Books and Bushes: Schooling Decisions and Coca Production in Colombia

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Abstract

This paper explores the relation between agricultural shocks in illegal crops and schooling decisions. I focus on the case of Colombian coca leaves, the main input to produce cocaine. The country's main strategy to eradicate coca crops was the fumigation of herbicide until 2015, when the practice was banned. I exploit a plausible exogenous variation in the probability of being sprayed and the temporal effects of the fumigation campaigns as an instrument for the presence of coca fields. This temporal variation along with the cross-sectional variation of the spraying campaigns lead to an instrumental variable difference-in-differences. I use data on coca presence, eradication missions, and school outcomes at the municipal level from 2012 to 2018 to test whether a change in the presence of coca crops has an effect on schooling decisions. I show that my setting does not meet all the assumptions of the traditional difference-in-differences strategy but it fits those of Fuzzy Difference-in-Differences. My empirical findings suggest that an increase in the area cultivated with coca crops increases the high-school dropout rate and it has no effect on the enrollment rate. I rule out the possibility that coca presence crowds out other legal crops. Taken together, these results suggest that high school-age individuals are leaving school to work on coca related activities.

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1 Introduction

This paper explores the relation between agricultural shocks and schooling decisions. There are many papers that relate booms in legal markets with schooling decisions. Examples abound such as the coffee boom in Brazil, where poorer children were withdrawn from school (see for instance Kruger, 2007) Yet, there are less papers that relate booms in illegal markets with schooling decisions. In particular, there are just a handful of papers that related the presence of coca leaves with schooling decisions (Angrist and Kugler, 2008; Dammert, 2008; Sviatschi, 2022).

In this paper I look at the effect of coca crops presence on school participation. I focus on the case of Colombia where coca fields were increasing at an average annual rate of 25 percent, from 2013 to 2016. I take advantage of the temporary nature of the fumigation campaigns of herbicide as a strategy to eradicate coca crops to assess whether school-age individuals decide to remain in school. To do so, I first explore whether there is variation on school outcomes; in particular, I look at the effect of coca presence on enrollment and dropout rate. Then, I focus the attention on what happen to school-age individuals that decide to remain and to leave school. I look at school attainment measures to document the changes in the patterns of individuals that decide to remain in school. Finally, I look at (legal) agricultural activities to shed light on whether the presence of coca crops is related to changes in the agricultural sector.

The ideal experiment would compare school outcomes in municipalities that are identical in all respects except exposure to coca fields. To approximate such an experimental ideal, I use municipal variation on the share of area cultivated with coca fields. I take advantage of the spike in the presence of coca fields starting 2013, which can be characterized as a boom in coca leaf production and whose production is labor intensive. Harvesting coca crops demands time and physical effort, but it does not require different skills than the ones needed to harvest legal crops.[1] Either children or adults can work on the harvesting activities of coca where a plot is harvested a minimum of 4 times a year. Previous studies have related coca production with children and teenage work, both in Colombia (Angrist and Kugler, 2008; Rodríguez, 2020) and in Peru (Sviatschi, 2022).

As part of the 'war on drugs', the United States and the Colombian government launched *Plan Colombia* in late 1999, a policy-package aimed at reducing the country cocaine supply. The strategies implemented included the forced eradication of coca crops through the aerial spraying campaigns of herbicide. However, after the World Health Organization found that the active component of

[1] Note, coca leaf is the primary input in the production of cocaine. Turning coca leaves into coca paste and then into cocaine is less labor intensive and require from additional inputs, mostly chemicals.

the herbicide sprayed (namely glyphosate) is "probably carcinogenic to humans," the Colombian government under the then-President Santos suspended the aerial spraying of coca fields in late 2015.

Aerial spraying of herbicide is a short-term strategy as it does not have a permanent effect. Areas fumigated can recover in less than one year. Thus, they could be fumigated multiple times over the years or within the same year. Fumigation only occurred in areas affected with coca presence yet not all the areas affected are indeed sprayed. Therefore, I look at exogenous variation in the policy using both cross-sectional and longitudinal variation. I calculate the share of area affected with coca presence in a given year, and I instrument it using a dummy variable for whether the area was fumigated or not in that year. Notice, the last year I can study is 2016 as the fumigation policy was suspended in 2015.

Intuitively, my instrument picks two consecutive periods and compare an area that was not sprayed with an area that was sprayed. Using the policy suspension, I exploit the temporal variation as in a difference-in-differences framework. On the other hand, I exploit the cross-sectional variation as not all the areas with coca presence are sprayed which lead to a fuzzy design. Notice, spraying missions are centrally planned and administered by the Anti-Narcotic Police after aerial recognition of cultivated areas, then I can hardly claim that fumigation is random. Nonetheless, I present some evidence suggesting that the missions are determined by geographic characteristics rather than by coca presence. Therefore, I claim that the spraying mission are decided quasi-randomly.

Both the temporal and cross-sectional variation lead to a difference-in-differences framework, however my setting differ from that of the 'classical' difference-in-differences so I borrow from the literature the Fuzzy Difference-in-Differences methodology (de Chaisemartin and D'Haultfœuille, 2018). First, there are areas where the government stop spraying before the suspension of the fumigation campaigns, which could be interpreted as staggered adoption of the 'treatment.' Then, the aerial spraying missions did not have a permanent effect as municipalities do not remain exposed to the treatment at all times afterwards. These challenges are tackled by the fuzzy difference-in-differences design by comparing groups that adopt and remove the treatment while controlling for the timing of the adoption/removal of the policy, i.e., whether or not the municipality is being sprayed.

My empirical results are consistent with the expected values of a negative effect of coca presence on school outcomes. My findings suggest that the increasing presence of coca crops is significantly correlated with more students dropping out from high school, while I do not find any effect on the other grades nor in the enrollment rate. I find that on average dropout rate increases by 0.33 standard deviations in areas with presence of coca crops, which represent a decrease of almost 30% relative to the 3.15% mean high school dropout rate. In addition, the retention rate decreases, although its magnitude is much smaller (0.1 percentage points).

I look at the performance of the students that decided to stay in school using data on the rate of students that either pass or fail and repeat a level in primary, middle, and high school. My results suggests that the increasing presence of coca fields have almost no effect on the students that remained in school, except for those in high school, where there is a negative effect on the rate of students that approved of their level. This means that students that did not drop out from school are not fulfilling the requirements of their grades. Moreover, I use information from the standardized tests—Saber5, Saber9, and Saber11 that students take at the end of primary, middle, and high school respectively—to assess the effect of coca presence on learning outcomes. I do not find any effect on the tests scores except for the mathematics component in primary school which present a positive effect. Even though this results is consistent with previous studies that show that students that remain in school tend to perform better, it is unexpected as there were no changes in dropout nor enrollment in that level.

Finally, to shed light on an outside option for the school-age students, I explore changes in the production of other legal crops. I use data on the area cultivated and harvested in each municipality, as well as its ratio. These measures allow me to evaluate whether coca crops crowd out legal crops. My results suggests that the coca presence has no effect either on the area sown nor in the area harvested, which could be interpreted as the agricultural labor market being in equilibrium. Since the only change is in the area cultivated with illegal crops and not on the area with licit crops, I interpret these results as suggestive evidence that, on the one hand, there is not a crowd out effect of the coca crops on the legal crops, and on the other hand, that school-age individuals that decide to drop out are working on coca related activities. Notice, I cannot claim that this is in fact the case, as I do not have data to support it, but I cannot rule it out either.

