Are Anti-drug Programs Affecting Productivity? The case of coca leaf producers in Colombia

Sandra V. Rozo**

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Abstract

This paper uses two rounds of surveys collected by the United Nations Office for Crime and Drugs (UNODC) in Colombia between 2005 and 2010 to assess whether governmental intervention induces productivity innovation in coca cultivation. I estimate the effect of aerial spraying for seven outcomes in the short and the long-run including: i) kgs of coca leaf produced by hectare and per year, ii) kgs of coca leaf per hectare and per harvest, iii) number of harvests collected per year, iv) density of crops (measured as distance between plants), v) productive age of coca plants in years, vi) number of workers in coca crops, and vii) total harvested area in hectares. To solve the endogeneity problem between these variables and aerial spraying I instrument the treatment with the proximity of coca producers to protected areas (e.g., natural parks and reserves). This last is possible since by explicit governmental mandate protected areas cannot be fumigated in Colombia. The results of the estimations suggest a negative effect of aerial spraying over all outcomes in the short-term (i.e., one year). In particular, those producers that were fumigated produced 2868.9 less kgs of coca leaf per hectare and per year, and 433 less kgs of coca leaf per hectare and per harvest relative to the other producers. These results contradict the view that aerial spraying increased productivity of coca producers, at least for the period 2005 and 2010. However, I also found evidence that the effect of the fumigations over productivity in the long-term (1 or 2 years) is not statistically different from zero.

JEL Classification: O13, O33, O54 and Q18.
Keywords: Drug Production, Productivity, Latin America.

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1 Introduction

Drug trafficking has great influence over political, social and economic structures in the world. It is not only a problem of producing countries in which illegal groups benefit from the rents it generates and violence is greatly increased (Angrist and Kugler (2008), Dube and Vargas (2008) and Dell (2011)), but also, it is a problem for consumer countries in which it induces huge health costs. For instance, according to the World Drug Report (2011) in 2010 alone 210 million people use illicit drugs, of which almost 200,000 died due to drug related causes.

Although thirty years ago, given the limitations on data availability, the emphasis of analysis was on the demand for drugs, in the last years newer and richer data sets have made it possible to improve our understanding of the supply dynamics for this market. In particular, in the last decade the United Nations Office of Drugs and Crime (UNODC)–with financial support from the US and the Andean governments– has been collecting and processing unique data sets that are suitable for characterizing coca supply in the Andean countries (i.e., Peru, Bolivia and Colombia), the main producers of coca bush in the world. Specifically, since in the last decade around half of the world's coca leaf was produced in Colombia most of the available data collected by UNODC characterizes coca supply in this country.

A representative group of the papers produced in the last years, proposes general and partial equilibrium models to study the effects of anti-drug policies over coca production and drug trafficking (see for example Mejía (2008), Chumacero (2008), Costa-Storti and De Grauwe (2008), Grossman and Mejía (2008), Tragler et al. (2008), and Rydell et al. (1996)). An important contribution among these group of papers is presented by Mejía and Restrepo (2011a) who calibrate a general equilibrium model using aggregate available data on cocaine production and trafficking to simulate the effect of anti-drug policies implemented between 2000 and 2006 in Colombia. The authors identify an elasticity of cocaine reaching consumer countries with respect to the amount of resources invested in anti-drug policy of 0.007%, and an elasticity of drug trafficking with respect to amount of resources invested against drug trafficking of 0.296%.

However, so far, the emphasis in these papers, has been either theoretical or on aggregate trends and there is relatively little empirical evidence to characterize the behavior of drug producers at the micro level. This paper aims at contributing in this direction by identifying the effect of anti-drug governmental policies on the productivity of coca leaf producers in Colombia. For this purpose I will use two unique rounds of surveys produced by UNODC through its integrated information system on illicit crops in Colombia (SIMCI, for its initials in Spanish). The first round of surveys was collected between 2005 and 2006, and the second round of surveys was collected by dividing the country in regions between 2007 and 2010[1]. Both surveys are representative at the national level and for the first time directly interviewed coca producers on their production techniques. Thus, they are exceptionally useful to identify if anti-drug policies are affecting coca leaf producer's productivity, and if so, in which direction.

