefore, even though an increase in price may lead to an increase in production of illegal crops, it may not result in an expansion of cropland, especially in forested areas.

(3) Income from poppy production may have ambiguous impact on migration which in turn may be related to land pressure. As discussed in Daniele et al. (2023), increasing violence due to increase of poppy value may cause migration towards other municipalities or to United States. On the other hand, increasing revenue due to increased prices may reduce the migration flow or even increase the attraction of poppy suitable municipalities.

In case of price reduction related to a demand shock the picture may differ substantially:

(1) The income loss related to poppy cultivation and opium gum production may lead both farmers and cartels to expand their income sources. In isolated, densely tree covered areas an immediate, short-termed solution may be the timber extraction (assuming that they have access to forests). Moreover, farmers may compensate their losses by increasing the maize production. The strategies regarding this income loss may be depend on the duration of low poppy prices. In the long-term case, farmers may be directed towards to other cash crop such as avocado, lime etc.

(2) Another plausible reaction of farmers may be linked to migration and off-farm work. The income loss may incite off-farm work and migration towards areas with off-farm employment which may lower the pressure on land and thus decrease the deforestation.

As mentioned above, beside farmers, an important actor in these isolated poppy growing municipalities is the infamous cartels. The cartels are not unique in the sense of their strategies. They may have different relation with the communities and the local environment. This heterogeneity may impact their behaviour in regard of forest preservation:

(1) The cartels who have long termed aspiration in a given municipality. In this case, they may want to preserve forest to conceal illegal crop cultivation and drug production.

(2) In case of competition over the control of a municipality, cartels may prefer extractive strategies.

(3) The shock to heroin demand could result in a loss of income, which may prompt cartels to seek new sources of revenue and shift their focus towards timber production.

Overall, my expectations about farmers behaviour regarding the timber extraction is that in high (or normal) poppy price period, they will not have an impact on deforestation however after the fentanly introduction, farmers may compensate their income loss with timber extraction. On the other hand, the cartels after establishing in a municipality, may start timber extraction immediately as an income diversification strategy or they may preserver the forest to conceal the poppy cultivation.

4 Empirical strategy

4.1 Data & sample

4.1.1 Homicides

The primary source of homicide data is derived from the mortality database maintained by INEGI. This dataset comprises homicides of males aged 25-40 over the time span of 2005-2020. The selection of this specific demographic group and gender is based on the literature (Herrera and Martinez-Alvarez, 2022). I chose to focus on males aged 25-40 in the data analysis because they are more likely to be killed due to activities related to cartels.

In order to create the homicide rate variable, the number of homicides was divided by the interpolated annual population variable. The latter was obtained by interpolating the census population data, which is reported at five-year intervals and was retrieved from National Municipality Information System (Sistema Nacional de Información Municipal).[8] I use both raw homicide rate variable and normalised (z-score) homicide rate in the analysis. The z-score computed by using the mean and standard deviation of municipality level homicide rate for the period 2005-2020.

4.1.2 Deforestation

The deforestation dataset used in this study comes from widely known Global Forest Watch (GFW) (Hansen et al., 2013). It provides information on the tree cover loss across the globe at an estimated resolution of 30 x 30 meters. The data was collected using multispectral satellite imagery and corrected with supervised machine learning algorithms. The dataset provide two variables: "tree cover" variable, available only for 2000, shows the vegetation higher than 5 meters while "tree cover loss" refers to complete canopy removal at 30 x 30 meters pixel scale.[9]

I isolate pixels with tree cover higher then 30% in 2000 with the aim of detecting high canopy covered areas. To estimate annual deforestation in each Mexican municipality, the number of deforested pixels is multiplied by the corresponding pixel area in hectares within the municipal borders. This yielded the annual deforestation in hectares per municipality in areas with at least 30% tree cover.

Furthermore, annual deforestation is calculated separately for deciduous and coniferous forest areas. To achieve this, I use land use map for 2009, obtained from the Mexican National Statistics Agency.[10] This map provides information on various forest types, including deciduous and coniferous forests. The latter are primarily used in the timber sector at national level for construing and manufacturing activities, while the former are mainly utilized for local wood consumption. Figure 3 presents the distribution of these two forest type in Mexico. The cause of deforestation differs between these two forest types. The primary cause in deciduous forest is agricultural expansion while in the coniferous forest both agricultural expansion and logging activities play an important role. The objective of this separation was to estimate the deforestation related to timber production that is expected to occur in coniferous forest areas. Using the same tree cover threshold, deforestation in coniferous and deciduous forest areas was calculated for each Mexican municipality.

Besides the raw deforestation variable in hectares, I calculate the deforestation part which is equal to raw deforestation divided by the tree cover in 2000. Moreover, I transform the raw variable with inverse hyperbolic sine transformation and finally I calculate the normalised (z-score) deforestation.[11]

4.1.3 Poppy and cannabis suitability index

The widely used crop suitability index from FAO/GAEZ database do not have information on illegal crops. The literature on poppy and cannabis cultivation relies on self-made indexes. I employ poppy and cannabis indexes elaborated by Daniele et al. (2023) for Mexico. Authors use Mexican land use map which is divided in several territory with similar agro-ecological characteristic. They create a dummy variable which equals to 1 if the territory has the necessary temperature, rainfall, and soil pH characteristics for poppy or cannabis cultivation (Daniele et al., 2023).[12] Then, they calculate the poppy and cannabis suitables land area (in km^2) for each municipality (Daniele et al., 2023). Figure 2 shows the distribution of poppy and cannabis suitable municipalities.