A limitation of my analysis is the level of aggregation of the school outcome variables. They are at the year-municipal level while the decision of enrolling or dropping out of school is at the individual level. Moreover, tests are taken by individual students and this level of aggregation could mix top-performing schools with bottom-performing in the same municipality. Similarly, both the coca presence and the spraying data are at the year-municipal level, which do not allow me to capture short-term dynamics nor find a more precise effect. For instance, the presence of coca crops could increase at the end of the year and the student might dropout in the middle of it because families decide to migrate from the rural area to the urban area or to a different municipality. On the other hand, I cannot distinguish the effect by grades, or within school levels. For instance, the positive enrollment in one grade is averaged with the negative enrollment in another grade within the same school level.

This study connects with the literature related to eradication of coca crops through aerial spraying. Some of these studies have found evidence of small but positive effects of the aerial spraying campaigns aimed at reducing coca cultivation (Abadie et al., 2015; Cote, 2019; Ibanez and Carlsson, 2010; Mejía et al., 2017; Prem et al., 2023; Reyes, 2014), although there is one study that suggests that an increase in forced eradication leads to an increase in the area cultivated (Reyes, 2014). Other studies have found that the presence of coca fields is related to children and teenager work, both in Colombia (Angrist and Kugler, 2008; Rodríguez, 2020) and in Peru (Sviatschi, 2022). While others have also related aerial spraying with more displacement (Espinosa, 2010), and with health outcomes, such as of medical consultations related to dermatological and respiratory illnesses, as well as the number of miscarriages (Camacho and Mejía, 2017)

This paper also contributes to the studies that explore the relation between exposure to illegal markets and education and labor decisions (Dammert, 2008; Dávalos and Dávalos, 2020; Ibáñez, 2010). There is one paper that exploits the boom in Colombian illegal gold mining, finding that school attendance decreases as well as the probability of child work increases (Santos, 2018). There are two papers that uses the presence of coca fields in Peru and relate it with child work and schooling decisions; one uses the shift of production from Peru to Colombia (Angrist and Kugler, 2008) while the other exploit the exposure to illegal labor markets (Sviatschi, 2022).

The studies closer to mine are those of Rodríguez (2020) and of Prem et al. (2023). The former investigates the effect of the aerial spraying policy on education decisions using survey data in areas affected with coca presence; although, their study cover the period before the boom in coca fields. On the other hand, the latter study exploit the unintended consequences of a policy announcement where the coca growing farmers would receive incentives for voluntarily crop substitution. Their results suggests that the surge in coca fields is differentially higher in areas with presence of illegal armed groups.

To the best of my knowledge, this is the first paper that studies the consequences of the coca boom of the beginning of the 2010s. In addition, this is the first paper that studies the removal of the aerial spraying strategy and that uses the standardized test scores Saber 5 and Saber 9 to show heterogeneous effects of learning outcomes across grades while relating them to coca presence.

The rest of the paper is organized as follows. Section 2 provides some background on the Colombian case. Section 3 summarize the data sources and describe the research design. Section 4 describes the empirical strategy to estimate the effect of coca presence on school outcomes. Section 5 reports the main findings on school outcomes, school efficiency, and school attainment. Finally, Section 6 concludes.

2 Institutional Context and Background

2.1 Dynamics of coca presence in Colombia

Coca leaf is the main ingredient of cocaine, a powerful addictive drug, whose mayor producer is Colombia with 70 percent of the world supply[2] and approximately 89 percent of the cocaine seized and subjected to laboratory analysis in the United States in 2019.[3] This is a permanent or multi-annual crop that can be harvested a minimum of 4 times a year (4.6 times on average), and the cost of producing it decreases over time. Harvesting coca leaves is a labor-intensive process and demands time and physical effort, a similar set of skills than the ones needed to harvest licit crops. Workers are needed for plowing the earth, plantation, and fumigation besides of harvesting, where there is more demand (Dammert, 2008; Rodríguez, 2020). One hectare[4] (ha) of coca bushes produces on average 1,217 kilograms of fresh coca leaves per harvest, and 1 kilogram of coca leaves can produce between 1.1 and 1.4 grams of cocaine. Depending on multiple factors, such as density of sowing, soil nutrients, and weather condition, it can present different yield , but it is estimated between 5 and 6 kilograms of cocaine per hectare per year (DIRAN, 2014; Mejía and Posada, 2008).

The revenue from this stage of production depends on how many kilograms of coca leaves one person can harvest and carry. In 2016, the price for one kilogram of coca leaves was on average $2,900 Colombian pesos (roughly[5] $0.95 US dollars), although the price varies between regions. It is estimated that a person could receive about $960 US dollar a year (UNODC, 2017). For a farmer harvesting its own plot, the National Police has estimated an income between 2 and

[2]See https://www.semana.com/mundo/articulo/produccion-de-coca-crece-en-el-mundo-y-colombia-aporta-el-70/621010.

[3]See https://www.state.gov/bureau-of-international-narcotics-and-law-enforcement-affairs-work-by-country/colombia-summary/.

[4]One hectare (ha) is equivalent to approximately 2.5 acres.

[5]$1 US dollar is equivalent to $3,052 Colombian pesos using 2016 exchange rate.

3 monthly minimum wages which is slightly above the region's median income (DIRAN, 2014). Notice, farmers decide to grow coca as there is no possibility of making a living from legal forms of agriculture (Ibáñez, 2010), either because they are located far from city centers (Zuleta, 2019) or because they have less access to formal credits for their licit crops (Dávalos and Dávalos, 2020), among other reasons.

Since the late 1990s, Colombia has aggressively pursued coca eradication to reduce the land devoted to it (Reyes, 2014). In 1999, the United States and the Colombian governments launched *Plan Colombia*, a $7.5 billion co-financed policy-package, aimed at reducing 50 percent the cultivation over a period of six years. Aerial spraying of herbicide (fumigation) over coca fields was the main instrument to eradicate the crop, along with manual eradication either forced or voluntary (Abadie et al., 2015; Zuleta, 2019). Notice, Colombia is the only country that allowed aerial spraying for counter-drug purposes (Isacson, 2019).

Spraying missions are centrally planned by the Anti-Narcotic Police (DIRAN) after aerial reconnaissance of cultivation areas. This strategy allows operating in remote and insecure areas where manual eradication is cost prohibitive or too dangerous (Abadie et al., 2015). Spraying missions are made through small aircraft spraying glyphosate, the active ingredient in the herbicide RoundUp (Isacson, 2019), using modified military planes (fumigation equipment instead of weapons). Spraying aircraft are protected and escorted by the National Police with armed helicopters to protect fumigation planes from armed attacks from the ground. These helicopters have a range of 80 miles from the airport, beyond that range missions are not canceled but fumigation planes must go unprotected (Reyes, 2014).

According to DIRAN, spraying glyphosate is 90 percent effective.[6] To estimate the area affected with coca fields presence, the monitoring system SIMCI uses an 8.8 percent survival rate of a sprayed crop (UNODC, 2017). Once a field is sprayed, the land takes six to eight months to regenerate to a point at which coca can be grown again. However, if it rains or if growers wash the crops immediately after the spraying, the effect of the spraying is mitigated and the land recovers much faster. If done right, the herbicide can be "washed out" from plants, as long as this is done right after the spraying has taken place (Prem et al., 2023; UNODC, 2014). Given this, plots are likely to be sprayed more than once in a given year. Spraying missions were suspended in October 2015 by the Colombian government after the World Health Organization classified glyphosate as "probably carcinogenic to

[6] Personal communication with official from DIRAN, July 2019

humans" in March of the same year.[7]

Figure ?? presents the dynamics of the coca crops in Colombia. It shows the total area under coca bush cultivation and the total area eradicated. Notice, the latter is higher in magnitude than the former for various years during the 2010s. This is evidence of areas being sprayed more than once in a given year. After the suspension of the missions in 2015, the eradication is done through 'manual' eradication by pulling coca bushes from the ground. The area with coca presence increased from 48,000 ha in 2013 to 146,000 ha in 2016. Previous studies have suggested that the peace dialogue between the Colombian government and the FARC guerrilla play a role in this increment as there is a non-trivial relation between the latter group and the illicit crops (López et al., 2019; Zuleta, 2019). One study suggest an anticipatory effect generated by the announcement of material incentives for voluntary crop substitution as the reason for this increment (Prem et al., 2023).

