On the Effectiveness and Welfare Consequences of Anti-drug Eradication Programs**

Sandra V. Rozo *

Abstract

This paper studies the impact of aerial spraying on coca-producing areas in Colombia. For this purpose, I use panel data with satellite information on the location of coca crops between 2000 and 2010. I exploit the plausibly exogenous variation created by restrictions to spraying in protected areas and US international supply anti-drug expenditures to identify the effect of the program. My results suggest that spraying reduces coca production by around 25%, and that this income shock worsens the socioeconomic conditions of the treated areas. The negative effects of the program on poverty and health are maintained 2 years after the fumigations.

JEL Classification: O12, O13, O54, I32 and I38.

Keywords: Public Policy, Latin America, and Welfare.

**: I would like to thank the United Nations Office of Drugs and Crime and all the members of SIMCI in Bogota for providing the data for this study and answering all my questions. I also thank Daniel Mejia for the additional support in obtaining the data through the Center of Studies in Security and Drugs (CESED) at Universidad de los Andes. I am extremely grateful to Adriana Lleras-Muney, Aprajit Mahajan, Walker Hanlon, Paola Giuliano, Leah Boustan, and seminar participants of LACEA in Lima, the Impact Evaluation Network in Harvard University, the Workshop on Illegal Drug Markets, Crime and Violence in Latin America at UCLA, Universidad de los Andes, and UCLA for helpful comments and suggestions.

*PhD candidate. Department of Economics-UCLA, email: sandrarozo@ucla.edu.

1 Introduction

In 2011, 18 countries were implementing anti-drug forced eradication programs (World Drug Report of 2012). Most of these programs remain in place today and are mainly focused on the eradication of opium poppy and coca leaf crops—the main inputs of heroin and cocaine production. According to data from the United Nations Office of Drugs and Crime (UNODC), of all the countries that have implemented these types of initiatives in the last two decades, Colombia has applied the most aggressive program in terms of financial resources invested and total hectares of coca eradicated. This occurred because the country became the top producer of cocaine in the world in 1994 (Angrist and Krueger (2008)), facilitating the direction of a vast amount of financial resources from the Colombian and the US governments toward reducing cocaine´s supply. In fact, according to the Office of National Control Policy between 2000 and 2010 the US government spent around 16 billion dollars in international supply control programs, and at least 25% of these resources were spent in Colombia. For its part, between 2000 and 2010 the Colombian government disbursed US$668 million/year in its war against illegal drug production.

Despite the huge amount of resources invested, as of today, there is very little empirical evidence at the micro level on the impact of these programs on the sprayed areas. Most of the related work consists of theoretical models calibrated with aggregate data to simulate the effect of anti-drug policies on drug trafficking and econometric analysis based on aggregate time series (see for example Rydell et al. (1996), Moreno-Sanchez at al. (2003), Diaz and Sanchez (2004), Mejía (2008), Chumacero (2008), Costa-Storti and De Grauwe (2008), Grossman and Mejía (2008), Tragler et al. (2008), Dion and Russel (2008), and Mejía and Restrepo (2011)).

This paper contributes in this direction by assessing the impact of aerial spraying on coca production, violence, education, health, and poverty in Colombia. For this purpose I use two data sets. The first one is a panel constructed from satellite images collected yearly by the Integrated Monitoring System of Illicit Crops of UNODC between 2000 and 2010. It includes information on all the areas that had some coca crops during those 11 years. The unit of observation is a grid which corresponds to an area of 1 km^2. For each grid I observe the hectares of coca, the hectares sprayed, and the hectares manually eradicated.

The second data set is a panel for all the municipalities that had some coca crops between 2001 and 2010. It allows me to identify the effects of the program on: i) violence outcomes–e.g., homicide rates, armed actions, and forced displacement; ii) education outcomes–e.g., enrollment rates and school dropout; iii) health outcomes--e.g., infant mortality; and iv) poverty outcomes–e.g., unsatisfied basic needs index, rural quality of life index, and poverty rates.

The identification of the effects of aerial spraying is challenging given the treatment is not randomly assigned, but is targeted through satellite images.

The targeting mechanism creates two types of endogeneity issues. *Cross section endogeneity* arises since the targeted areas have more hectares of coca and are ones with the lowest governmental presence. Hence, they are also the ones with worse socioeconomic outcomes. Thus, a simple mean comparison of the outcomes between treated and control areas will be biased in absolute value towards zero on coca production and will show a strong negative effect of the program on socioeconomic outcomes.

Panel endogeneity arises from the time variation that spraying may create in other anti-drug public programs. In practice, the areas that reduce coca production are more likely to receive additional support. For example, other programs such as *Programa Familias Guardabosques* and *Programa Proyectos Productivos* give economic temporary support to producers that have left the coca crops over a short period of time (i.e., around 3 months). It may be argued that once the temporary economic support ends producers may have additional incentives to go back to the coca crops since they will either sell those crops to drug traffickers or get sprayed again and receive additional temporary support from the government. Thus, a regression that includes year and municipality fixed effects may still be biased in absolute value towards zero for hectares of coca cropped. Yet, this *panel endogeneity* is not a big concern for the socioeconomic outcomes since they correspond to mean values by municipality, and the economic support is given to only some producers during a short period of time. Hence, the aggregate figures are unlikely to be affected.

To address these problems, I exploit the plausibly exogenous variation created by governmental restrictions to spraying in protected areas (i.e., natural parks and indigenous territories). Since aerial spraying is forbidden in protected areas it follows that coca crops outside or further away from these areas face a higher likelihood of being treated. Moreover, to gain time variation in the instrument, I interact these restrictions with the US international anti-drug expenditures. Since an important share of US supply expenditures were directed to Colombia during the period, it should be expected that higher expenditures will increase the treated intensity more in non-protected areas.

Notice that by using the interaction between these two variables my identification strategy is not threatened by the possibility that protected and unprotected areas may be systematically different. Given that my estimates will include year and grid or municipality fixed effects, the instrument is effectively comparing non-protected areas with a high change in enforcement expenditures (high instrument intensity) with protected areas with a low change in enforcement expenditures (low instrument intensity). Hence, there will only be a violation in the exclusion restriction if non-protected areas adjust more quickly than protected areas to annual changes in anti-drug policy. I address this concern by showing that there are no differences in the growth rates of public expenditures (aggregated or by type) by instrument intensity.

I also check for the other two main concerns about my identification strategy, namely that: i) farmers do not respond to the program by moving their coca plants to protected areas; and ii) that the government is not compensating by applying other eradication programs such as manual eradication on protected areas.

My results suggest that when aerial spraying increases in one hectare, coca production decreases by 25%. I obtain similar results when I use a random sample collected at the producer level by SIMCI-UNODC. The estimates for poverty rates, rural quality of life (RQL) and unsatisfied basic needs (UBN) support the idea that the reduction in coca production is reflected in a negative income shock on coca farmers. In particular, I find that when the share of area sprayed increases by 1% in each municipality, poverty rates increase by 4pp, the UBN increases by 1.5%, and the RQL decreases by 2.5%. More striking is the fact that these effects persist 2 years after the fumigations.

I also find that this negative income shock is reflected in worse education and health conditions of coca producers. In particular, I find a negative effect of the program on secondary school enrollment (drops by -2.35pp.) and dropout rates (increases by 0.96pp.). Yet, I find no evidence of an effect on primary enrollment rates. These suggest that as a result of the program older children may be pulled out of school to work and compensate the loss in value of the coca crops. The negative effect of the program on education outcomes disappears 1 year after the treatment implementation. This is in line with the results by Beegle et al.(2006) and Dehejia and Gatti (2002) who document the impact of a loss in the value of crops on child labor.

Related to health outcomes, I find that when the share of area sprayed increases by 1%, infant mortality increases by 1.3pp. This effect may be explained by a combination of a direct effect of the herbicide on health outcomes as documented by Mejía and Camacho (2012) and an indirect effect of the program caused by the income shock. This effect persists 2 years after the fumigations.

I also find evidence of an increase on violence outcomes in the short term (12 months or less after treatment). My results indicate that when the share of area sprayed increases by 1% in each municipality homicide rates increase by 4.56pp, the number of armed confrontations increase by 1.69, and the number of individuals displaced by force increases by 41.6. Local authorities suggested the negative effect of aerial spraying on violence may be explained by the military check-ups that take place on the ground before the aircraft begin their flights. These inspections may be increasing the likelihood of a confrontation between the authorities and the drug traffickers, increasing violence on the treated areas in the short run. Moreover, this effect may be explained by retaliation from drug traffickers as a response to the crop eradication. These explanations are consistent with the fact that these effects seem to disappear in the long-term estimates.

Finally, I check for evidence of spillovers of the program at the grid, municipality, and department level[1]. I find no evidence that coca production increases

[1] Colombia is divided into 32 departments and 1123 municipalities.

in the non-treated areas close to the treated ones. This may suggest that if producers are changing locations they may be going to areas further away from the treated ones, or even other countries with similar coca-growing conditions (i.e., Peru and Bolivia). The aggregate figures support this hypothesis.

In the next section, I provide an overview of the involuntary eradication programs, section 3 describes the data, section 4 presents the identification strategy, section 5 presents the results, and section 6 presents some robustness checks. Finally, Section 7 offers concluding remarks.

2 Forced Eradication Anti-Drug Programs

Currently the only types of forced eradication programs implemented in the world are manual eradication and aerial spraying. Manual eradication is performed by a group of men who destroy coca or opium poppy crops and by hand (UNODC (2012)). Aerial spraying is executed with an herbicide called glyphosate, commercially sold as Roundup. It kills the plants inhibiting their ability to produce amino acids. The herbicide is sprayed from small aircrafts as closely as possible to the coca crops. Figure 1 shows the intensity of these programs in the main producers of coca and opium. The figure shows that for 2010, Colombia, Mexico, Peru, Morocco, Myanmar, Bolivia and Afghanistan were the countries most actively involved in this type of initiative.