[8] http://www.snim.rami.gob.mx

[9] https://data.globalforestwatch.org/maps/gfw::tree-cover-loss-1/about

[10] https://www.inegi.org.mx/temas/usosuelo/#Descargas

[11] Z-scores are computed by the following formula where i is municipality and t is year. $MeanDef_i$ equals to average deforestation in municipality i during the period 2005-2020 and $SDDef_i$ equals to standard deviation of deforestation in municipality during the same period: $ZSDef_{it} = (Def_{it} - MeanDef_i)/SDDef_i$

[12] The information for environmental requirements of poppy and cannabis related to these three variables comes from FAO EcoCrop database

4.1.4 Cartel presence

The only, openly available cartel presence data at municipality level is from Coscia and Rios (2012). This dataset covers the period 1990-2010 and it has information at municipality level at annual basis on cartel presence, number of cartels present in a municipality and the name of the organisation Coscia and Rios (2012). Coscia and Rios (2012) construct this data by using MOGO framework which consists of three steps: First, they define the query terms such as the cartel names, municipality names, and actors, second, they send the queries to Google News, third they identify the year and municipality matched in the queries (Coscia and Rios, 2012).

4.1.5 Other variables

I use agricultural dataset provided by SIAP/SAGARPA. The data has the production, sown area, and local agricultural price information at annual basis and municipality level for the period 2003-2020. I calculate average nighttime light per municipality using harmonised nighttime light dataset from Li et al. (2020) to approximate the urbanisation rate of Mexican municipalities. The aerial illegal crop eradication data comes from SEDENA. I calculate median elevation for each municipality using the JPL (2020) dataset.

4.2 Defining poppy growing municipalities

The lack of official statistics on poppy production at municipality level necessitate creative solutions to determine the poppy producing municipalities. Two distinct methods come out during the literature review. The first one consist of employing a poppy suitability index as a proxy for poppy cultivation (Lopez, 2022; Daniele et al., 2023; Sobrino, 2020). All of the mentioned studies show that the poppy suitability indexes, created by different methods, correlate with poppy eradication at municipality level.

The Dube et al. (2016), on the other hand, benefits from the poppy eradication data available at municipality level and published since more than three decades by the Secretariat of National Defense (SEDENA) to approximate the poppy production at municipality level. Authors emphasize that the Mexican army eradicates approximately 75% of the poppy cultivation each year and conclude that the eradication data would be a good proxy for the poppy cultivation (Dube et al., 2016). However, a qualitative study on poppy eradication reports that the Mexican army use the eradication as a mean for oppression and a justification for military presence which casts doubt on usage of eradication data as a proxy (Alvarez et al., 2022).[13]

In this study, I elaborate on the empirical strategy, following recent literature, by basing it on the Poppy Suitability Index. The utilization of a weather and geography-based index reduces potential endogeneity concerns associated with poppy eradication data. I use the poppy suitability index elaborated by Daniele et al. (2023).

4.3 Identification strategy

The following are the counterfactual questions arising in this context: What would happen if there were no poppy price shocks? Would cartels increase or decrease their deforestation activities? Would farmers continue poppy production in the absence of reducing heroin demand?

The identification strategy, aimed to answer the questions above, consists of comparing the poppy suitable municipalities with the cannabis suitable ones. These municipalities share similar characteristics (show in Daniele et al. (2023)) which allows to isolate the impact of poppy price shocks. The poppy suitable municipalities represent the treatment group while cannabis suitable ones are the counterfactuals.

In my setting, different than Daniele et al. (2023), there are two opposite price shocks occurring subsequently during the study period. First shock, begins around 2010 due to OxyContin reformulation, increases the poppy prices in Mexico (Daniele et al., 2023; Sobrino, 2020). The second one, related

[13] https://blogs.lse.ac.uk/latamcaribbean/2022/12/01/operations-to-eradicate-illicit-crops-ended-as-counterinsurgency-actions-in-mexico/

to introduction of fentanly to U.S. drug market around 2014, reduces the heroin demand in U.S. and consequently the poppy prices in Mexico (Lopez, 2022; Le Cour Grandmaison et al., 2019).

4.3.1 Threats to identification

In this context, the concern revolves around the legalization of cannabis in certain states in the United States and its effect on land use decisions in Mexico. The decrease in demand for cannabis may result in the search for alternative income sources in municipalities that produce cannabis, potentially leading to an increase in deforestation. Additionally, there may be a spatial spillover effect from municipalities that cultivate cannabis to those that cultivate poppies. If profits from cannabis production decrease, cartels may shift their focus to poppy cultivation. This latter concern is particularly pertinent during the period from 2010 to 2013, when poppy prices were elevated. Contrary to the approach adopted in Daniele et al. (2023), which incorporates an interaction term between the suitability for cannabis cultivation and a binary variable indicating years post-2010, I pursue an alternative strategy in this study to control both spillover effects from cannabis producing municipalities and cannabis demand shock.