2.2 Colombia's education system

Colombia's education system is regulated centrally by the Ministry of Education (MEN), but it is administered 'locally' by local certified entities, or ETC,[8] in accordance with MEN'S regulations. All children between five and fifteen years old are legally required to attend one year of preschool, 5 years of primary school, and 4 years of middle school (lower secondary education), the only compulsory levels (MEN, 2013), yet from 7 to 13 years is the age range at which over 90 percent of the school age population is enrolled (OECD, 2016). In order to access tertiary education, students must finish the 2 years of high school (upper secondary education) and take the SABER 11 standardized test.[9] Children usually enroll into preschool (grade 0) at age 5 and require 12 consecutive years of schooling to finish high school, at age 17.

School attainment varies depending on the region. The average years of schooling in rural areas is 5.5 years while that of its urban counterpart is 9.6. In 2014, 87% of schools were public and 78% were located in rural areas (OECD, 2016). Areas where there is presence of coca crops present relative lower values or coverage and quality than other parts of the country, as well as higher

[7]After the suspension, Colombia's Constitutional Court, one of the three highest judicial review authorities, placed restrictions on any use of glyphosate from aircraft, but did not ban the practice (Isacson, 2019).

[8]Colombia is administratively divided into 32 *departamentos* and Bogota, the capital district. These are equivalent to the US states. The departamentos are divided into *municipalities*, the smallest administrative unit. There are 96 *entidades territoriales certificadas* (ETC) and they can be either a departamento, a municipio, or a district.

[9]The SABER 11 test is administered prior to graduation in Colombian high schools (grade 11th). It is similar to the SAT in the United States, but it is administered by the Colombian government.

poverty levels (Zuleta, 2019). Extremely poor farmers are more likely to grow coca than non-poor farmers in the same areas (Dávalos and Dávalos, 2020). In these areas, it is not uncommon for children to join the labor force (Rodríguez, 2020) or for them to skip school during harvesting season. Nonetheless, according to a recent survey among farmers in the voluntarily substitution program, the farmers who grow coca use the revenue to invest in their children education (Marín et al., 2020).

3 Data and Research Design

3.1 Data

I built a municipality-year level panel data to study the effect of coca presence on school participation. In particular, I use the increasing area affected with coca crops to study its effect on school dropout, enrollment, and retention. I focus on the period from 2012 to 2016, during the President Santos term only, who initiated peace negotiations with FARC guerrilla in 2012. Notice that the period of the peace process overlaps with that of constant growth of the area effected with coca bushes, and contains the year of the suspension of the aerial spraying strategy (see Figure **??**).My sample consist of all 1,120 municipalities of Colombia, except for the 2 municipalities that form the departamento of San Andrés, Providencia and Santa Catalina and are not in the mainland.[10] I describe the main variables and the data sources below.

3.1.1 Education data

The main dependent variables are school-related outcomes that come from the MEN. This data has information aggregated at the municipal level each year over the period 2012 to 2016. It has the enrollment and dropout rates, as well as the rate of students that approved, failed, and repeated primary, middle and high school, separately. Note that, students enrolled either pass, fail, or dropout, and among those that fail, some students repeat the grade while others also dropout or change of school. My analysis is focused on the enrollment, dropout, and retention rates. A limitation, however, is that it does not have an attendance variable that captures short term dynamics of students. It also does not have information on either households' or students'

[10] The state of San Andrés, Providencia and Santa Catalina is located in the Caribbean Sea, approximately 482 miles northwest of mainland Colombia. I drop them from the sample due to their location and because the presence of coca crops is not monitored.

migration decisions to study. It is important to clarify that, even though the outcome comes from a decision from the individual, my treatment and data is at the municipal level.

The dropout rate captures yearly dynamics as it is measured as the share of students that leave school at any point during the academic year relative to the initial enrollment. Under this methodology, for instance, a student that changes school during the academic year will be counted as if she has dropped out of school. On the other hand, the enrollment rate is measured as the number of students of an age group that enrolled in school at the beginning of the academic year relative to the size of the population of that age group (MEN, 2013). Notice that the latter rate can take values greater than one because of overage students outside the reference age group or student attending school from neighboring municipality. It is not possible to distinguish between these two however, the latter is more likely to happen in more urban municipalities where students from surrounding areas come to study, while the former is more likely to happen in the more rural municipalities as the access to school is more limited (Forero, 2019). The grade pass and grade fail rates capture the share of students that fulfill the academic requirements of their grade, and the ones that do not fulfill them, respectively. These two rates are aggregated into the retention rate that speaks of the share of students that did not drop out from school. The grade repetition rate reports the share of students that have to repeat or go through an academic grade again (MEN, 2013).

3.1.2 Illegal crops and spraying data

Data on illicit crops comes from the Integrated Monitoring System of Illicit Crops (SIMCI by its Spanish acronym) of the United Nations Office on Drugs and Crime (UNODC). It has information on the municipal area (measured in hectares) cultivated with coca bushes each year between 2001 and 2018.[11] SIMCI is a satellite-based monitoring system that uses imagery of the entire territory of Colombia's mainland to estimate the extension of the coca crops annually, as of December 31 of each year. 70 percent of the satellite images are obtained within two months range (two months before or after the cut-off date), while of the remaining 30 percent, about half is obtained from August to November of the estimate year, and half between March and April of the following year (Abadie et al., 2015). Coca plots identification are based on visual interpretation of satellite images, including three stages: (1) preliminary visual interpretation includes an analysis of the historical coca series and georeferenced photographs taken in overflights by the National Police, (2) verification

[11] Data availability goes back to 1999, although starting 2001 the data evaluates the entirety of the country.

overflights based on visual inspection from an aircraft on the territories affected by coca crops, and (3) edition using the verification overflights information to adjust the preliminary interpretation (UNODC, 2017). Note that, using this methodology, an area that was affected during a particular year can be reported as not having coca if eradication was effective in the territory.[12]

Reports on illicit crops eradicated using aerial spraying are produced by DIRAN. This information is available from 1999 to 2015, when aerial spraying was suspended. The aerial spraying of coca crops was the most important strategy during the first years of *Plan Colombia* and its use declined in the last years. Figure **??** presents evidence of this by showing the area eradicated by aerial spraying present a downward trend from 2006 until its suspension. There is no information on what municipalities were sprayed or how many times, however following the previous discussion on effectiveness, I assume that all the municipalities that report positive values of eradication in a given year were sprayed in that year. Using this definition, it exists the possibility of labeling some areas as "non-sprayed" where in fact those areas were sprayed. However, had this be the case, the impact of the intervention would be effective.

3.2 Evaluation design

The ideal experiment would compare school outcomes in municipalities that are identical in all respects except exposure to coca fields. To approximate such an experimental ideal, I use municipality-level variation on the share of area affected with coca fields. However, the municipalities that have presence of coca bushes could be systematically different the ones that do not have such presence leading to a selection bias problem.