In terms of scale, of the 18 countries that implement these programs, Colombia applies the most aggressive eradication strategy. Data from the Colombian Antinarcotics Police (DIRAN) suggest that in 2010, 146,340 hectares were treated by these programs in Colombia. This is more than double the size of Mexico´s eradication program, which takes second place in terms of hectares eradicated (UNODC (2012)). Aerial spraying began to be implemented in Colombia in 1978 (Gaviria and Mejia (2011)), and it is the biggest forced eradication program in the world (UNODC (2012)). Yet, data on the size of the program began to be collected only in 1986. Since that year, the program has been growing extensively. The total area sprayed increased from 870 to 103,302 hectares between 1986 and 2010.

Figure 2 presents the evolution of the hectares eradicated by type of program and hectares cropped during the last decade. The time series show that the rise in hectares sprayed has been coupled with a reduction in coca production in the last decade. However, the causality of the program on the total hectares of coca cropped cannot be inferred from these aggregate figures alone since other changes may have been occurring in Colombia during these years.

Aerial spraying is mainly targeted through satellite images produced and processed by UNODC. These satellite pictures are taken in the last months of the year and are processed with great detail to identify the exact location of coca crops. This information is then passed to the Antinarcotics National

Police (DIRAN) in charge of executing the program. Before the fumigations are performed, DIRAN confirms the location of the crops through flight inspections. Due to the magnitude of the area cropped in Colombia and the governmental financial restrictions, not all the coca crops are sprayed in Colombia. Thus, the program concentrates on areas where there is a higher crop density.

The manual eradication program began in 2007 and maintains a modest size given its high costs in terms of human lives. Reports from DIRAN estimate that since its implementation 135 men have been killed through explosions of mines hidden in the ground to prevent the eradication. In 2010, 32,140 hectares were eradicated through this program.

Unlike the manual eradication program, aerial spraying has been implemented for a more than 30 years, and has a clear targeting mechanism. Thus, this study will focus on identifying the effectiveness and welfare consequences of the aerial spraying program.

3 The Data

I will use two data sets to identify the impact of the program. The first one contains panel data at the grid level, which corresponds to an area of 1 km^2 or 100 hectares. The data come from satellite images collected by SIMCI-UNODC each December. It includes all grids that had at least 1 hectare of coca between the period 2000 and 2010. For each unit of observation I observe the hectares of coca cropped, the hectares aerially sprayed, the hectares manually eradicated, and the exact location of each of the 1,1115,840 grids in the sample. I use this sample to identify the effect of aerial spraying on hectares of coca cropped. Appendix 1 presents descriptive statistics for this data set.

The second panel contains the 288 municipalities of Colombia that had at least 1 hectare of coca between 2001 and 2010[2]. In this sample I observe: i) violence related outcomes (i.e., homicide rates per 100,000 pop., forced displacement, and number of armed confrontations); ii) education outcomes (i.e., enrollment rates and school dropout); iii) health outcomes (i.e., infant mortality rates); and iv) poverty outcomes (i.e., unsatisfied basic needs index, rural quality of life index, and poverty rates). I also observe the treatment intensity measured in total hectares of coca aerially sprayed, and other covariates such as area, rural population, geographic conditions (i.e., rain, altitude, erosion) institutional presence, and public expenditures. I use this data set to asses the welfare consequences of aerial spraying on coca producer municipalities in Colombia. Appendix 2 presents the data sources, the definition of each variable, and descriptive statistics for this data set. Table 1 presents a summary of the information available in both data sets.

[2]Colombia is divided into 1,123 municipalities.

4 Estimation Framework

There are several challenges to identifying the impact of aerial spraying on producer areas given that there was not randomization in the treatment assignment. In particular, two sources of endogeneity can be distinguished. First, in each period the program uses satellite images to target the areas with a higher concentration of coca crops, so these areas have a higher likelihood of being aerially sprayed. Since coca is illegal in Colombia, those are also the areas with lower governmental presence, and hence, with poorer welfare outcomes. Hence, an OLS estimation that compares the treated and control areas will likely be biased towards zero in absolute value on hectares cropped, and may show a negative effect of the program on violence and socioeconomic indicators. I will refer to this endogeneity source as *cross section endogeneity*.

The second endogeneity source comes from the time variation in public expenditures on other anti-drug programs that is correlated with the change in aerial spraying. The areas that reduce coca production, say as a result of the program, are more likely to receive additional support from other smaller programs. For instance, other programs such as *Programa Familias Guardabosques* and *Programa Proyectos Productivos* give economic temporary support to the producers that have left the coca crops for a short period of time (i.e., 3 months). It may be argued that once the temporary economic support ends producers may have additional incentives to go back to coca since they will either sell those crops to drug traffickers or get sprayed again and receive temporary support from the government. Hence, an OLS regression including fixed effects by municipality will continue to be biased in absolute value towards zero for hectares cropped. I will refer to this type of endogeneity as *panel endogeneity*. This type of endogeneity is not expected to affect the socioeconomic indicators given they correspond to averages by municipality. Thus, it is unlikely that small transfers received by some producers in a short period of time can affect the aggregate figures. Yet, I will check that this is indeed the case in my estimates.

By governmental mandate, natural parks and indigenous territories cannot be sprayed in Colombia[3]. According to the National Geographical Institution in Colombia (i.e., Instituto Geográfico Agustin Codazzi) natural parks and indigenous territories occupy 12% and 27.6% of the Colombian territory, respectively. Figure 3 presents the exact location of these areas. It is worth pointing out that there are coca crops inside and outside of these areas in Colombia. For instance, in 2010 18% of the total hectares of coca were located in protected areas.

To introduce time variation in the instrument I interact restrictions to spray-

[3]According to Decree 143 of 1991 aerial spraying is prohibited in indigenous territories and natural parks. The decree also establishes a 100 meter band around these areas for which aerial spraying is also forbidden. The resolution 0015 approved the 5th of August of 2005 allows aerial spraying in natural parks if several requirements are fulfilled. Yet, as of today these conditions have never been met and aerial spraying has never been done in protected areas.

ing in protected areas with US international anti-drug expenditures. Since a relevant portion of US expenditures for anti-drug policy was directed to Colombia during the period of analysis, it should be expected that higher expenditures will imply a higher treatment intensity in non-protected areas. I use this plausibly exogenous variation to identify the effect of the program on five group of outcomes: i) drug production, ii) violence, iii) education, iv) health, and v) poverty. The specific outcomes included in each group are presented in Table 2. The specification that I estimate is:

$$Y_{it} = \alpha_0 + \alpha_1 Spr_{it} + g_t + k_i + e_{it} \quad (1)$$

$$Spr_{it} = \beta_0 + \beta_1 Outside\,PA_i * US\,Exp_t + g_t + k_i + u_{it} \quad (2)$$

where Y_{it} represents the outcomes by grid or municipality i in year t; $Spri_{it}$ is the treatment intensity measured as hectares sprayed; g_t are time fixed effects; k_i are grid or municipality fixed effects; $Outside\,PA_i$ is an indicator variable that takes the value of 1 if the grid is located outside protected areas, and corresponds to the number of hectares outside protected areas for the municipality sample; and $US\,Exp_t$ are the US international anti-drug expenditures in real billions of dollars of 2010. For the municipality data I scale hectares cropped, sprayed and outside the protected areas by the total area. This is necessary due to the diverse size of municipalities in Colombia. In the specification of equation (1) and (2) α_1 will identify the Local Average Treatment Effect of the program for the group of compliers (that is the group for which there is variation in spraying caused by the instrument).

Finally, notice that the correlation between the instrument and the treatment intensity should be positive since non-protected areas have a higher likelihood of being treated, and given that the treatment intensity should increase when there are higher expenditures in the US international anti-drug expenditures.

4.1 Assessing the instrument's quality

I begin by presenting some evidence on the correlation between the instrument and the treatment intensity. Figure 4 presents the hectares sprayed by deciles of $Outside\,PA_i$ at the municipality level. Recall that this variable is defined as the share of area represented by non-protected areas. Hence, higher deciles of this variable imply a higher likelihood of treatment. Panel A of Figure 4 presents fitted values of hectares sprayed on the deciles of $Outside\,PA_i$ for years with different levels of US supply expenditures. The figure suggests that: i) municipalities with a higher share of non-protected areas had a higher number of hectares sprayed, and that ii) in years when the US anti-drug expenditures were higher (as shown in Panel B), the intensity of treatment increased more for non-protected areas; in other words, the slope of the fitted lines increases when US anti-drug expenditures are higher.

A formal test of the relevance assumption (as defined by Imbens and Angrist (1994), Abadie (2003) and Angrist et al. (1996)) is presented in Tables 3 and 4. The tables present the results of the first stage for the samples with units by grid and municipality. Both tables show the estimates of three regressions: column (1) presents the first stage regression using the interaction of the area outside protected areas and the US anti-drug expenditures, and columns (2) and (3) present the results of the regression using each of these variables individually.

The results for column (1) confirm that the relevance assumption is satisfied. The coefficient on the instrument has a positive sign and is statistically significant at 1%. The R^2 is 18% and 17% for the grid and municipality sample, respectively. Also the partial R^2 is higher than 5% for both samples, and the F-test for excluded instruments takes a value of 48.87 for the grid and 21.71 for the municipality data. For the case of a single endogenous regressor Staiger and Stock (1997) suggest rejecting the hypothesis of weak instrument if this F-statistic is higher than 10. Hence, these estimates rule out concerns of having the finite sample bias of IV (as defined by Bound, Jaeger and Baker (1995)). Moreover, the estimates in columns (2) and (3) confirm that each of the variables has predictive power on the treatment intensity and affect it in the expected direction.