First, I construct a cannabis demand shock variable which consist of interaction of cannabis suitability index with the cumulative number of the states legalised recreational cannabis usage in United States. In theory this variable capture the demand reduction over the years in a municipality producing cannabis:

$$CannabisDemandShock_{i,t} = CannabisSuit_i * CumStateNumber_t \tag{1}$$

$CannabisSuit_i$ equals to inverse hyperbolic sine transformed amount of cannabis suitable land in km^2, (obtained from Daniele et al. (2023)) $CumStateNumber_t$ reflects the cumulative number of state legalised the recreational cannabis usage in United stated between 2005-2020.

Second, related to spatial spillover effect, I create a variable which reflects the cannabis suitable area around a poppy-growing municipality corrected by the distance. For each poppy-growing municipality I calculate the distance to all cannabis-growing municipalities. Then, I divide the cannabis suitable area with this distance to finally sum up these values. I interact this spatial variable with cumulative number of states legalised recreational cannabis usage in United States:

$$CannabisSpatialEffect_{i,t} = (\sum_{k=1}^{N} CannabisSuit_k / Distance_{i,k}) * CumStateNumber_t \tag{2}$$

A second threat to identification is related to aerial fumigation activities which may reduce the agricultural yields and forest cover. I control for the annual aerial fumigation at municipality level.

Thirdly, it is possible that the suitability index for poppy is correlated with the levels of tree cover and deforestation. To investigate this possibility, I conduct a test of this hypothesis as shown in Table 2. The results show no significant differences in tree cover or deforestation levels in poppy-growing municipalities between the years 2005 and 2009.

4.3.2 Baseline specification

The baseline specification is estimated by the following equation for the period 2005-2020 :

$$Y_{it} = \beta_1 PoppySuit_i * OxyPer_t + \beta_2 PoppySuit_i * FentanylPer_t + X'_{it}\gamma + \delta_i + \phi_t + \psi_{st} + \omega_{it} + \epsilon_{it} \tag{3}$$

The different outcomes in municipality i and year t are represented by the variable Y_{it}. The primary outcomes of interest are the homicide rate and deforestation. For the homicide rate, both raw and z-score variables are utilized.[14] In terms of deforestation, four alternative measures are used, including raw deforestation in hectares, deforestation as a percentage of the municipality-level forest area in 2000,

[14] For details regarding the transformation methods, please refer to subsubsection 4.1.1

the inverse hyperbolic sine transformation of raw deforestation, and z-score.[15] The treatment variables are constructed by interacting the poppy suitability variable in km^2, obtained from Daniele et al. (2023), $PoppySuit_i$ with period dummies $OxyPer_t$ and $FentanylPer_t$, respectively, which are equal to one if the year t falls within the periods of 2010-2013 and 2014-2020.

X_{it} symbolise the following municipality level time-varying control variables: nighttime lights provided by Li et al. (2020), agricultural area per municipality area from SIAP/SAGARPA, aerial eradication activity by spraying pesticide in hectares from SEDENA[16]. X_{it} also included the $CannabisDemandShock_{it}$ and $CannabisSpatialEffect_{it}$ variables described in Equation 1 and Equation 2, respectively.

δ_i are municipality fixed effects controlling for time invariant characteristics of municipalities, ϕ_t are year fixed-effects capturing time shocks common to all municipalities, and ψ_{ts} include state-year or macro region-year fixed effects.[17] ω_{it} represents baseline characteristics interacted with year fixed effects. These baseline characteristics are distance to nearest U.S. border entrance point, mean elevation, and area of coniferous and deciduous forests (all transformed with inverse hyperbolic sine formula). Finally, ϵ_{it} is the error term and standard errors are clustered at the municipality level.

5 Results

5.1 Impact on homicides

First, I replicate the analysis conducted in Daniele et al. (2023) with little modification[18] and extend the study period to encompass the year 2020, in order to incorporate the price shock associated with the introduction of fentanyl. The dependent variable in this analysis is the homicide rate for PPML estimator. For TWFE estimator I use inverse hyperbolic sine transformed homicide rate as well as z-score homicide rate, with the aim of detecting changes in the violence conducted by cartels in response to changes in poppy prices. The results displayed in Table 1 are consistent with the findings of Daniele et al. (2023) and imply an increase in the homicide rate in municipalities where poppies are grown following the reformulation of OxyContin (but only for z-score homicide variable and when macro region-year fixed effects included). This may indicate a conflict between cartels for control over these areas. However, during the subsequent period when poppy prices stabilized and declined, the increase in the homicide rate ceased. This finding supports the idea that the value of poppy-growing municipalities decreased.

However, the effects are near zero when state-year fixed effects are included. This suggest that the state-year trends may have an important correlation with homicide rate and probably with cartel activity. Therefore in following analysis, I include state-year fixed effects instead of macro region-year fixed effects.

[15]For details regarding the transformation methods, please refer to subsubsection 4.1.2

[16]All the mentioned variables are transformed by inverse hyperbolic sine formula

[17]Daniele et al. (2023) use macro region-year fixed effects in their study. These regions, created by by Mexican National Institute of Statistics, share similar environmental characteristic and divide the country to 8 regions. I prefer to use state-year FEs as it presents better control for state specific trends but I also present results with macro region-year FEs.