I take advantage of the increasing trend in coca cultivation and use the exposure to fumigation missions as a source of exogenous variation, as not all the areas affected with coca presence are sprayed. The targeted areas are dynamically determined by changes over time and over municipalities, although they present a persistent location pattern (UNODC, 2017, 2019). Figure **??** and Figure **??** show this pattern using 3-years of data. The removal of the aerial spraying missions can be seen in panel (d) of Figure **??** where any of the municipalities is shown to be sprayed, even though there were still areas affected with coca. Notice that the areas affected are persistent in time, but it is important to highlight that this figures do not allow me to separate whether the existing fields affected were increasing in plot size or moving within the municipality.[13]

[12] Abadie et al. (2015) discuss the advantages of using this methodology relative to alternative ways of measuring coca cultivation at the municipal level.

[13] Prem et al. (2023) findings suggest that the increase in coca fields comes from a growth in pre-existing plots as

I exploit the temporal variation created by the temporary effects of the fumigation on the coca fields to instrument the presence of coca. I also use the cross-sectional variation of the fumigation strategy as not all the municipalities affected with coca presence are effectively sprayed. Notice, spraying missions are administered and centrally planned, then I can hardly claim that fumigation is random; however, if the missions take place in an area where there is coca presence and all areas are equally accessible, then I can test whether the probability of spraying is given by the presence of coca crops and by geographic characteristics.

To determine the probability of a municipality being sprayed, I use geographic characteristics at the municipal level that help explain the presence of coca crops (Acevedo and Bornacelly, 2014; **?**), and information on the area cultivated. The former set of characteristics do not vary over time while the share of area cultivated does vary. Assuming, for simplicity, that I define an area as fumigated as

$$D_{mt} = \mathbb{1}\{Spray_{mt} > 0\}$$

where $\mathbb{1}\{\cdot\}$ is the indicator function and D is a dummy variable that takes the value of 1 when the municipality m in year t reports a positive area eradicated through an aerial spraying mission, $Spray_{mt}$; and 0 otherwise. Then, I estimate the following linear probability model

$$D_{mt} = \beta coca_{mt} + X_m\delta + e_{mt} \ , \qquad (3.1)$$

where $coca_{mt}$ is a measure of coca presence in municipality m and year t normalized by the area of the municipality, and X_m is a vector of geographical characteristics that do not vary over time. Specifically, it includes the distance to the closest airport from where spraying missions depart, the number of airports within the 80 miles radius, the distance to the Department's capital and closest market, the share of rural population and area, and the characteristics used to create the coca suitability index (**?**).

Table **??** report the estimates. Column (1) presents the results using the full sample of municipalities, including those without presence of coca crops. The estimates suggest a positive relationship between the presence of coca crops and the probability of spraying, as well as a significant relationship with some of the geographic characteristics. However, further examination of the data revealed that this result is driven mainly by the municipalities that do not have coca crops and are

well as in plots detached from pre-existing ones.

not sprayed. In Column (2), I present the estimates restricting the sample to the subset of municipalities that have been sprayed at least one time, i.e., ruling out the ones that either do not have presence of coca or have never been sprayed for other reasons. Interestingly, the results suggests that the share of area cultivated marginally and negatively explains the probability of the spraying mission. Furthermore, some of the geographic conditions explain this probability. For instance, the distance to the principal market and to the Department's capital is positively estimated as expected as coca is grown in more remote areas. In addition, water disposability—which captures areas with more precipitation—is also positively correlated with the probability of spraying. This result is less expected as spraying missions need to have 'optimal' weather conditions that includes less rain so as the glyphosate is not wash out from the crops, but on the other hand, more rains could affect positively the production of the crop (Rodríguez, 2020). Finally, the soil erosion and elevation are negatively correlated with the probability of being sprayed, although these two characteristics are related to the presence of coca crops (**?**).

Columns (3), (4), and (5) further explore the dynamics of the spraying campaigns on the municipalities that have been sprayed. Since spraying campaigns could be decided the prior year based on the information available at the time, the results of Column (3) include the lagged value of the cultivated area while those of Column (4) include both the contemporaneous and the lagged values of the cultivated area. These two results go in line suggesting no relation. Finally, in Column (5) instead of the current and the lagged value, I include the variation between to two as the government could focus on the areas that present a higher increase. Similarly to previous results, there seems to be no relation between the presence of coca and the spraying campaigns except for the growth in area cultivated that presents a negative relation but marginally significant. I take these results as suggesting evidence that the decision to spray is quasi-randomly determined based on observable geographic characteristics and not decided deterministically.

4 Empirical strategy

To uncover the relation between coca presence and school participation, I am interested in the following relation:

$$school_{mt} = \delta_m + \delta_t + \beta coca_{mt} + \varepsilon_{mt} \tag{4.1}$$

where the parameter of interest is β. However, it is likely that the estimates will be biased given that the presence of coca fields is not random. To tackle this issue, I use the fumigation missions of coca fields as a source of exogenous variation. Particularly, I label as treated a municipality being fumigated (D_{mt}=1) if there is any positive area reported as eradicated through a fumigation mission (see previous section). Formally, this relation can be written as:

$$coca_{mt} = \gamma_m + \gamma_t + \theta D_{mt} + \upsilon_{mt} \tag{4.2}$$

which lead to a difference-in-differences framework. However, my setting differs from that of the 'classical' difference-in-differences as D_{mt} varies within municipalities over time. I use the Fuzzy Difference-in-Differences methodology developed by de Chaisemartin and D'Haultfœuille (2018), which allows me to consider the 'fuzzy' setting by comparing groups who adopt and remove the treatment while controlling for the timing of the fumigation missions, and to recover the Wald estimand of the difference-in-difference.

This comparison deal with (*i*) the plausibly staggered adoption of the treatment, as there were some municipalities that were first fumigated in different years. (*ii*) It relaxes the assumption that treatment is an absorbing state, i.e., units exposed to treatment remain treated thereafter, as fumigation has no permanent effect on the coca fields; an area sprayed takes six to eight months to regenerate to a point in which coca can be grown again. This could imply that municipalities switch from being sprayed one year to not sprayed the next one (or vice versa); moreover, (*iii*) part of the fuzzy design comes because not all the areas affected with coca presence are being sprayed every year and some areas being sprayed report zero area affected due to the effectiveness of the fumigation, i.e. they report control areas as being treated.

The Fuzzy Difference-in-Differences allow me to recover the Wald-DID estimand of the switchers based on pair-wise comparisons of the switchers, i.e., those who adopt the treatment and those who have the treatment removed. The LATE for the "treatment group switcher" is defined by

$$\Delta = E(Y_{11}(1) - Y_{11}(0)|S)$$

where S represent the group of switcher units going from non-treatment to treatment between two consecutive periods. $Y_{gt}(D)$ denote the potential outcomes of Y in treatment group g and period t under treatment D. Similarly, it is possible to define the LATE, Δ', for the control group switchers S', i.e., the switcher units that go from being treated to being untreated between two consecutive periods. Then, the Wald-DID is equal to a weighted average of the LATEs of treatment and control group switchers defined by

$$W_{DID} = \alpha\Delta + (1-\alpha)\Delta' \ , \tag{4.3}$$

where $\alpha = (P(D_{11} = 1) - P(D_{10} = 1))/DID_D$ and $1-\alpha$ are the weights, and DID_D is defined as $E(D_{11}) - E(D_{10}) - (E(D_{01}) - E(D_{00}))$. Notice, the Wald-DID allows for the possibility of heterogeneous treatment effects between groups, that is, $\Delta \neq \Delta'$.