The second assumption that must be satisfied for the validity of my identification strategy is the exclusion restriction. The exclusion restriction requires that the instrument only affects the outcomes though aerial spraying. Since the model is exactly identified there is no formal proof to support this argument. Yet, I will attempt to make a case that the assumption is met in this case.

Recall that the estimates of equations (1) and (2) will include time, and grid or municipality fixed effects, for which I should only be concerned by a violation of the exclusion restriction caused by variables that are changing over time. In other words, my identification strategy is not threatened by the static potential differences between protected and non-protected areas. The instrument is effectively comparing non-protected areas with a high change in enforcement expenditures with protected areas with a low change in enforcement expenditures. Hence, there will only be a violation in the exclusion restriction if non-protected areas adjust more quickly than protected areas to these changes (and these adjustments are not directly caused by changes in the spraying program).

I address this concern by presenting evidence of no differences in governmental expenditures or investment by instrument intensity. Notice that if non-protected areas were adjusting their outcomes more quickly relative to protected areas as a response to enforcement programs, then there should be a differential governmental response in terms of public expenditures between these areas. Hence, no differences in public expenditures and investment could be seen as evidence of no direct relation between the change in instrument intensity and the change in the outcomes.

In Figures 5 and 6 I use the data by municipality to present evidence to support this argument. I cannot use the sample with observations at the grid level since I only observe hectares of coca, hectares sprayed and hectares manually eradicated for that sample. In the figures, I divided the municipality panel into two groups according to instrument intensity. The **high instrument intensity** group includes all the observations with an instrument decile higher than 5, whereas the **low intensity** group includes all municipalities with deciles equal to or lower than five. The figures suggest that there are no differences in the growth rates of total public expenditures, total public investment, total education expenditures or total health expenditures between groups in the period under analysis. In other words, the figures show that the changes in anti-drug policy expenditures have not created any differential governmental response between protected and non-protected areas.

The third assumption that must be satisfied for the validity of the instrument is the monotonicity assumption, which rules out the existence of defiers. In other words, protected areas should be less exposed to aerial spraying throughout the period of analysis. Figure 7 shows evidence that supports the validity of this assumption. As can be seen, those municipalities with a higher share of protected areas have very low levels of aerial spraying.

4.2 Is there manipulation of the treatment assignment?

An important threat to my identification strategy is given by a possible manipulation of the treatment by producers. If producers are aware of the governmental restrictions to aerial spraying on protected areas and they do not face restrictions to change locations, it could be expected that they will move their coca crops to protected areas to prevent the fumigations. If that were the case the instruments could no longer be used as a plausibly exogenous variation for treatment assignment. Figure 8 presents deciles of the percentage of area covered by non-protected against the percentage of area covered by coca crops in each municipality. The figure suggests that there is not a concentration of coca crops in protected areas throughout the period of analysis.

4.3 Is the government substituting programs in protected areas?

Another concern with the validity of the results is that the government may have been substituting the aerial spraying program with manual eradication in the protected areas. If that is the case, equations (1) and (2) no longer identify the impact of aerial spraying, but the difference between two treatment effects. Figure 9 presents the deciles of the area covered by unprotected areas against the mean hectares manually eradicated (both as a percentage of total area). The figure suggests that the government is not increasing the number of hectares manually eradicated in protected areas. In fact, Decree 143 of 1991 in Colombia imposes restrictions on any involuntary eradication program implemented in protected areas.

5 Empirical Results

Tables 5 through 9 present the estimates of equations (1) and (2). I only use the grid sample to identify the impact of the program on drug production since it is the only outcome available at this level. The tables present the outcomes by categories into 5 groups: i) drug production (Table 5), ii) violence (Table 6), iii) education (Table 7), iv) health (Table 8) and v) poverty (Table 9). In all tables, column (1) shows the results of a pooled OLS regression including year dummies, column (2) presents the estimates of an OLS regression including year, and grid or municipality fixed effects, and column (3) presents the instrumental variable estimates including time and grid or municipality fixed effects.

Since I am testing several outcomes in each category I also present the Bonferroni´s adjusted p-values which correct for the higher likelihood of identifying a significant effect when multiple hypothesis are being tested in the same sample[4].

Finally, to identify the long-term effect of the program I lag the treatment in equation (2) one and two periods. This allows me to assess the impact of aerial spraying one and two years after the treatment reception. The results of these exercises are presented in columns (4) through (9) throughout the tables.

5.1 Impact on Drug Production

Table 5 presents the estimates for the effect of spraying on hectares of coca. The results by OLS suggest that the program had a positive effect nearly equal to zero on the total hectares of coca cropped. Yet, as expected, the 2SLS estimates that correct for the endogeneity bias of the OLS coefficients show a negative effect of the program. Specifically, the results suggest that in the treated grids the hectares of coca cropped were reduced by -0.21 per additional hectares sprayed. Given that the mean hectares of coca by grid was 0.84, this amounts to a reduction of 25% on the treated grids.

The long-term estimates present a similar pattern, showing a negative impact of the program only for the instrumental variable regressions. In particular, the effect of the program one year after the treatment is -0.36 ha and two years

[4]Bonferroni´s correction is a multiple-comparison correction used when several statistical tests are being performed simultaneously. It rejects the null hypotheses of non statistical significance for each outcome if the p-values are smaller than $\frac{\alpha}{s}$, where α is the significance level and s is the number of tests being performed. See Wright (1992).

after the program is -0.18 ha. Hence, there is evidence of a sustained negative effect of the program in the long term (i.e., 1 or 2 years after the fumigations).

There are several reasons why aerial spraying may not be having a higher impact on coca leaf production. For instance, Dávalos et al. (2009), Caulkins and Hao (2008), and Mejía and Restrepo (2011), suggest some of the ways that producers may reduce the effect of the herbicides on coca are: 1) applying manual defoliation, 2) selecting highly productive coca varieties with more resistance to the herbicides, or 3) switching to agroforestry coca, which mixes tall plants such as plantains or fruits with coca to prevent the effect of fumigations.

5.2 Impact on Violence Outcomes

Table 6 presents the results of equations (1) and (2) for three different outcomes: i) homicide rates per 100,000 inhabitants, ii) number of armed confrontations, and iii) number of individuals displaced by force in each municipality.

The positive signs of the OLS coefficients of the regressions of these outcomes on spraying (see column (1)) suggest that there is indeed a cross section endogeneity issue. Specifically, the areas that tend to be sprayed tend to have worse violent outcomes. This is not a surprise due to the illegal character of coca crops in Colombia. In consequence, these crops tend to develop in areas with low governmental presence.

When I add year and municipality fixed effects in column (2) the impact of the program becomes smaller in absolute value but it is still positive and significant for the three outcomes. Moreover, the 2SLS estimates including fixed effects in column (3) are very similar in magnitude to the panel OLS estimates in column (2), confirming there should be no endogeneity concerns for these outcomes. Specifically, the estimates in column (2) suggest that when the share of area sprayed increases by 1%, the homicide rates increase in 4.56pp, the number of armed confrontations increase in 1.69, and the number of displaced individuals increases to around 42.

In the past, several studies have shown the relation between drug trafficking and violence (see for instance Angrist and Kugler (2008), Dube and Vargas (2008) and Dell (2011)), but the role that anti-drug involuntary eradication programs have on violence has never been studied before with micro data, to the best of my knowledge. Local authorities suggested the negative effect of aerial spraying on violence may be explained by the military check-ups that take place on the ground before the aircraft begin their flights. To guarantee the security of the pilots, aerial spraying only begins once a group of men from the military or the police check the aircraft trajectory to prevent any retaliation of drug traffickers against the aircraft. These check-ups may be increasing the violence level of the treated areas in the short-run by increasing the likelihood that authorities have more confrontations with drug traffickers.

An alternative explanation for this effect may be a retaliation response from drug traffickers as a consequence of the eradication. Both of these explanations are consistent with the fact that these effects seem to disappear in the long-term estimates.

5.3 Impact on Education Outcomes

The group of outcomes categorized under education is made up of three variables: primary enrollment rates, secondary enrollment rates and school dropout rates. The estimates of the structural equation for these outcomes are presented in Table 7. I only find a significant effect of the program on secondary enrollment and school dropout in the short term. As for the case of the violence outcomes the sign of column (1) confirms the cross section endogeneity problem between the treatment and the welfare conditions. In particular, the areas that are treated tend to have worse socioeconomic outcomes since they are also the areas with less governmental presence.

The results in columns (2) and (3) suggest a negative effect of aerial spraying on secondary enrollment rates and school dropout. The estimates in both columns are very close, suggesting no panel endogeneity issues on these variables. In particular, the panel OLS estimates suggest that when the share of area sprayed increases by 1%, secondary enrollment rates decrease by 2.35pp and school dropout rates increase by 0.96pp. Given the mean values of these variables for the periods of interest in the rural areas, this represents a decrease of 3.3% in secondary enrollment rates, and 8.8% in school dropout. I do not find any effect on primary enrollment rates.

Together these results may be indicating that since a relevant part of the household's income is reduced by aerial spraying the older children are being pulled out of school to work and compensate for the income shock (as suggested in a theoretical model by Basu and Van (1998)). Similar responses to shocks in the value of crops have been documented by Beegle et al. (2006) and Dehejia and Gatti (2002).

5.4 Impact on Health Outcomes

Table 8 presents the estimates for infant mortality. As for the other cases, the estimates in column (1) suggest a problem of cross section endogeneity between the treatment and the socioeconomic conditions. The results in columns (2) and (3) continue to present very similar results, suggesting no evidence of panel endogeneity.

The estimates point to a negative and significant effect of the program on infant mortality in the short and the long term. The coefficients indicate that when the share of area treated increases in 1%, infant mortality increases by 1.3pp, 1.02pp and 1.04pp, the same, one and two years after the fumigations.