[18]In addition to the different time period, my study includes the following baseline characteristics that are interacted with year fixed effects: Ihs (distance to entry points), Ihs (median elevation), and Ihs (sum of coniferous and deciduous forests in 2009 in hectares). Furthermore, the control variables used in my study are different from those used in Daniele et al. (2023).

Table 1: Homicides in poppy suitable municipalities during OxyContin and Fentanyl periods - Treatment: IHS poppy suitability interacted with period dummies (2010-2013 and 2014-2020) - Period: 2005-2020

	Macro region FEs			State FEs		
	(1) Homi. rate	(2) Ihs(Homi. rate)	(3) ZS Homi. rate	(4) Homi. rate	(5) Ihs(Homi. rate)	(6) ZS Homi. rate
Poppy X OxyPer	0.016 (0.018)	0.022 (0.014)	0.018* (0.009)	0.004 (0.018)	0.003 (0.013)	0.003 (0.009)
Poppy X FenPer	0.006 (0.016)	-0.002 (0.014)	0.005 (0.009)	-0.002 (0.017)	-0.015 (0.014)	-0.003 (0.009)
Ihs(NTL)	-0.505*** (0.085)	-0.358*** (0.047)	-0.289*** (0.033)	-0.465*** (0.091)	-0.327*** (0.052)	-0.273*** (0.035)
Ihs(Agri. area per ha)	-0.383 (0.463)	0.439 (0.301)	0.149 (0.209)	0.003 (0.478)	0.446 (0.297)	0.087 (0.204)
Ihs(Aerial Spraying)	-0.018 (0.015)	-0.031 (0.021)	-0.018 (0.020)	-0.029* (0.015)	-0.038* (0.021)	-0.025 (0.020)
Cannabis spillover	0.000 (0.000)	0.000** (0.000)	0.000* (0.000)	-0.000 (0.000)	-0.000 (0.000)	-0.000 (0.000)
Ihs(Cannabis demand)	0.001 (0.002)	-0.001 (0.002)	0.001 (0.001)	0.002 (0.002)	-0.000 (0.001)	0.001 (0.001)
Observations	13,131	15,003	15,003	13,129	15,003	15,003
Municipalities	.	938	938	.	938	938
Mean Y	12.064	1.607	-0.000	12.066	1.607	-0.000
Treated units	460	460	460	460	460	460
R^2	0.465	0.008	0.010	0.499	0.005	0.007
PPML	Yes	No	No	Yes	No	No
MacroRegion-Year FEs	Yes	Yes	Yes	No	No	No
State-Year FEs	No	No	No	Yes	Yes	Yes

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Standard errors in parentheses are clustered by municipality. All regressions include municipality, year fixed effects. Table presents adjusted within R^2 for TWFE and pseudo R^2 for PPML. Following baseline characteristics are interacted with year FEs: Ihs(Distance to entry points), Ihs(Median elevation), and Ihs(Sum of coniferous and deciduous forests in 2009 (ha)). Units of observation are municipality-years from 2005 to 2020. All control variables are presented in table. User-written command is used for TWFE estimations (Correia, 2016) and user-written is used for PPML estimations (Correia et al., 2019).
Data sources: Deforestation data come from GFW (Hansen et al., 2013), agricultural data from SIAP/SAGARPA, nighttime light data from Li et al. (2020)..

However, the cease of homicide rate does not necessarily means that the cartels are leaving the area. It may indicate the end of the turf wars, total control of one cartel over the municipality, or resistance breakdown of local groups.

5.2 Impact on deforestation

This study focuses on the land use repercussions of poppy demand shocks. I start to land use analysis with deforestation and continue with agricultural outcomes. I calculate the deforestation separately for deciduous and coniferous forests in Table 2 and Table 4 as described in subsubsection 4.1.2. The timber production industry places significant value on coniferous trees due to their high-quality wood. Deciduous trees, by contrast, are mostly utilized for local consumption. Sawnwood manufacturers primarily rely on coniferous wood. Agricultural expansion is identified as the major contributor to deforestation in deciduous forests, and current evidence suggests that timber production has a limited impact on these forests. However, in Mexico, coniferous trees are a significant source of timber, and reports indicate that cartels may be involved in the illegal extraction of this valuable resource.[19]

Before presenting the results on deforestation, Table 2 shows the differences between municipalities in pre-treatment period (i.e. between 2005-2009) regarding tree cover and deforestation outcomes. The dependent variable for initial tree stock equals to part of tree covered area out of total municipality area. The deforestation variables are average deforestation occurred during the period 2005-2009 in whole municipality, in coniferous forests and in deciduous forests. I use inverse hyperbolic sine transformed version of these variables but results are very similar if I use raw variables. Moreover I include all

[19] https://insightcrime.org/investigations/drug-cartels-illegal-logging-mexico/

of the control variables mentioned in Equation 3.[20] The cross-section regression provides descriptive information and implies that the treatment variable, $Ihs(PoppySuitability)$, does not have a significant relation with tree cover and deforestation in pre-treatment period once conditioned for control variables and state fixed effects.