To recover the Wald estimands of my parameter of interest β, I use the stata package `fuzzydid` provided by the same authors (de Chaisemartin et al., 2019). Standard errors are block bootstrapped at the municipal level in all regressions (Abadie et al., 2022).

Intuitively, I expect the suspension of the aerial spraying to reduce the uncertainty of coca growing farmers and then increase the production of coca crops. At its turn, this increase in production should lead to an increase in the demand for unskilled labor force. This excess in demand is accompanied by an increase in the labor supply through more children joining the labor force, especially from the upper grade level. This implies that I expect a negative sign for the enrollment and retention rates and a positive sign for the dropout rates.

5 Results

5.1 Coca presence and school outcomes

Table **??** presents the Wald estimate for the main outcome variables using the Fuzzy Difference-in-Differences strategy. Each column of the table uses a different outcome as reported in the column header. The outcome variables are standardized to have zero mean and unit variance in the sample. As expected, the estimates for dropout rate for the three school levels are positive and for enrollment rates are negative, although only the high school dropout rate is statistically different from zero at the 5 percent level. This result goes in line with the idea that teenage students are more likely to join the labor force in areas sprayed (Rodríguez, 2020). In particular, a one percent increase in the area affected with coca crops cause an increase in 0.3 standard deviations in high-school dropout rate. This implies that, on average, the high school dropout out rate increase by almost 0.9 percentage points. Given that the average rate is 3.15, this results suggest an effect of an increase in almost 30%.

On the other hand, the results in the retention rate are the complement to those of dropout rate but they need not to be exact opposites. As in the case of the dropout rate, both retention rates for primary and middle school are not statistically different from zero, while the one for high school is statistically significant at the five percent level. In terms of size, they are much smaller with only a decrease of about 0.1 percentage point, however given that the students that remain in school are the ones that either fail or pass the academic year, the results are less obvious. I further explore these results in section 5.2.

5.2 Students retained

In this section, I explore what happens with the students that do not drop out from school. It is comprised of students who do not dropout from school but finish the academic year either fulfilling the academic requirement of their grade (pass) or not fulfilling them (fail). Finally, among those who do not fulfill the requirements, there exist those who have to repeat the grade for academic reasons. This is a concern in Colombia's education system as the proportion of grade repeaters of 15-years-old having to repeat at least one year is 41 percent (OECD, 2016). A possible explanation for the low academic performance of students is that they skip school, for instance, during harvesting time. Note that, had the students decide to skip school, their learning would be affected. Therefore, the share of students who fulfill the academic requirements will decrease, and the share of students who do not fulfill them will increase. The expected sign for the grade repetition rate is not obvious because students who fail a grade might have incentives to retire themselves from the education system, and not to repeat the academic grade. However, if this is not the case, the expected increase in the share of students that fail might lead to more students repeating a grade.

I follow the same empirical strategy using as outcomes the share of students that fulfill, do not fulfill the academic requirement, and those who repeat. For simplicity, I will refer to these grade pass, grade fail, and grade repetition rates, respectively, and report the results in Table **??**. All the estimates are not statistically different from zero, except for the high school grade pass rate that present a negative sign and significance only at the 10 percent level. This result is expected for primary and middle school as the presence of coca fields seems to not be related to students leaving school. In addition, the students that are not dropping out are performing worse than their counterparts in places without coca presence. Therefore, this result goes in line with the hypothesis that students miss school during harvesting seasons, although they do not drop out of school completely. Yet, there is no finer data to test this hypothesis.

5.3 Test scores

To further explore what happens with the students that remain in school, I use data on standardized test scores to see whether there is an effect on their learning outcomes. Data on these tests comes from the ICFES, a Colombian governmental agency in charge of measuring the quality of education. I am using information on the high school exit standardized test (namely, Saber 11), and from the end of primary and middle school test (Saber 5 and Saber 9, respectively). These exams are used to measure the quality of the education institutions and the high school exit exam is also used by the students to access higher education. The data cover the period 2012 to 2016, however due to comparability of test, the year 2012 and 2013 results for Saber 11 are excluded from the sample. Outcomes are standardized to have zero mean and unit variance in the sample.

I use the same strategy using the test scores averaged at the municipal level as outcome and present the results in Table **??** for the mathematics and language components of the Saber 5, 9, and 11 exams. Surprisingly, most of the estimates are not statistically different than zero, except for the mathematic results in primary school students. The results suggests that students that stayed in primary school perform better. This idea goes in line with the opportunity cost of students staying in school and with heterogeneity of unobserved preferences. That is, students that decide to stay in school are those whose opportunity cost of leave is higher because they are potentially better students, but also, they are receiving a more personalized education.[14] Nonetheless, given that there are no more students dropping out of school, as the previous results showed, this is somewhat surprising. The rest of the coefficients present a positive point estimate, which is consistent with the hypothesis, except for the high school language exam. The point estimate does not have the expected sign, although it is not statistically different than zero. Note that these results might be driven by other factors like the presence of civil conflict, as suggested by Rodríguez and Sánchez (2010). The relation between presence of coca fields and civil conflict has been proven in previous studies, as well as the relation between civil conflict and school attainment. However, if this were the case, then the presence of both coca crops and civil conflict should have a bigger impact on test scores as both effects go in the same direction.

5.4 Legal crops

So far, my results suggests that there are larger dropout rates among school-age individuals in the areas with more coca fields, in particular for high-school students. Similarly, these students

[14] Vargas et al. (2014) found a similar result using the municipalities in Colombia that faced civil conflict.

are also not fulfilling the requirement to advance to their subsequent grade yet, those that finish high school have not differential effects on their exit exam. There is no evidence that students are dropping out from school to join the labor market or coca related activities. Since school-age students may have more difficulties joining the formal labor market, I can explore whether there are changes in the production of other agricultural crops.

I shed light on this mechanism by using data from the Ministry of Agriculture, gathered by Universidad de los Andes (Acevedo and Bornacelly, 2014), that report for a variety of agricultural products the area devoted to cultivation and the area harvested. Using these two measures, I create the ratio of area cultivated to area harvested to explore the possibility that there are less crops being harvested relative to what is cultivated. In addition, I calculate the share of area cultivated and harvested relative to the municipality area to explore the possibility independently as the presence of coca crops could be affecting both variables. These measures will allow me to evaluate whether there is a crowd out effect of the coca crops on the legal crops.

My results suggests that the presence of coca crops have no effect on the legal crops, neither in the area cultivated nor in the area harvested (Table **??**). These results suggest the absence of a crowd out effect due to the presence of coca crops. One could interpret these results as the agricultural labor market being in equilibrium despite the coca surge, i.e., the coca crops are not replacing the licit crops and the labor force is fully allocated. If this were the case, it opens the possibility to school-age students to fill the excess in labor demand on coca-related activities. Overall, these results go in line with the hypothesis that school-age students are joining the labor force to work on coca related activities (Rodríguez, 2020; Sviatschi, 2022). However, I cannot claim that this is in fact the case, as I do not have data to support it, but I cannot rule it out either.

6 Conclusion

I provide evidence that school-age individuals exposed to agricultural shocks experience less human capital accumulation. I focus on the case of the illegal market of coca leaves, the primary input in cocaine production. I use the case of Colombia as it carry out fumigation missions where coca fields are aerially sprayed with herbicide as part strategy to force eradicate coca crops. I exploit no permanent effect of this fumigation missions to test my hypothesis. This temporal effect led me to an instrumental variable difference-in-differences setting. However, since not all the assumptions were met, I borrow from the literature the Fuzzy Difference-in-Differences methodology to tackle the challenges in the assumptions.