Mejía and Camacho (2012) find similar results when they study the effects of the program on health pathologies. Using the reports of all health institutions in Colombia the authors identify a negative effect of aerial spraying on skin pathologies and abortion rates. Although the negative effect of the program may be explained by the direct effect that the herbicide may be having on health outcomes, it must be pointed out that these effects may also be explained by the negative income effect of the program. Evidence of the effect of negative income shocks on health outcomes has been also found by Adda et al (2009) and Ferreira and Schady (2009).

5.5 Impact on poverty

Since the estimates point to a negative effect of the program on coca crops, it may be argued the negative socioeconomic effect of the program may be induced by a negative income shock. Table 9 tests this hypothesis, assessing the effect of the program on three income proxies including: i) unsatisfied basic needs (UBN), ii) rural quality of life (RQL), and iii) rural poverty.

The UBN index is constructed by the Colombian Statistical Department with variables that give some information on whether the basic needs of the population are covered. Some of the indicators included in this index are inadequate materials of housing, overcrowding, adequate public services, households with high economic dependence, and households with kids of schooling age that do not attend a schooling institution. Higher values of the index indicate more unsatisfied needs in a household. The index is available only for 2005 and 2010.

The RQL index is a function of access to public services, human capital, social security access, housing conditions, and demographic conditions for each household. It is constructed to take values between 1 and 100 for each household. Higher values indicate better quality of life conditions.

The poverty rates are constructed based on the percentage of the rural population under the poverty line[5]. Since the RQL and the rural poverty rates were constructed with the information available in the population census of 2005 they are only available for those years. Hence the estimates for those variables will not include fixed effects by municipality.

All estimates suggest a negative income effect of the program. More strikingly, these effects seem to be maintained in the long-term estimates. Specifically, column (2) suggests the UBN index is 0.98, 0.91 and 0.76 higher in the same, one and two years after the treatment. This amounts to an effect of 1.5%, 1.4% and 1.1% for each of the periods, respectively. The 2SLS estimates for UBN are very similar in magnitude to the panel OLS results, suggesting no time varying endogeneity concerns. Yet, the instrumental variable estimates are not statistically significant for the long-term estimates.

[5] The poverty line is the 60% of the median household income from the data published by the Colombian Statistical Department in the population census of 2005.

Results in column (3) for RQL and poverty rates suggests that the areas that had a 1% higher share of area aerially sprayed had a rural quality of life index 1.21pp. lower and poverty rates 4% higher in the short term. One year after the treatment these effects are -1.62pp. and -3% on the RQL index and the poverty rates; and two years after the treatment -1.32pp. and -3%, respectively. This represents suggestive evidence of the negative effect of the program on household income and supports the idea that income effect are the mechanism through which the program may be worsening education and health outcomes.

6 Robustness Check

6.1 Estimates by Producer

In this section I use a sample collected by SIMCI-UNODC at the producer level to check the effects of the programs on drug production outcomes. The sample consists of two rounds of cross sections, one collected between 2005 and 2006, and the second between 2007 and 2010. The producers to be surveyed were chosen by dividing the country in seven regions according to geographical characteristics. Each of the regions was divided in areas of 1 km^2, and all those grids with coca production were identified through the satellite images. The producers that were surveyed were selected randomly from the areas with coca.

The surveys contain information on the socioeconomic characteristics of producers, productivity related variables (i.e., number of harvests and kgs/ha), and the geographic location of rural producers. In the survey, I observe which producers were aerially sprayed within the last 12 months. The sample has 2535 observations. Appendix 3 presents the descriptive statistics of these variables. For the productivity variables the information was collected directly on the coca crops by field workers of UNODC and not only self-reported by coca producers.

I use this sample to run equations (1) and (2) for three outcomes related to drug production: i) hectares cropped, ii) kilograms of coca per hectare, and iii) number of harvests per year. Given that there are few observations where producers are located inside protected areas, I use the distance from the location of coca producers to the border of the nearest protected area as an instrument for aerial spraying. It is expected that those producers near or within protected areas face a lower probability of being aerially sprayed. Figure 10 presents some graphical evidence on the relation between the distance to the nearest protected area and aerial spraying.

As for the case of the grid and municipality sample, I multiplied the instrument by total US international anti-drug expenditures. Table 10 presents the estimates of the first stage equation. The estimates include the producer's age, education and gender as well as dummies for year, region, department and municipality. They confirm a positive effect of the instrument on the treatment assignment and reject the possibility of weak instruments.

Table 11 presents the results of the OLS and 2SLS estimates of equation (1). For both, the effect of aerial spraying is negative. Yet, the impact of the program increases in absolute value for the 2SLS coefficients. This is in line with the idea that OLS estimates were biased in absolute value towards zero in the cross section.

The 2SLS results suggest that at the time of the survey the producers that were sprayed in the last 12 months had 0.31 less hectares of coca cropped relative to the other producers. This is a reduction of approximately 26%, given that the mean number of ha of coca cropped is 1.15. The table also shows that at the time of the survey the kilograms per hectare were 81.98 lower for treated producers. This is a reduction of around 8% given a mean value of kgs/ha of 1020.97 in the data set. In addition, the results suggest that the number of harvests collected by producers that were sprayed was 0.98 lower relative to the other producers. This is a reduction of around 22% given a mean value of 4.35 for the number of harvest/year. In particular, the total hectares cropped in around 26% lower for the treated producers relative to the control group.

These results are reassuring since they point to results similar to the ones obtained with the sample with grid units. Although I cannot address the panel endogeneity for this case, and the coefficients may be underestimating the effect of the program, at least they point to the same signs and similar magnitudes.

6.2 Are there spillover effects?

In this subsection I check whether the program is creating spillover effects. These effects will occur if, for example, when the hectares of coca cropped drop in the treated areas, they increase in other close areas that were not treated by the program. I use the following specification to test for spillovers:

$$Coca_{-it} = \alpha_0 + \alpha_1 Spr_{it-1} + g_t + k_i + e_{it} \tag{3}$$

where Spr_{it-1} represents the total ha sprayed in municipality i in $t-1$, $Coca_{-it}$ represents the total hectares of coca cropped in the municipalities that belong to the same department as municipality i but which were not treated in $t-1$ or in t[6]; g_t and k_i stand for year and municipality fixed effects. Standard errors were clustered at the municipality level in the estimates. Appendix 4 presents the estimates of equation (3), which suggest no evidence of a spillover effect of the program. In particular, the effects show the opposite sign, suggesting coca production decreased in the municipalities not treated by the program as well. I also estimate this specification with the grid sample, analyzing the effect around the adjacent grids that were not treated in the previous period. The results are not statistically significant as well for this specification.

[6] Colombia is divided into 1123 municipalities, which can be grouped into 32 departments.

This may indicate that if coca producers are changing locations as a result of the program, they may be moving to areas further away from the treated areas or to other countries with similar coca-growing conditions (e.g., Peru or Bolivia). In fact, the aggregate series of coca production by country support this argument. While coca production fell in Colombia in 60.81% between 2000 and 2010, it increased by 136% in Peru and by 44% in Bolivia during this period. However, despite the increase of hectares cropped in Peru and Bolivia the world's coca production has been decreasing.

6.3 Placebo Test

As another robustness check I run a placebo test, using the same specification as equations (1) and (2) but replacing the dependent variable with latitude and longitude in the grid sample and with rain and altitude in the municipality sample. There is no reason why aerial spraying should be affecting those variables, and hence this a good test for the quality of the data and of the estimates. Appendix 5 presents the results. They confirm the expected behavior showing no relation of any of the dependent variables with aerial spraying.

7 Conclusions

This paper documents and exploits plausibly exogenous variation in treatment assignment of aerial spraying in Colombia to identify the effects of forced eradication programs on rural producers. The results suggest that these programs are successful in decreasing coca production and reducing the productivity of coca crops. Yet, they also suggest that they create strong negative income shocks that worsen the socioeconomic indicators of rural producers. This evidence points at the urgency of exploring new alternatives for controlling drug supply in producing countries.

8 References

Abadie, A., J., and Imbens, G. (2002). Instrumental Variables Estimates of the Effect of Subsidized Training on the Quantiles of Trainee Earnings. Econometrica 70: 91-117.

Abadie, A., J. (2003). Semiparametric Instrumental Variable Estimation of Treatment Response Model. Journal of Econometrics 113: 231-263.

Adda, J., Gaudecker, H., and Banks, J., (2009). The Impact of Income Shocks on Health: Evidence from Cohort Data. Journal of the European Economic Association 7 (6): 1361-1399.

Angrist, J. , Imbens,G., and Rubin., D., (1996). Identification of causal effects using instrumental variables. Journal of the American Statistical Association 91: 444-72.

Angrist, J. and Krueger A., (2008). Rural Windfall or a new resource curse? Coca, Income and Civil Conflict in Colombia. The Review of Economics and Statistics. Vol. XC (2).

Basu, K., and Van, P.H, (1998). The Economics of Child Labor. The American Economic Review 88 (3): 412-427.

Beegle, K., Dehejia, R., and Gatti, R., (2006). Child Labor and Agricultural Shocks. Journal of Development Economics 81 (1): 80-96.

Bound, J., A. Jaeger, and R. Baker, (1996). Problems with Instrumental Variables Estimation When the Correlation Between the Instruments and the Endogenous Explanatory Variable is Weak. Journal of the American Statistical Association 90: 443-450.

Caulkins, J. and Hao, H., (2008). Modeling drug market supply disruptions: Where do all the drugs not go? Journal of Policy Modeling 30: 251-270.

Chumacero, R., (2008). Evo, Pablo, Tony, Diego, and Sonny General Equilibrium Analysis of the Illegal Drugs Market. Policy Research Working Paper 4565. The World Bank.

Costa Storti, C., and De Grauwe, P., (2008). Modeling the Cocaine and Heroin Markets in the Era of Globalization and Drug Reduction Policies. Paper presented at the CESifo Venice summer institute, 2008.