Table 2: Differences between municipalities regarding tree cover in 2000 and deforestation outcomes before poppy price shocks

	Tree cover % in 2000	Avr. deforestation (2005-2009)		
	(1) TC %	(2) Ihs(Def. total)	(3) Ihs(Def. coniferous)	(4) Ihs(Def. deciduous)
Ihs(Poppy suitability)	-0.424	-0.002	0.025	-0.014
	(0.324)	(0.020)	(0.018)	(0.014)
Ihs(Cannabis suitability)	0.313	0.098^{***}	0.027	0.061^{***}
	(0.397)	(0.025)	(0.020)	(0.018)
Ihs(NTL)	-9.248^{***}	-0.503^{***}	-0.195^{***}	-0.073
	(1.031)	(0.064)	(0.047)	(0.048)
Ihs(Agricultural area %)	-1.823	0.141	0.107	0.693^{***}
	(5.806)	(0.305)	(0.200)	(0.202)
Ihs(Aerial eradication)	1.527	0.090	0.182^{***}	0.221^{**}
	(1.294)	(0.074)	(0.046)	(0.086)
Ihs(Distance to US entry points)	0.520	-0.041	0.095	0.334^{**}
	(4.377)	(0.218)	(0.180)	(0.160)
Ihs(Elevation)	-0.148	-0.614^{***}	0.152^{***}	-0.494^{***}
	(0.769)	(0.062)	(0.035)	(0.058)
Ihs(Coniferous + deciduous forests)	0.837^{*}	0.202^{***}	0.234^{***}	0.343^{***}
	(0.474)	(0.029)	(0.020)	(0.024)
Observations	938	938	938	938
Mean Y	37.988	2.667	0.782	0.975
$Adjusted R^2$	0.382	0.661	0.395	0.620
State-Year FEs	Yes	Yes	Yes	Yes

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Standard errors in parentheses are clustered by municipality. All regressions include state fixed effects. Table presents adjusted R^2. All control variables are presented in table. Deforestation variables, NTL, agriculture area %, and aerial eradication are averages of 2005-2009. User-written *"reghdfe"* command is used for all estimations (Correia, 2016).
Data sources: Deforestation data come from GFW (Hansen et al., 2013), agricultural data from SIAP/SAGARPA, nighttime light data from Li et al. (2020).

The Table 3 presents the change of deforestation in poppy growing municipalities following subsequent and opposite heroin demand shocks without differentiating by forest type. According to hypothesis stated in section 3, I expect an increase of deforestation during the fentanly period, when the poppy prices fall down. I find insignificant relation between poppy suitability and deforestation during Oxycontin reformulation period (but only when macro region-. However, unexpectedly, the coefficients for poppy suitability variable during the fentanyl period are negative and significant (for at least ihs and z-score transformed outcomes).

[20] I use the average values for NTL, agricultural area %, aerial eradication for the period 2005-2009.

Table 3: Deforestation in poppy suitable municipalities during OxyContin and Fentanyl periods - Treatment: IHS poppy suitability interacted with period dummies (2010-2013 and 2014-2020) - Period: 2005-2020

	Deforestation (Hansen et al., 2013)							
	(1) Raw def. (ha)	(2) Def. part	(3) Ihs(Def.)	(4) ZS Def.	(5) Raw def. (ha)	(6) Def. part	(7) Ihs(Def.)	(8) ZS Def.
Poppy X OxyPer	-1.203	0.002	-0.011	-0.006	-0.700	0.002	-0.009	-0.004
	(1.458)	(0.002)	(0.007)	(0.009)	(1.138)	(0.002)	(0.006)	(0.009)
Poppy X FenPer	-2.111	-0.005	-0.024**	-0.034***	-0.445	-0.004	-0.026**	-0.029***
	(2.432)	(0.003)	(0.011)	(0.011)	(2.140)	(0.004)	(0.011)	(0.011)
Ihs(NTL)	24.554	0.108***	0.135***	0.170***	46.430***	0.122***	0.128***	0.164***
	(15.818)	(0.029)	(0.037)	(0.042)	(17.253)	(0.036)	(0.040)	(0.046)
Ihs(Agri. area per ha)	153.472**	-0.480	-0.159	-0.064	-0.247	-0.591	-0.224	-0.136
	(62.706)	(0.485)	(0.184)	(0.222)	(28.497)	(0.513)	(0.191)	(0.231)
Ihs(Aerial Spraying)	2.343	-0.000	0.014	0.029	0.915	-0.004	-0.001	0.009
	(4.414)	(0.003)	(0.020)	(0.021)	(2.842)	(0.003)	(0.017)	(0.019)
Cannabis spillover	-0.078***	-0.000	-0.000	-0.000***	-0.063***	-0.000	-0.000**	-0.000***
	(0.025)	(0.000)	(0.000)	(0.000)	(0.019)	(0.000)	(0.000)	(0.000)
Ihs(Cannabis demand)	2.447***	0.001***	0.002*	0.003**	1.723***	0.001***	0.002**	0.003***
	(0.797)	(0.000)	(0.001)	(0.001)	(0.519)	(0.000)	(0.001)	(0.001)
Observations	15,008	15,008	15,008	15,008	15,008	15,008	15,008	15,008
Municipalities	938	938	938	938	938	938	938	938
Mean Y	132.993	0.212	2.522	0.000	132.993	0.212	2.522	0.000
Treated units	460	460	460	460	460	460	460	460
R^2	0.010	0.008	0.005	0.009	0.007	0.009	0.008	0.011
MacroRegion-Year FEs	Yes	Yes	Yes	Yes	No	No	No	No
State-Year FEs	No	No	No	No	Yes	Yes	Yes	Yes