I find that the increasing presence of coca crops is associated with more students dropping out of high school, while I do not find any effect on the other grades nor in the enrollment rate. My results also suggests that high school students are less likely to fulfill the requirement to advance to the next grade. Finally, I explore possible effects on learning outcomes and find that only primary school students mathematics test score is positively affected, a result consistent with previous studies. I rule out the possibility that school-age students are dropping school for working in legal agricultural activities which—along the other results— I interpret as suggestive evidence that school-age students that drop out from school are working in coca related activities.

Overall , this paper provide an additional step at understanding the role of illegal markets in schooling decisions and schooling outcomes in the presence of external shocks.

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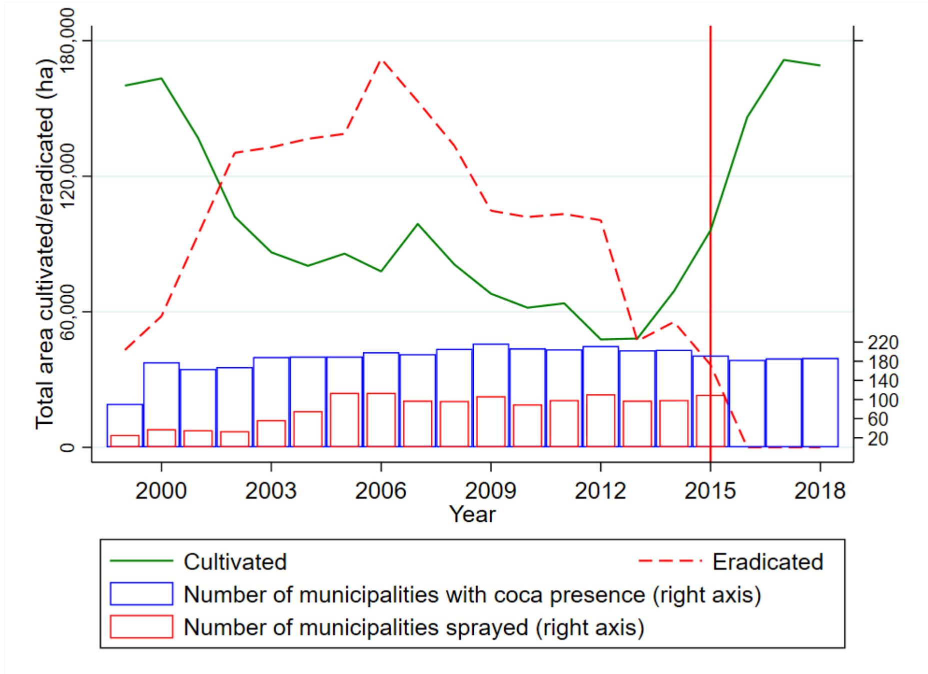
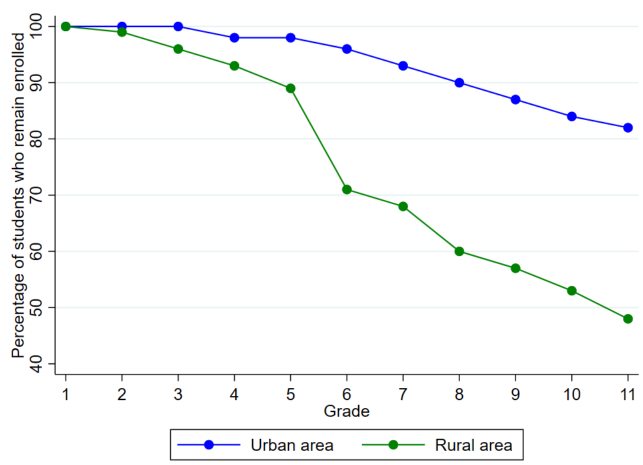
Figure 1: Dynamics of the coca cultivation and eradication in Colombia, 1999-2018



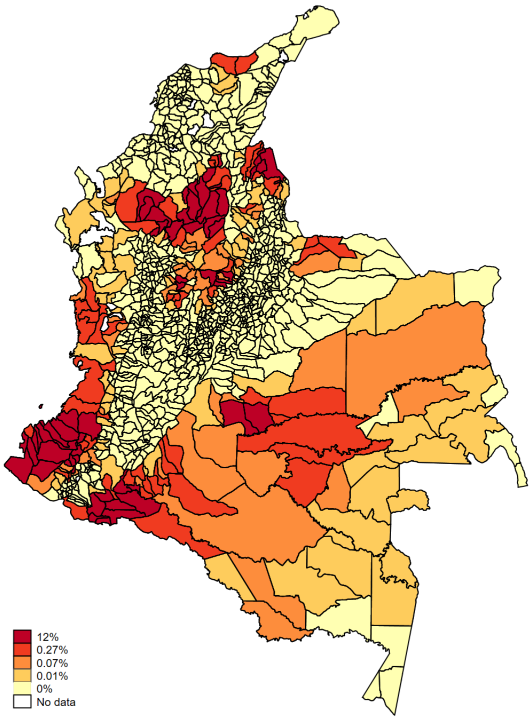
Note: Data from UNODC-SIMCI and DIRAN. Over the period, there has been 327 municipalities that have had presence of coca at least in one year, and 235 that have been sprayed at least once. There are 208 that have had presence of coca and have been sprayed at least once. The total area in hectares is reported in the left axis, while the number of municipalities affected and sprayed is reported in the right axis.

Figure 2: Percentage of students who remain enrolled by grade

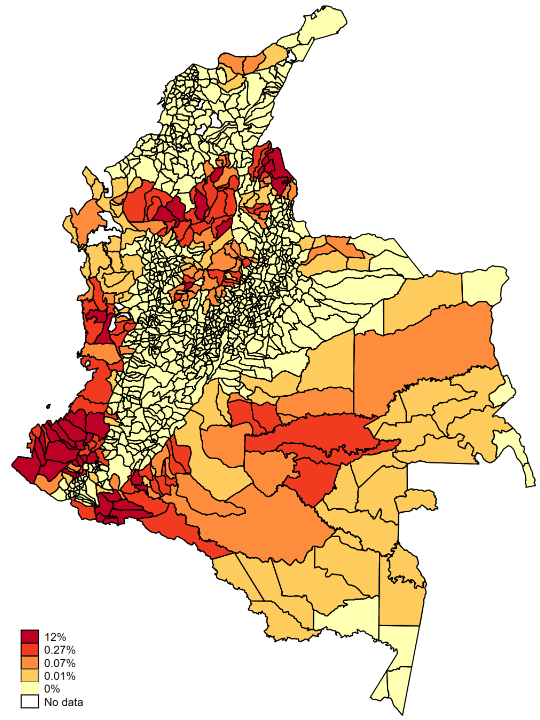


Source: Taken from MEN (nd). Data from 2008 Quality of Life Survey.