Dávalos, L.M., and A.C. Bejarano. (2008). State of the Wild 20082009: A global portrait of wildlife, wildlands, and oceans. Washington, D.C.: Island Press.

Dejejia, R., and Gatti, R., (2002). Child Labor: The Role of Income Variability and Access to Credit Across Countries. NBER Working Paper N. 9018.

Dell, M., (2010). Trafficking Networks and the Mexican Drug War. Job Market Paper.

Diaz, A., and Sanchez, F., (2004). A Geography of Illicit Crops (Coca Leaf) and Armed Conflict in Colombia. Crisis States Programme. Working Paper Series N. 1 (47).

Dion, M., and Russler, c., (2008). Eradication Efforts, the State, Displacement and Poverty: Explaining Coca Cultivation in Colombia During Plan Colombia. Journal of Latin American Studies 40(3): 399-421

Dube, O., and Vargas, J., (2008). Commodity price shocks and civil conflict: Evidence from Colombia. Working Paper.

Ferreiro, F., and Schady, N., (2009). Aggregate Economic Shocks, Child Schooling and Child Health. The World Bank Research Observer 24 (2).

Gaviria, A. y Meja D., (2011). Polticas antidroga en Colombia: xitos, fracasos y extravos. Universidad de los Andes. Editorial Kimpres. Bogota.

Grossman, H. and Meja, D., (2008). The War Against Drug Producers. Economics of Governance 9(1): 5-23.

Imbens and Wooldridge (2007b). What's New in Econometrics. Lecture Notes Summer 2007 NBER.

Imbens, G. W. and Angrist, J. D., (1994). Identification and estimation of local average treatment effects. Econometrica 62(2): 467-475.

Mejia, D., (2008). The War on Illegal Drugs: The interaction of anti-drug policies in producer and consumer countries. Mimeo, Universidad de los Andes.

Mejia C., and Camacho, A., (2012). The Health Consequences of Aerial Spraying of Illicit Crops: The Case of Colombia. Mimeo.

Mejia, D., and Posada, J., (2008). Cocaine Production and Trafficking: What do we know? Policy Research Working Paper 4618. The World Bank

Mejia, D and Restrepo, P., (2011). The War on Illegal Drugs in Producer and Consumer Countries: A simple analytical framework. Documento CEDE No. 2, 2011. Universidad de los Andes. Forthcoming as Chapter 10 in the book Illicit Trade and the Global Economy (P. De Grawe and C Costa-Sorti, eds.), MIT Press.32

Moreno-Sanchez, R., Kraybill. D., and Thomson, S., (2003). An Econometric Analysis of Coca Eradication Policy in Colombia. World Development 31 (2): 375-383.

Office of National Control Policy (2012). Budget Summary of the US. Washington D. C.

Rydell, P., Caulkins, J., and Everingham, S., (1996). Enforcement or Treatment: Modeling the Relative Efficacy of Alternatives for Controlling Cocaine. Operations Research 44(5): 687-95

Staiger, D., and J. Stock, (1997), Instrumental Variables Regression with Weak Instruments. Econometrica 68: 1055-1096.

Tragler, G., Caulkins, J., and Feichtinger, G., (2001). Optimal Dynamic Allocation of Treatment and Enforcement In Illicit Drug Control. Operations Research 49(3): 352-62.

UNODC (2010). World Drug Report -2010. New York.

UNODC (2011). World Drug Report -2011. New York.

UNODC (2012). World Drug Report -2012. New York.

Wright, S., (1992). Adjusted P-Values for Simultaneous Inference. Biometrics 48: 1005-1013.

9 Tables

Table 1: Summary of Data Sets

	Data Set 1	Data Set 2
Units	Grid (1 km^2=100 ha)	Municipality
Years	2000-2010	2001-2010
Frequency	Yearly	Yearly
Type of Data	Panel	Panel
Representative Sample	with coca	with coca
Observations	1,115,840	2880
Coca (ha)	Yes	Yes
Aerial Spraying (Ha)	Yes	Yes
Manual Eradication(Ha)	Yes	Yes
Other Variables	–	Violence, Education, Health, Poverty, Geographic Characteristics, Area, Rural Population, and Government Expenditures, and Authorities Presence.

Table 2: Outcomes Grouped by Category

Group Category	Variables	Grid	Municipality
Drug Production	Ha of coca cropped	X	
Violence	Homicide rates/100,000 inh		X
	Armed Confrontations		X
	Displaced Individuals		X
Education	Primary enrollment rate		X
	Secondary enrollment rate		X
	School dropout rate		X
Health	Infant mortality		X
Poverty	Unsatisfied basic needs index		X
	Quality of life index		X
	Poverty rates		X

Table 3: First Stage Results (Grid Sample)

Dependent Variable: Ha Sprayed			
Independent Variables	(1)	(2)	(3)
$Instrument_{it}$	0.48***		
	(0.06)		
$I(Outside\,Protected\,Areas)_i$		0.64***	
		(0.03)	
$US\,Anti-drug\,Expenditures_t$			0.45***
			(0.05)
Year FE	X	X	
Grid FE	X		X
R^2	0.18	0.2	0.08
F-Test (excluded instruments)	48.87	269.52	62.91
Partial R^2	0.08	0.09	0.03
N. of Clusters		101,440	
Observations		1,115,840	
Mean Values			
$Instrument_{it}$		1.27	
$I(Outside\,Protected\,Areas)_i$		0.84	
$US\,Anti-drug\,Expenditures_t$		1.51	

Note: Clustered standard errors at the grid level are presented in parentheses. ***: Significant at 1% level.

Table 4: First Stage Results (Municipality Sample)

Dependent Variable: Area Sprayed (% of Total Area)			
Independent Variables	(1)	(2)	(3)
$Instrument_{it}$	0.18***		
	(0.03)		
$Share\, Outside\, Protected\, Areas_i$		0.32***	
		(0.07)	
$US\, Anti-drug\, Expenditures_t$			2.04***
			(0.05)
Year FE	X	X	
Municipality FE	X		X
R^2	0.17	0.2	0.11
F-Test (excluded instruments)	21.71	19.91	17.96
Partial R^2	0.05	0.06	0.04
N. of Clusters		288	
Observations		2880	
Mean Values			
$Instrument_{it}$		1.29	
$Share\, Outside\, Protected\, Areas_i$		0.86	
$US\, Anti-drug\, Expenditures_t$		1.50	
Aerial Spraying (ha)		0.26	

Note: Clustered standard errors at the municipality level are presented in parentheses. ***: Significant at 1% level.

Table 5: Structural Equation Results (Grid Sample)- Impact of Spraying on Coca Production

	Dependent Variable: Coca (ha)								
	Short-term			1 year after treatment			2 years after treatment		
	OLS		2SLS	OLS		2SLS	OLS		2SLS
Independent Variables	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Ha Sprayed at t	0.00***	0.00**	-0.21***						
	(0.00)	(0.00)	(0.04)						
Ha Sprayed at t-1				0.00***	0.00**	-0.36***			
				(0.00)	(0.00)	(0.07)			
Ha Sprayed at t-2							0.00***	0.00**	-0.18***
							(0.00)	(0.00)	(0.06)
Year FE	X	X	X	X	X	X	X	X	X
Grid FE		X	X		X	X		X	X
R^2	0.15	0.12	-5.89	0.11	0.09	-25.19	0.09	0.06	-9.73
N. of Clusters		101,440			101,404			101,440	
Observations		1,115,840			1,014,400			912,960	
Mean Values									
Ha Sprayed					0.54				
Coca (ha)					0.84				

Note: Clustered standard errors at the grid level are presented in parentheses. Columns (1), (4) and (7) include dummies for region, department and municipality. ***: Significant at 1% level; **: Significant at 5% level.

Table 6: Structural Equation Results (Municipality Sample)- Impact of Spraying on Violence

	Short-term			1 year after treatment			2 years after treatment		
	OLS		2SLS	OLS		2SLS	OLS		2SLS
Independent Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Homicide Rate	6.54***	4.56***	4.23**	5.01	-6.12	-5.1	2.26	-3.86	-3.56
	(1.47)	(1.54)	(1.60)	(2.54)	(4.8)	(5.62)	(2.05)	(2.86)	(3.45)
Armed Confrontations	2.03***	1.69***	1.51***	0.45	-0.49	-0.37	0.48	-0.59	-0.52
	(0.46)	(0.51)	(0.59)	(0.24)	(0.51)	(0.82)	(0.26)	(0.41)	(0.91)
Forced Displacement	69.29***	41.6***	39.52***	131.44***	41.46	37.26	106.52***	59.88	41.99
	(10.89)	(11.74)	(15.79)	(37.98)	(34.55)	(39.95)	(41.45)	(70.62)	(90.95)
Year FE	X	X	X	X	X	X	X	X	X
Mun FE		X	X		X	X		X	X
N of Clusters		288			288			288	
Observations		2880			2592			2304	
Mean Values									
Homicide Rate	55.85								
Armed Confrontations	7.17								
Forced Displacement	592.7								
Area Sprayed (% of Total Area)	0.26								

Note: Clustered standard errors are presented in parentheses. In the table coefficients are only marked as significant if the $p-value <= \alpha/outcomes\,tested$, where α is the significance level and the outcomes tested corresponds to 3. This adjustment corresponds to Bonferroni´s correction for multiple hypothesis testing. *: Significant at 10%, **: Significant at 5%, ***: Significant at 1%.