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Standard errors in parentheses are clustered by municipality. All regressions include municipality and year fixed effects. Table presents within R^2 for TWFE and pseudo R^2 for PPML. Following baseline characteristics are interacted with year FEs: Ihs(Distance to entry points), Ihs(Median elevation), and Ihs(Sum of coniferous and deciduous forests in 2009 (ha)). Units of observation are municipality-years from 2005 to 2020. All control variables are presented in table. User-written *"reghdfe"* command is used for all estimations (Correia, 2016).
Data sources: Deforestation data come from GFW (Hansen et al., 2013), agricultural data from SIAP/SAGARPA, nighttime light data from Li et al. (2020).

Intrigued by these results, I continue to analysis by separately investigating the deforestation occurring in different forest types. The poppy and cannabis cultivation overlap particularly with coniferous and deciduous forests (see Figure 2 and Figure 3 in Appendix A). My expectations, in this case, would be to see an increase of deforestation in coniferous forests. The Table 4 presents the deforestation by coniferous and deciduous forests and the results imply no change of deforestation in coniferous forest while a significant reduction of deforestation in deciduous forest lands.

Overall, I do not find an increase of deforestation following the decline of poppy prices. On the contrary the results in Table 3 and Table 4 indicate a decrease of deforestation in poppy growing-municipalities. The next section investigates the heterogeneity by cartel presence. Then, I investigate if the agricultural land and production is impacted by the poppy price shocks.

Table 4: Deforestation in poppy suitable municipalities during OxyContin and Fentanyl periods - Heterogeneity by forest type - Period: 2005-2020

	Raw def. (ha)	Def. part	Ihs(Def.)	ZS Def.
	(1)	(2)	(3)	(4)
Panel A: Deforestation in deciduous forests				
Poppy X OxyPer	0.105	0.000	-0.008	-0.001
	(0.224)	(0.001)	(0.005)	(0.008)
Poppy X FenPer	-0.678**	-0.001	-0.033***	-0.034***
	(0.313)	(0.001)	(0.008)	(0.009)
Panel B: Deforestation in coniferous forests				
Poppy X OxyPer	0.271	0.000	-0.005	-0.006
	(0.190)	(0.001)	(0.006)	(0.006)
Poppy X FenPer	0.435	-0.001	-0.011	-0.007
	(0.527)	(0.002)	(0.010)	(0.008)
Observations	15,008	15,008	15,008	15,008
Municipalities	938	938	938	938
Mean Y	8.498	0.026	0.792	0.000
Treated units	460	460	460	460
State-Year FEs	Yes	Yes	Yes	Yes

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Standard errors in parentheses are clustered by municipality. All regressions include municipality, year fixed effects. Following baseline characteristics are interacted with year FEs: Ihs(Distance to entry points), Ihs(Median elevation), and Ihs(Sum of coniferous and deciduous forests in 2009 (ha)). Units of observation are municipality-years from 2005 to 2020. All control variables are presented in table. User-written *"reghdfe"* command is used for all estimations (Correia, 2016).
Data sources: Deforestation data come from GFW (Hansen et al., 2013), agricultural data from SIAP/SAGARPA, nighttime light data from Li et al. (2020).

5.3 Heterogeneity by cartel presence

As indicated in section 3, the presence of a cartel may lead to an increase in deforestation if the cartel adopts an income diversification strategy or a short-sighted extraction strategy. The available municipality-level cartel presence data, retrieved from open access sources (Coscia and Rios, 2012), only extends up to 2010, which severely limits the scope of this analysis.

To assess heterogeneity by cartel presence, I first interact the treatment variables with a dummy variable which equals to one if the municipality had a cartel presence in 2010 (as seen in Panel A of Table 5). Next, in Panel B of Table 5, I modify the interaction term to reflect the number of years the municipality had a cartel presence. This allows me to determine if there is a correlation between the duration of cartel presence and increased deforestation. Finally, in Panel C of Table 5, I interact the treatment variables with two cartel indicators: $OneCartel$ variable equal to one if the municipality had only one cartel present in 2010, and $MultipleCartels$ variable equal to one if the municipality had multiple cartels in 2010. This allows me to test if competition between cartels contributes to extractive behavior.

Table 5: Deforestation in poppy suitable municipalities during OxyContin and Fentanyl periods - Heterogeneity by cartel presence - Period: 2005-2020