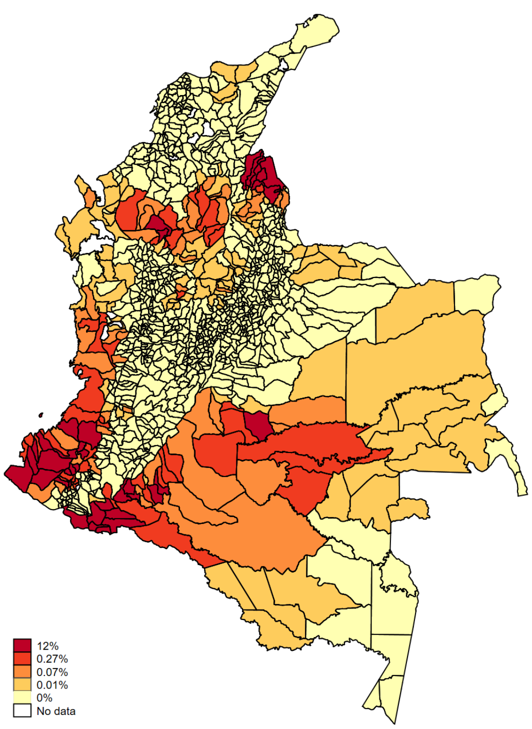
Figure 3: Areas affected by coca presence, 2007-2018



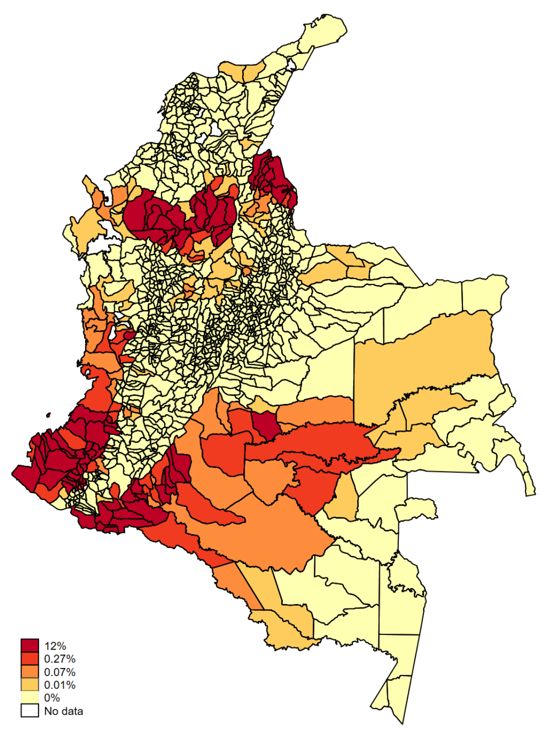
(a) 2007 to 2009



(b) 2010 to 2012



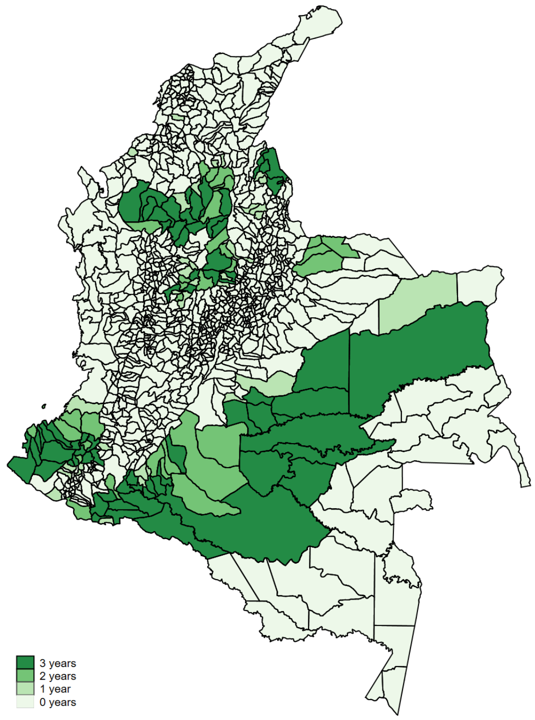
(c) 2013 to 2015



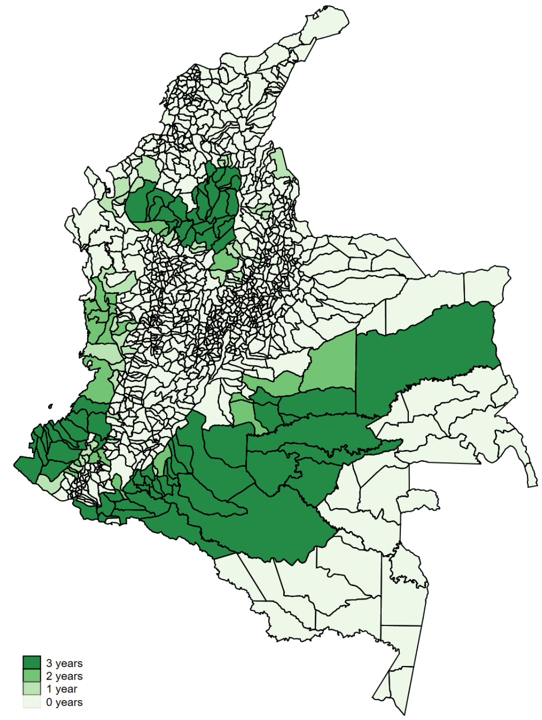
(d) 2016 to 2018

Note: Data from UNODC-SIMCI. The area affected is measured as the share of area with presence of coca crops, relative to the total area of the municipality. Panels (a) to (d) show the three-years average of the area affected from 2007 to 2018 using the same scale. Darker areas represent more affected municipalities.

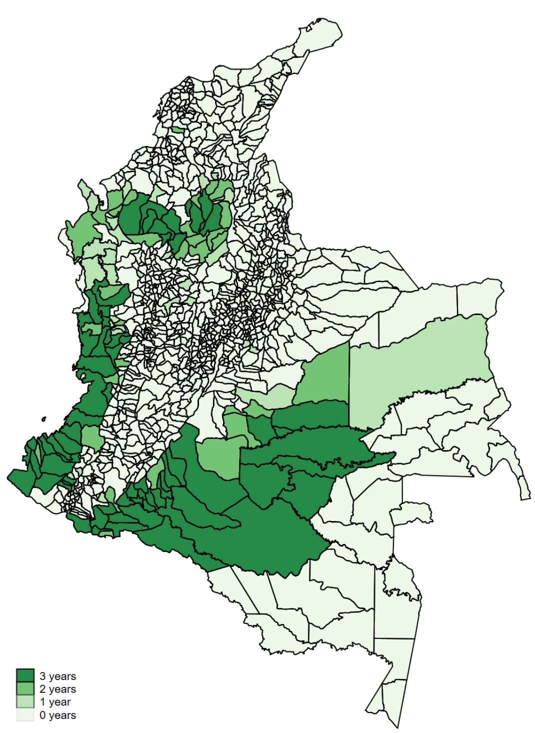
Figure 4: Territories sprayed, 2007-2018



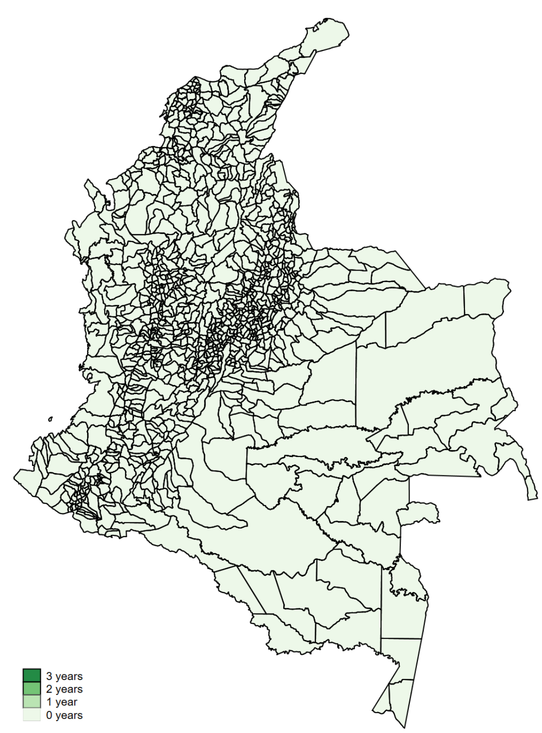
(a) 2007 to 2009



(b) 2010 to 2012



(c) 2013 to 2015



(d) 2016 to 2018

Note: Data from DIRAN. A municipality is considered sprayed if the area eradicated by aerial spraying is positive. Panels (a) to (d) show the three-years sum of the area affected from 2007 to 2018. Darker areas represent municipalities that were sprayed more times.