Table 7: Structural Equation Results (Municipality Sample)- Impact of Spraying on Education

	Short-term			1 year after treatment			2 years after treatment		
	OLS		2SLS	OLS		2SLS	OLS		2SLS
Independent Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Primary Enrollement	-5.4***	-0.98	-0.71	-4.65	-1.94	-1.18	-3.55	-2.04	-1.93
	(1.32)	(1.48)	(3.23)	(2.62)	(2.67)	(5.75)	(2.6)	(2.69)	(4.28)
Observations		1728			1728			1728	
Secondary Enrollment	-4.02***	-2.35***	-2.13***	-3.63***	-2.39	-1.75	-3.85***	-1.23	-1.09
	(0.17)	(0.32)	(0.43)	(1.13)	(1.07)	(4.3)	(1.07)	(1.09)	(4.2)
Observations		1728			1728			1728	
School Drop-out	1.77***	0.96***	0.82***	0.75***	0.74	0.36	0.66***	0.48	0.34
	(0.19)	(0.22)	(0.26)	(0.23)	(0.54)	(0.67)	(0.17)	(0.71)	(3.45)
Observations		864			864			864	
Year FE	X	X	X	X	X	X	X	X	X
Mun FE		X	X		X	X		X	X
N of Clusters		288			288			288	
Mean Values									
Primary Enrollment	128.93								
Secondary Enrollment	71.21								
School Drop-out	10.8								
Area Sprayed (% of Total Area)	0.26								

Note: Clustered standard errors are presented in parentheses. In the table coefficients are only marked as significant if the $p - value <= \alpha/outcomes\,tested$, where α is the significance level and the outcomes tested corresponds to 3. This adjustment corresponds to Bonferroni´s correction for multiple hypothesis testing. *: Significant at 10%, **: Significant at 5%, ***: Significant at 1%

Table 8: Structural Equation Results (Municipality Sample)- Impact of Spraying on Health

	Short-term			1 year after treatment			2 years after treatment		
	OLS		2SLS	OLS		2SLS	OLS		2SLS
Independent Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Infant Mortality	1.7***	1.3***	1.26***	1.41***	1.02***	0.97*	2.01***	1.04***	0.94***
	(0.07)	(0.14)	(0.29)	(0.18)	(0.23)	(0.31)	(0.11)	(0.13)	(0.26)
Year FE	X	X	X	X	X	X	X	X	X
Mun FE		X	X		X	X		X	X
N of Clusters		288			288			288	
Observations		576			576			576	
Mean Values									
Infant Mortality					44.1				
Area Sprayed (% of Total Area)					0.26				

Note: Clustered standard errors are presented in parentheses. *: Significant at 10%, **: Significant at 5%, ***: Significant at 1%.

Table 9: Structural Equation Results (Municipality Sample)- Impact of Spraying on Poverty

	Short-term			1 year after treatment			2 years after treatment		
	OLS		2SLS	OLS		2SLS	OLS		2SLS
Independent Variable	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
UBN Index	1.77***	0.98***	0.86***	1.67***	0.91***	0.62	1.43***	0.76***	0.42
	(0.11)	(0.19)	(0.23)	(0.15)	(0.18)	(0.27)	(0.21)	(0.27)	(0.49)
Year FE	X	X	X	X	X	X	X	X	X
Mun FE		X	X		X	X		X	X
N of Clusters		288			288			288	
Observations		576			576			576	
RQL Index	-1.84*	–	-1.21**	-1.82**	–	-1.62**	-1.44*	–	-1.32*
	(0.26)	–	(0.32)	(0.33)	–	(0.38)	(0.42)	–	(0.51)
Observations		288			288			288	
Poverty Rates	0.11***	–	0.04***	0.08***	–	0.03***	0.06***	–	0.03***
	(0.00)	–	(0.01)	(0.00)	–	(0.01)	(0.00)	–	(0.01)
Observations		288			288			288	
Mean Values									
UBN Index					64.07				
RQL Index					47.82				
Poverty Rates					0.56				
Area Sprayed (% of Total Area)					0.26				

Note: Clustered standard errors are presented in parentheses. In the table coefficients are only marked as significant if the $p-value <= \alpha/outcomes\, tested$, where α is the significance level and the outcomes tested corresponds to 3. This adjustment corresponds to Bonferroni´s correction for multiple hypothesis testing. *: Significant at 10%, **: Significant at 5%, ***: Significant at 1%.

Table 10: First Stage Results (Producer Sample)

	Dependent Variable: $I(Sprayed > 0)$		
Independent Variables	(1)	(2)	(3)
$Instrument_{it}$	0.03***		
	(0.00)		
$Min\,Distance\,to\,Protected\,Areas_i$		0.02***	
		(0.00)	
$US\,Anti-drug\,Expenditures_t$			0.73***
			(0.05)
Covariates	X	X	X
R^2	0.46	0.45	0.43
Partial R^2	0.1	0.08	0.13
F (excluded instrument)	29.3	13.77	160.9
Observations	2102	2102	2102
Mean Values			
$Instrument_{it}$	89.44		
$Min\,Distance\,to\,Protected\,Areas_i$	51.67		
$US\,Anti-drug\,Expenditures_t$	1.69		
$I(Sprayed > 0)$	0.23		

Note: the covariates included at the producer level were age, education and gender. The estimates also included dummies for year, region, department and municipality. Only the estimations with the US Expenditures do not included dummies for year. Robust standard errors are presented in parentheses. *: Significant at 10%, **: Significant at 5%, ***: Significant at 1%.

Table 11: Structural Equation Results (Producer Sample)- Impact of Spraying on Drug Production

	Dependent Variables					
	Coca (ha)		Kgs/ Ha		N. Harvest	
	OLS	2SLS	OLS	2SLS	OLS	2SLS
Indp. Variable	(1)	(2)	(3)	(4)	(5)	(6)
$I(Sprayed > 0)$	-0.04**	-0.31***	-76.60**	-81.63**	-0.93***	-1.17***
	(0.01)	(0.02)	(34.22)	(37.70)	(0.22)	(0.36)
Covariates	X	X	X	X	X	X
R^2	0.35	0.18	0.48	0.40	0.60	0.60
Observations	2099	2099	2099	2099	2099	2099
	Mean Values					
Coca (ha)	1.15					
Kgs/ Ha	1022.41					
N of Harvests	4.48					
$I(Sprayed > 0)$	0.23					

Note: The table reports the estimates of equation (1) and (2). The covariates included at the producer level were age, education and gender. The estimates also included dummies for year, region, department and municipality. Robust standard errors are presented in parentheses. *: Significant at 10%, **: Significant at 5%, ***: Significant at 1%.