	Total def.		Def. in coniferous forest		Def. in deciduous forest	
	(1) Ihs(Def.)	(2) ZS Def.	(3) Ihs(Def.)	(4) ZS Def.	(5) Ihs(Def.)	(6) ZS Def.
Panel A: Deforestation in cartel present municipalities in 2010						
Poppy X OxyPer	-0.012*	-0.006	-0.009	-0.012*	-0.010*	-0.001
	(0.007)	(0.010)	(0.007)	(0.007)	(0.006)	(0.009)
Poppy X OxyPer X CarPre2010	0.009	0.009	0.014	0.018*	0.005	-0.001
	(0.009)	(0.015)	(0.009)	(0.010)	(0.008)	(0.013)
Poppy X FenPer	-0.038***	-0.040***	-0.018*	-0.013	-0.032***	-0.034***
	(0.012)	(0.012)	(0.010)	(0.008)	(0.008)	(0.009)
Poppy X FenPer X CarPre2010	0.037**	0.034**	0.020	0.021*	-0.001	0.000
	(0.016)	(0.017)	(0.014)	(0.012)	(0.011)	(0.013)
Panel B: Deforestation by year of cartel presence						
Poppy X OxyPer	-0.010	-0.005	-0.009	-0.012*	-0.010*	-0.004
	(0.007)	(0.010)	(0.006)	(0.007)	(0.005)	(0.009)
Poppy X OxyPer X CarPreLT	0.000	0.001	0.002**	0.003**	0.001	0.002
	(0.001)	(0.002)	(0.001)	(0.001)	(0.002)	(0.002)
Poppy X FenPer	-0.030**	-0.034***	-0.017*	-0.013*	-0.030***	-0.033***
	(0.012)	(0.012)	(0.010)	(0.008)	(0.008)	(0.009)
Poppy X FenPer X CarPreLT	0.003	0.003	0.004**	0.004**	-0.001	-0.001
	(0.003)	(0.003)	(0.002)	(0.002)	(0.002)	(0.002)
Panel C: Deforestation by number of cartels						
Poppy X OxyPer	-0.012*	-0.007	-0.009	-0.012*	-0.010*	-0.001
	(0.007)	(0.010)	(0.007)	(0.007)	(0.006)	(0.009)
Poppy X OxyPer X OneCartel	0.009	-0.007	0.016	0.014	0.004	-0.018
	(0.013)	(0.021)	(0.012)	(0.015)	(0.012)	(0.017)
Poppy X OxyPer X MultipleCartels	0.009	0.019	0.012	0.021*	0.006	0.009
	(0.011)	(0.016)	(0.010)	(0.011)	(0.010)	(0.015)
Poppy X FenPer	-0.038***	-0.040***	-0.017*	-0.013	-0.032***	-0.034***
	(0.012)	(0.012)	(0.010)	(0.008)	(0.008)	(0.009)
Poppy X FenPer X OneCartel	0.029	0.010	0.022	0.012	0.000	0.000
	(0.021)	(0.023)	(0.022)	(0.017)	(0.017)	(0.018)
Poppy X FenPer X MultipleCartels	0.043**	0.048***	0.019	0.027*	-0.002	-0.000
	(0.018)	(0.018)	(0.017)	(0.014)	(0.013)	(0.015)
Observations	15,008	15,008	15,008	15,008	15,008	15,008
Municipalities	938	938	938	938	938	938
Mean Y	2.522	0.000	0.792	0.000	0.863	-0.000
Treated units	460	460	460	460	460	460
State-Year FEs	Yes	Yes	Yes	Yes	Yes	Yes

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$. Standard errors in parentheses are clustered by municipality. All regressions include municipality, year fixed effects. Following baseline caracteristics are interacted with year FEs: Ihs(Distance to entry points), Ihs(Median elevation), and Ihs(Sum of coniferous and deciduous forests in 2009 (ha)). Units of observation are municipality-years from 2005 to 2020. All control variables are presented in table. User-written *"reghdfe"* command is used for all estimations (Correia, 2016).
Data sources: Deforestation data come from GFW (Hansen et al., 2013), agricultural data from SIAP/SAGARPA, nighttime light data from Li et al. (2020).

The coefficients of the interaction terms in all three settings show results that are opposite to those indicated in the previous section when interacted with various cartel indicators. Specifically, the results indicate that deforestation increased during the period from 2014 to 2020, particularly in coniferous forests (as seen in columns 3 and 4 of Table 5). Panel A imply an important increase in total deforestation in cartel present municipalities due to deforestation in coniferous forest while in municipalities without cartel there has been a reduction. Panel B shows similar results and Panel C reveals that the increase in deforestation is higher in municipalities with at least two cartels compared to those with only one cartel, suggesting that the presence of competition may have led to extractive behavior. Alternatively, this could also indicate that the cartels are competing for natural resources Herrera and Martinez-Alvarez (2022), such as timber which can become a significant source of income for cartels during periods of reduced or disappearing classical income sources, such as poppy production.

6 Conclusion

Mexico's forest provide essential ecosystem services to millions of people and hosts endemic species, but the country has lost five million hectares of forest due to agricultural expansion and illegal timber extraction, with coniferous forest being the most affected by the latter. The growing literature on the impact of drug trafficking organizations on deforestation is alarming, and recent evidence shows that the *"Narco deforestation"* is becoming more and more widespread in Central America and Mexico. Furthermore, the demand for heroin in the United States has had a significant impact on poppy prices in Mexico, providing an opportunity to investigate the cartel's response and their impact on deforestation. The study provides evidence on cartel-induced deforestation following the two opposite demand shocks on a cash crop, poppy. The findings suggest that the presence of cartels increases deforestation in coniferous forests, used for timber manufacturing sector, while deforestation in deciduous forest stays stable or decreases. These results underline the importance of designing policies to address the root causes of illegal activities and provide alternatives to local communities to discourage deforestation. Future research in other forest-rich countries is also needed to better understand the impact of drug trafficking organizations on deforestation.