Table 1: Probability of sparying

	(1)	(2)	(3)	(4)	(5)
VARIABLES	Prob=1	Prob=1	Prob=1	Prob=1	Prob=1
Share of cultivated area	0.005***	-0.002*		-0.007	
	(0.001)	(0.001)		(0.005)	
Lag. Share of cultivated area			-0.002	0.007	
			(0.002)	(0.006)	
Δ Share of cultivated area					-0.007*
					(0.004)
Number of airports in radius	-0.002	0.030	0.030	0.030	0.030
	(0.009)	(0.034)	(0.033)	(0.034)	(0.034)
Distance to closest fumigation airport	-0.056***	-0.010	-0.009	-0.009	-0.009
	(0.014)	(0.034)	(0.034)	(0.034)	(0.033)
Distance to Department's capital	0.009*	0.022*	0.021*	0.021*	0.021*
	(0.005)	(0.013)	(0.013)	(0.013)	(0.013)
Distance to closest principal market	0.094***	0.218***	0.215***	0.216***	0.216***
	(0.016)	(0.052)	(0.052)	(0.052)	(0.050)
Elevation x 100 mts (MASL)	-0.002***	-0.006*	-0.006*	-0.006*	-0.006*
	(0.001)	(0.003)	(0.003)	(0.003)	(0.003)
Water disposability index	0.045***	0.100***	0.100***	0.100***	0.100***
	(0.006)	(0.020)	(0.020)	(0.020)	(0.020)
Soil erosion index	-0.016***	-0.044**	-0.044**	-0.043**	-0.043**
	(0.004)	(0.020)	(0.020)	(0.020)	(0.020)
Soil aptitud index	-0.018***	-0.017	-0.016	-0.017	-0.017
	(0.005)	(0.019)	(0.019)	(0.019)	(0.019)
Share of rural population	0.003	-0.036	-0.037	-0.037	-0.037
	(0.022)	(0.096)	(0.096)	(0.096)	(0.096)
Observations	6,348	1,308	1,308	1,308	1,308
R-squared	0.125	0.132	0.131	0.133	0.133

Notes: This table presents the probability of a municipality being sprayed. Column (1) include all the municipalities while Column (2) to (5) results restrict the sample to municipalities that have been sprayed at least once since 2001. Standard errors reported are clustered at the municipality level and presented in parenthesis. * is significant at the 10% level, ** is significant at the 5% level, *** is significant at the 1% level. .

Table 2: Main results of the effects of the coca presence

Dependent variable:	Dropout rate			Enrollment rate			Retention rate		
	Primary	Middle	High	Primary	Middle	High	Primary	Middle	High
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Area affected coca	0.109	0.136	0.328**	-0.028	-0.004	-0.022	-0.118	-0.104	-0.259**
	(0.133)	(0.128)	(0.157)	(0.021)	(0.032)	(0.046)	(0.124)	(0.169)	(0.105)
Observations	7,653	7,627	7,520	5,521	5,521	5,521	7,653	7,631	7,570
Dep. Var. Mean	2.73	4.57	3.15	86.93	90.15	73.35	97.27	95.43	96.84
Dep. Var. S.D.	2.12	3.20	2.71	22.78	23.81	22.78	2.09	3.18	2.70

Notes: This table presents the Wald estimad using the stata `fuzzydid` package. Each entry in the table comes from a different estimation. Outcomes are reported in the header of the column and each one is standardized to have zero mean and unit variance in the sample. Standard errors are clustered at the municipality level and bootstraped using 50 repetitions. They are reported in parenthesis. * is significant at the 10% level, ** is significant at the 5% level, *** is significant at the 1% level.

Table 3: School efficiency measures and coca presence

Dependent variable:	Grade pass rate			Grade fail rate			Grade repetition rate		
	Primary	Middle	High	Primary	Middle	High	Primary	Middle	High
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Predicted Area affected coca	0.098	0.024	-0.179*	-0.234	-0.152	0.026	0.126	0.027	-0.178
	(0.127)	(0.125)	(0.095)	(0.167)	(0.107)	(0.145)	(0.115)	(0.114)	(0.128)
Observations	7,721	7,699	7,661	7,653	7,648	7,618	7,599	7,595	
Dep. Var. mean	94.01	89.97	93.46	3.11	5.28	3.18	1.72	2.36	0.97
Dep. Var. S.D.	4.58	7.08	5.13	3.40	5.78	3.73	2.01	2.72	1.43

Notes: This table presents the Wald estimad using the stata `fuzzydid` package. Each entry in the table comes from a different estimation. Outcomes are reported in the header of the column and each one is standardized to have zero mean and unit variance in the sample. Standard errors are clustered at the municipality level and bootstraped using 50 repetitions. They are reported in parenthesis. * is significant at the 10% level, ** is significant at the 5% level, *** is significant at the 1% level.

Table 4: School attainment and coca presence

	Language			Mathematics		
	Primary	Middle	High	Primary	Middle	High
Dependent variable:	Saber5	Saber9	Saber11	Saber5	Saber9	Saber11
	(1)	(2)	(3)	(4)	(5)	(6)
Area affected coca	0.143	0.121	-0.036	0.174**	0.072	0.012
	(0.089)	(0.082)	(0.034)	(0.086)	(0.085)	(0.039)
Observations	6,555	6,536	4,366	6,553	6,534	4,366
Dep. Var. mean	295.51	284.33	48.78	294.78	290.51	47.86
Dep. Var. S.D.	30.79	31.95	3.68	33.30	33.8	4.28

Notes: This table presents the Wald estimad using the stata `fuzzydid` package. Each entry in the table comes from a different estimation. Outcomes are reported in the header of the column and each one is standardized to have zero mean and unit variance in the sample. For primary and middle school, estimates uses data from 2012 to 2017, while for high school, from 2014 to 2017. Standard errors are clustered at the municipality level and bootstraped using 50 repetitions. They are reported in parenthesis. * is significant at the 10% level, ** is significant at the 5% level, *** is significant at the 1% level.

Table 5: Legal crops and coca presence

Dependent variable:	Ratio harvest-sown	Share area sown	Share area harvested
	(1)	(2)	(3)
Area affected coca	0.004	0.004	0.005
	(0.012)	(0.004)	(0.005)
Observations	5,403	5,459	5,459
Dep. Var. mean	0.850	0.141	0.121
Dev. Var. S.D.	0.124	0.166	0.145

Notes: This table presents the Wald estimad using the stata `fuzzydid` package. Each entry in the table comes from a different estimation. Outcomes are reported in the header of the column. Standard errors are clustered at the municipality level and bootstraped using 50 repetitions. They are reported in parenthesis. * is significant at the 10% level, ** is significant at the 5% level, *** is significant at the 1% level.