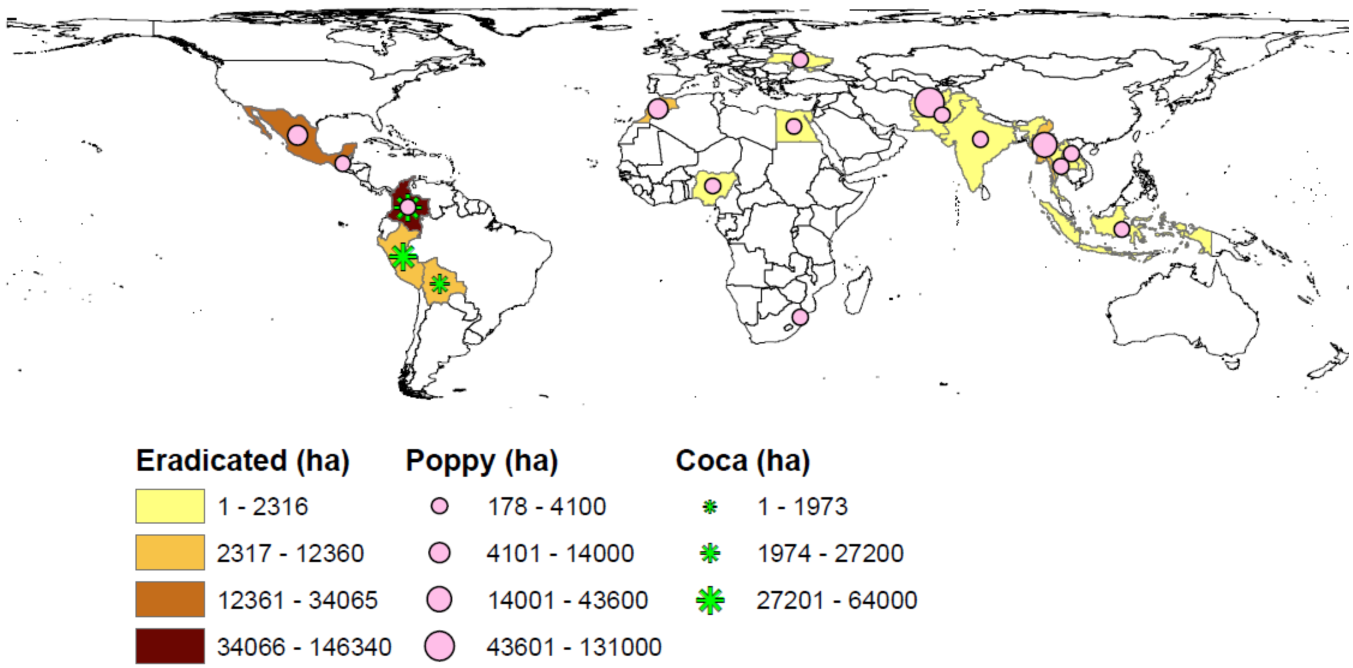


Figure 1: Intensity of Forced Eradication Programs in the World

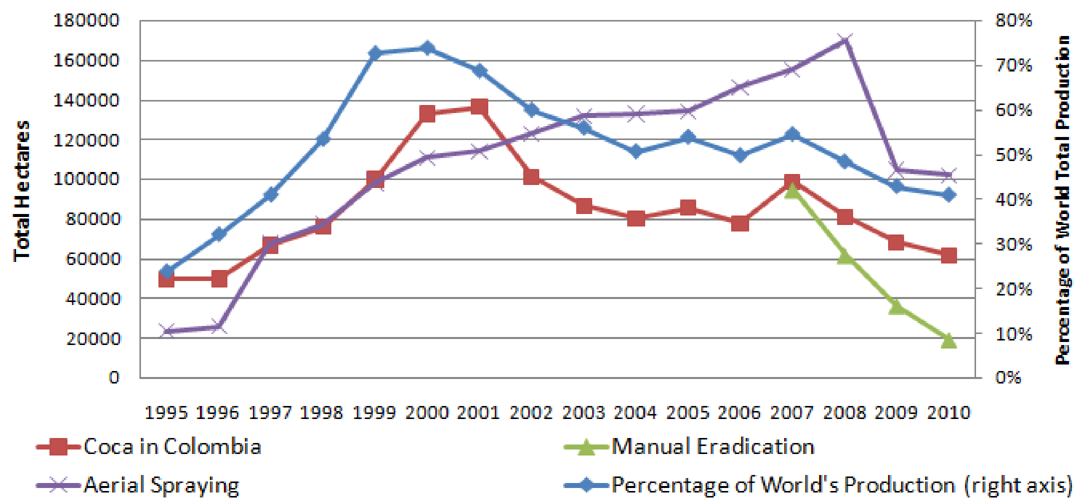


Figure 2: Coca Production, Aerial Spraying and Manual Eradication in Ha

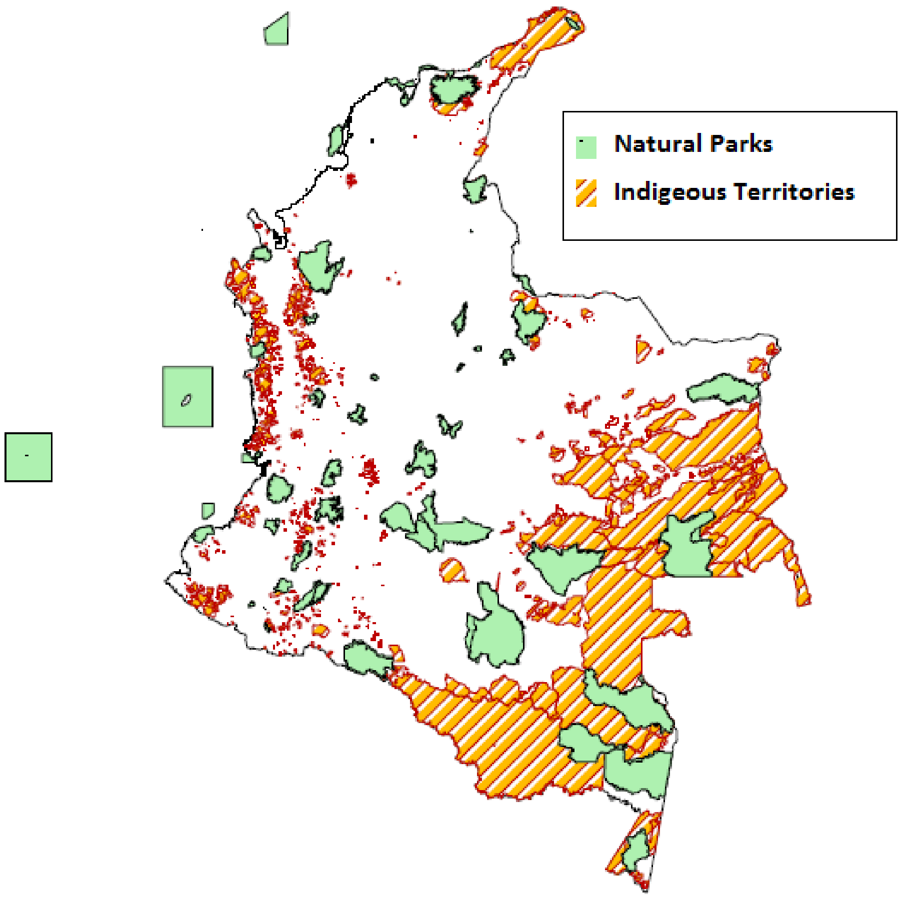


Figure 3: Location of Protected Areas in Colombia

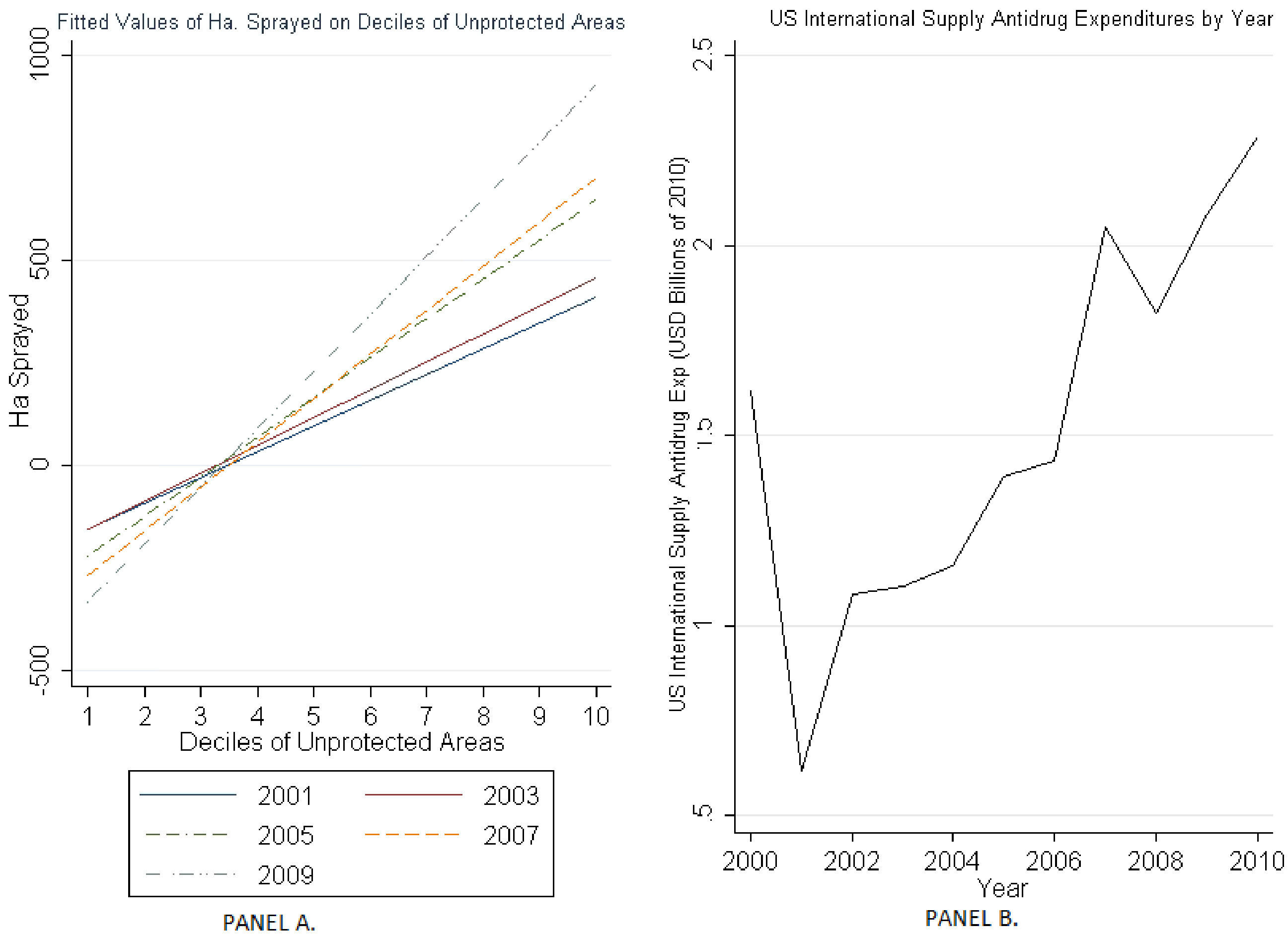


Figure 4: Treatment Intensity and Instrument Variation

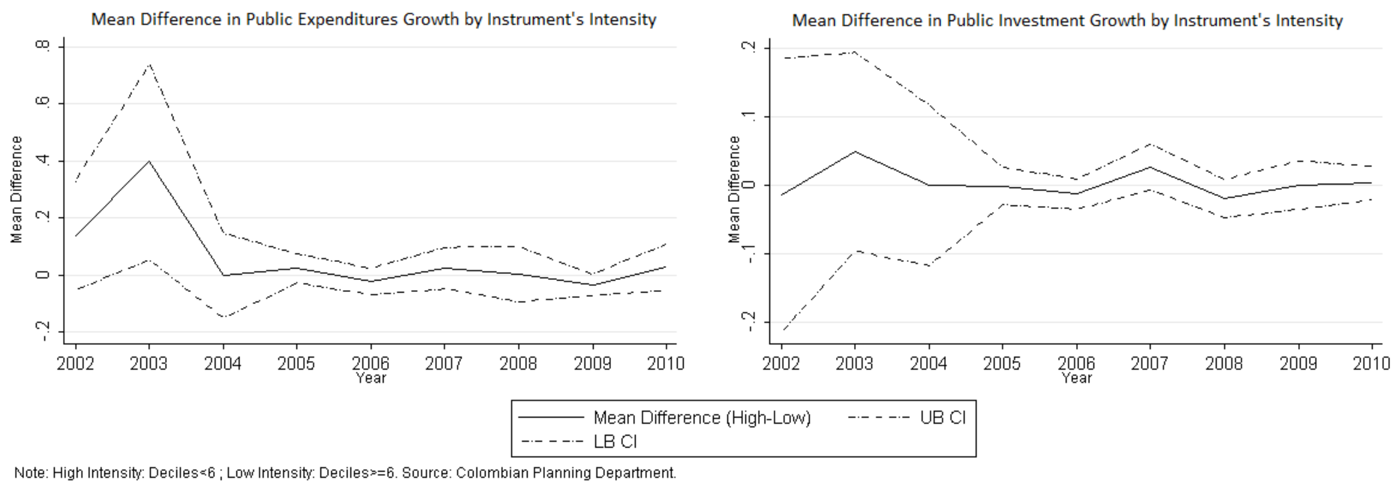
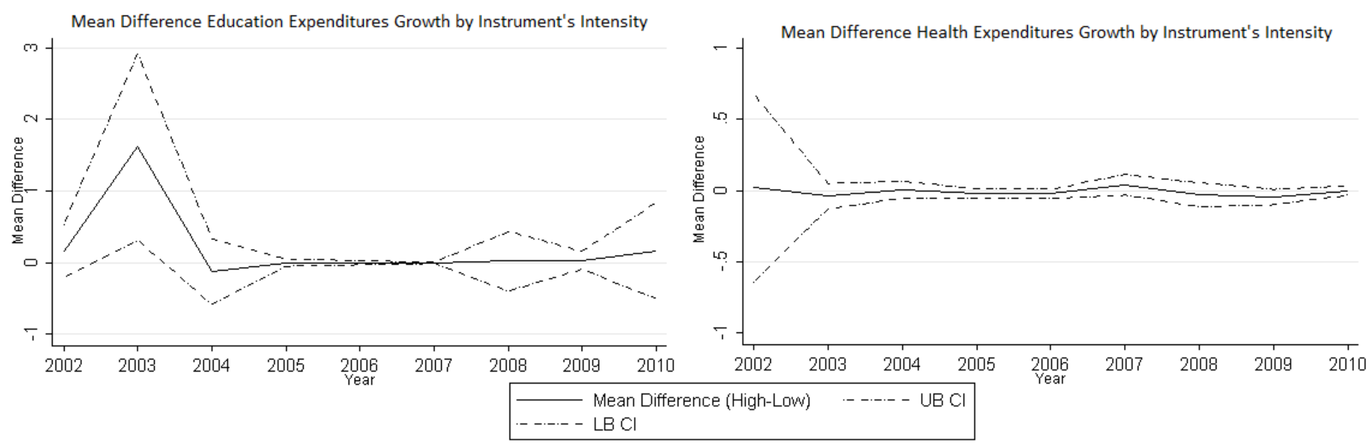
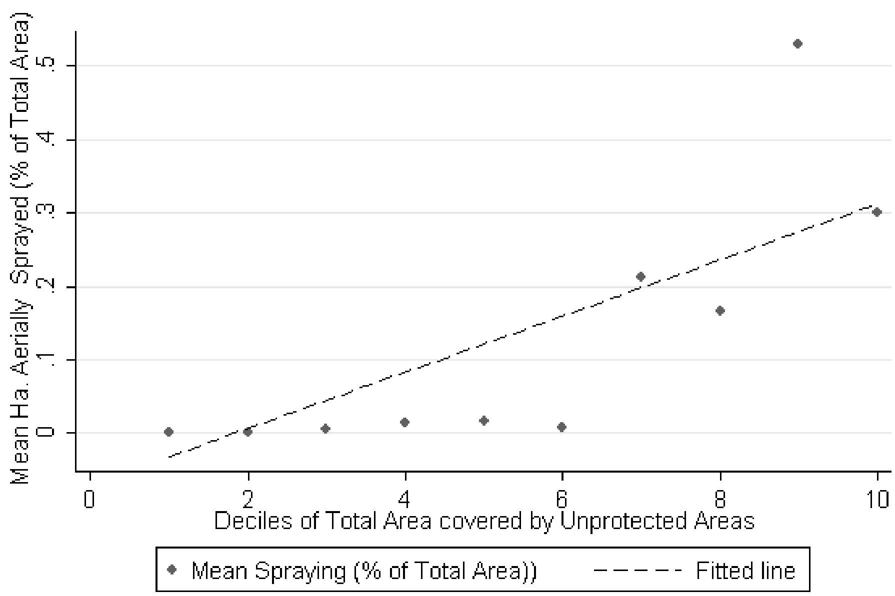


Figure 5: Mean Difference by Instrument's Intensity