In the last two decades, the Colombian government has applied voluntary and involuntary eradication programs as part of the anti-drug policy program. Among the voluntary programs, are all those that incentivize producers to abandon illicit crop production such as Conditional Cash Transfers (CCTs) or Alternative Development Programs (ADPs). ADPs support coca producers in developing alternative licit sources of income. The involuntary eradication programs mainly consist of aerial spraying on coca cultivated areas, although a manual eradication program is being implemented since 2006.

I will focus on identifying the effectiveness of aerial spraying on coca producer's productivity for two reasons. First, the aerial spraying program began in 1978 and accounted for more than 40% of the total public expenditures in anti-drug policy during most of the last decade in Colombia. Thus, it is the biggest and older anti-drug program applied by the Colombian government; and second, the identification of the effects of other programs is not possible since the targeting criteria for the voluntary eradication programs is not completely clear[2], and the manual eradication program is relatively small and new.

The effect of aerial spraying over coca leaf productivity is not obvious. Although, if herbicides are effective in killing the coca plants the expected effect should be negative, this analysis ignores that coca producers may be learning how to reduce the effectiveness of the fumigations or that governmental interventions may be incentivizing innovation. In fact, local authorities in Colombia are aware of the different actions that local farmers use to prevent the effectiveness of aerial spraying. The most common ones include intensively washing the crops right after the fumigation, cutting the plant but leaving the roots planted, and spraying the coca bushes with molasses to prevent the effect of the herbicides (See Mejía and Restrepo (2011a)). The first two techniques may be effective since the herbicides used in aerial spraying are absorbed by coca plants through the leafs and not the roots of the plants.

Moreover, according to data from UNODC, although the total area of hectares of coca cropped in Colombia and in the world has decreased in 57% and 27% respetively, the prices of coca paste, coca base or cocaine in the world have not changed as a consequence. In addition, the availability of cocaine in consumer countries has remained roughly stable (see Mejía and Posada (2008)). Thus, questions have been raised towards the effectiveness of anti-drug public expenditures over coca production and cocaine trafficking. In other words, as is pointed in UNODC (2005), even if the total area cropped is lower if productivity per hectare increases total supply of cocaine may not be affected[3]. This paper

[1] The surveys were collected in this way given budget considerations.

[2] Moreover, evidence by Mejia et al. (2011) suggest that in practice complications in the implementation of these type of programs has compromise their effectiveness.

[3] Other authors have suggested that this aparent *price puzzle* may be explained by an

aims at testing the validity of this hypothesis, at least for coca leaf production in Colombia.

The identification of the effect of aerial spraying is challenging given governmental interventions are not (and should not be) random. In particular, since aerial spraying is targeted through satellite images, those places with higher number of hectares of coca will be treated more likely since they are more visible. Hence, if coca producers choose their location freely, they will locate where they have the highest productivity. In that sense, by targeting the areas with the highest number of hectares of coca the government targets the most productive producers.

To solve for this endogeneity problem I instrument aerial spraying with the proximity of coca producers to natural parks and natural reserves (henceforth called protected areas). This is possible since by explicit government mandate, aerial spraying cannot be done in protected areas in Colombia. It then, naturally follows, that coca producers near or at these areas face lower probabilities of being sprayed with glyphosate.

I estimate the effect of aerial spraying in the short-term (i.e., one year) and the long-term (i.e., 2 to 3 years) using 2SLS for seven outcomes including: i) kgs of coca leaf produced by hectare and per year, ii) kgs of coca leaf per hectare and per harvest, iii) number of harvests collected per year, iv) density of crops (measured as distance between plants), v) productive age of coca plants in years, vi) number of workers in coca crops, and vii) total harvested area in hectares. The results in the short- term suggest a strong and negative effect of aerial spraying in all outcome variables. In fact, all of the coefficients of interest are statistically significant but once the treatment variable is instrumented the effect of aerial spraying grows in absolute value. This finding is in line with the idea that OLS was biased downwards in absolute value.