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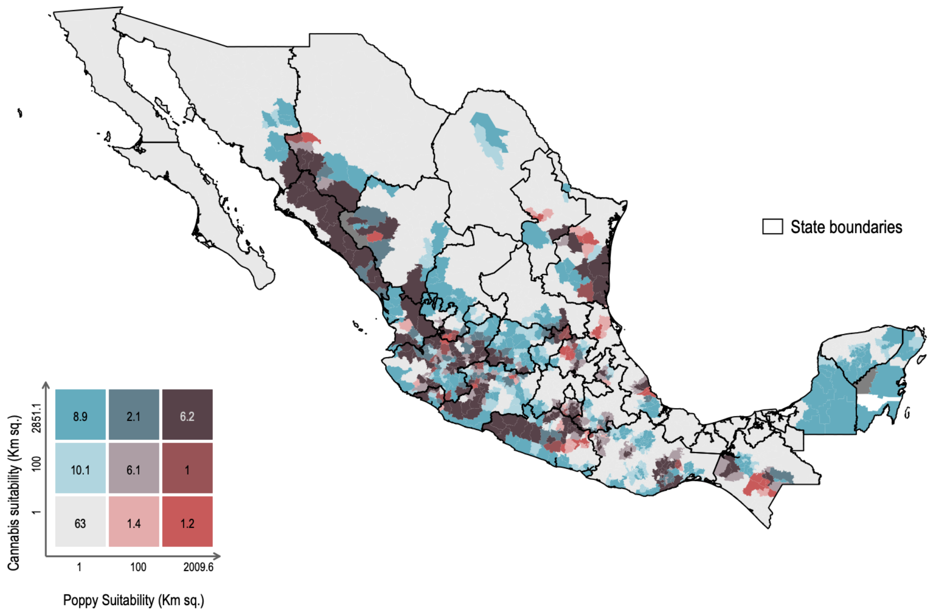
Appendix

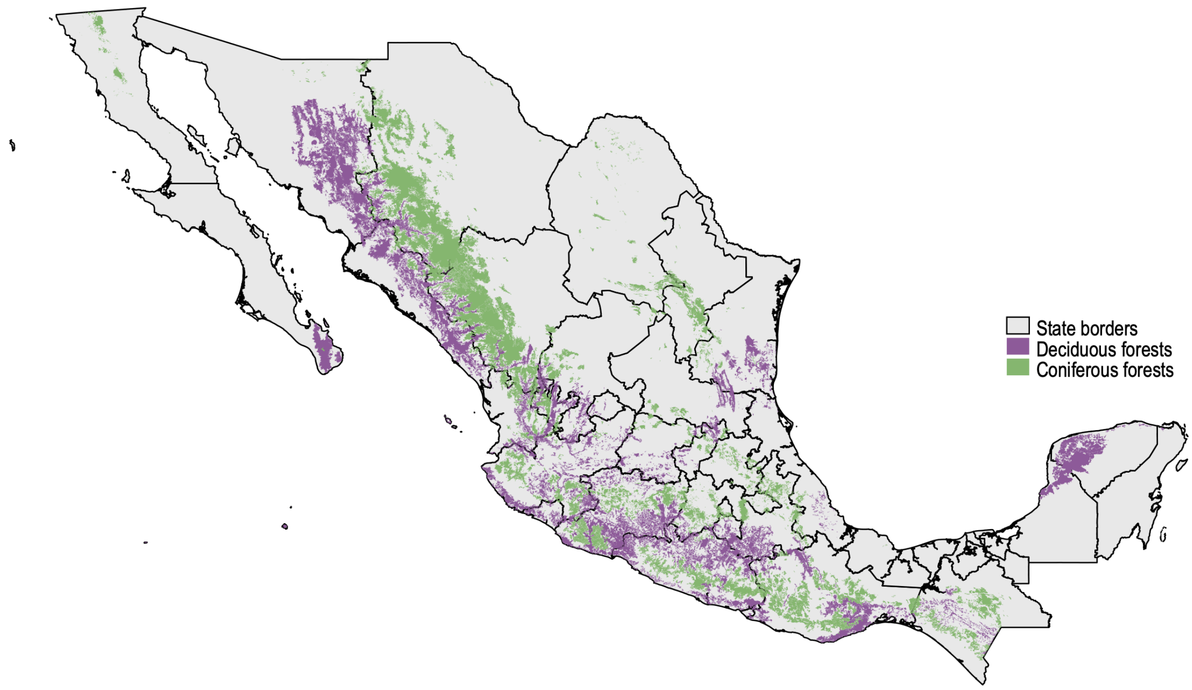
Appendix A: Maps

Figure 2: Poppy and cannabis suitability in km^2 at municipality level for Mexico



Note: Suitability data comes from Daniele et al. (2023). The map represents poppy and cannabis suitability at the municipality level in km^2. Values in the boxes indicate the percentage of municipalities belonging to that specific interval. For instance, 63% of municipalities have less than 1 km^2 of land suitable for poppy and cannabis crop production. The map was created using the user-written Stata package *"bimap"*.

Figure 3: Distribution of coniferous and deciduous forests in Mexico



Note: The location of coniferous and deciduous forests come from land use map of INEGI for 2009. The map was created using the user-written Stata package *"spmap"*.