Note: High Intensity: Deciles<6 ; Low Intensity: Deciles>=6. Source: Colombian Planning Department.

Figure 6: Mean Difference Public Expenditures Growth by Instrument's Intensity



Note: Protected areas include natural parks, natural reserves and indigenous areas.

Figure 7: Aerial Spraying in Unprotected Areas (Municipality Units)

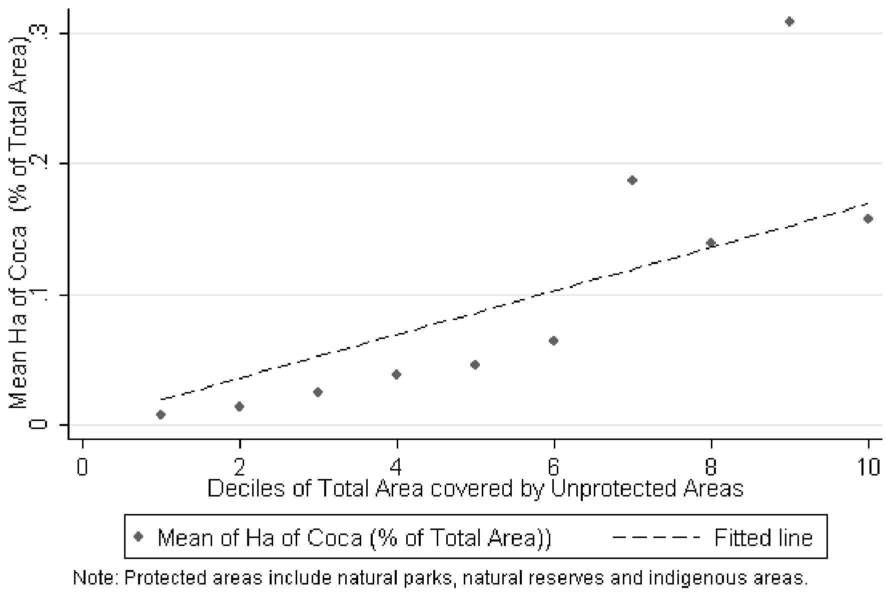


Figure 8: Coca Cultivation in Unprotected Areas (Municipality Units)

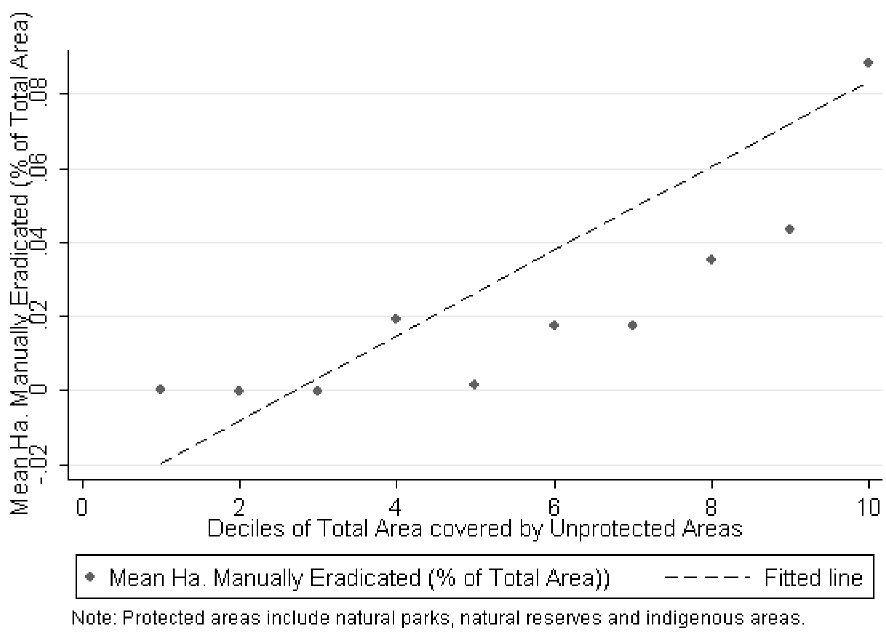


Figure 9: Manual Eradication in Unprotected Areas (Municipality Units

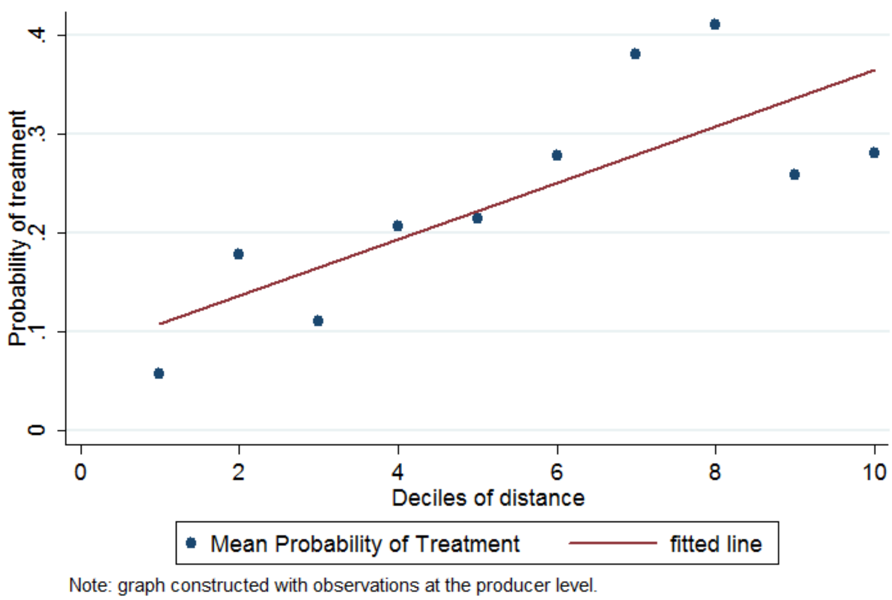


Figure 10: Distance to Nearest Protected Area and Probability of Treatment