In particular, those producers that were fumigated produced 2869 less kgs of coca leaf per hectare and per year, and 433 less kgs of coca leaf per hectare and per harvest relative to the other producers. Moreover, the number of harvests collected each year is reduced in , the productive age of coca plants decreases in 1.12 years, and the harvested area decreases in 1.09 hectares. These results contradict the view that aerial aspersions increased productivity of coca producers, at least for the period 2005 and 2010.

However, I also found that the effect of the program over productivity in the long-term is not statisticall different from zero, which suggests producers recover from aerial sparying with no visible consequences over productivity in longer periods of time.

This paper is structured in five sections. The first section describes the current trends of coca production in Colombia, and explains why Colombia is a suitable place to answer the specific question I addressed in this paper. Section 2 presents the theoretical model to illustrate the relevance of identifying the direction of the effect of anti-drug public expenditures on productivity of coca

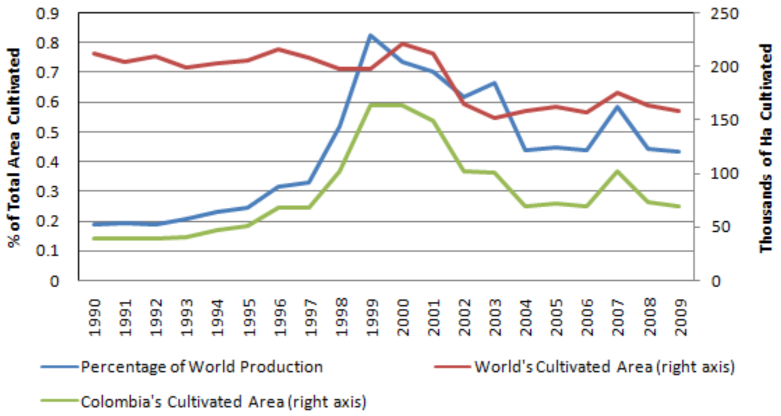
strategic response of coca producers to aerial aspersions that has lead to higher yields per hectare of land cultivated (see for example Mejia and Restrepo (2011) and Caulkins and Hao (2008)).

leaf producers. The next section deals with the empirical strategy, the data description, the identification strategy and the description of the instrument. Section 5 presents the results of the estimations, and finally, the last section presents some concluding remarks.

2 Why is Colombia a relevant case?

During the 90s Colombia became one of the main suppliers of coca leaf and cocaine in the world. According to Angrist and Krueger (2008) this was explained by the closure of the so-called "air bridge" connections of coca cultivation centers in Peru and Bolivia with refinery centers in Colombia, which took place around 1994 in response to the increasingly effective air interdiction by American and local militaries. As a consequence, coca cultivation and paste production shifted to Colombia's country side. In fact, data from the World Drug Report of 2011 suggests that between 1990 and 2000 Colombia passed from producing 18.9% to 73.7% of the total coca bush of the world (Figure 1).

Figure 1: Ha of Coca Cultivated in Colombia

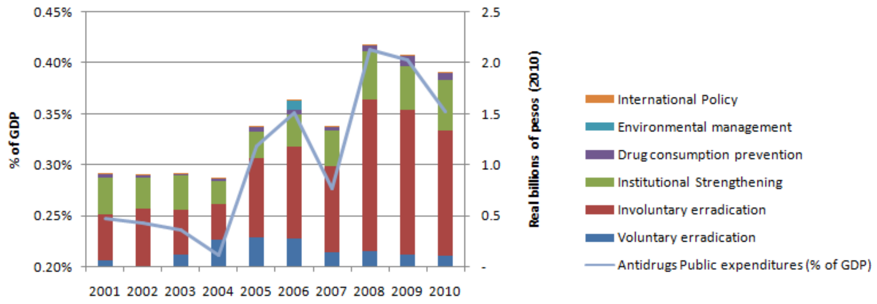


Source: Author's estimations with data from UNODC.

Coca cultivation has traditionally been of concern to the Colombian government since illegal armed groups fund their activities through drug trafficking. In the late 90s, given the dimension of the problem, the Colombian government dramatically increased its efforts to reduce coca leaf cultivation in the country. Governmental interventions can be broadly classified between two types: i) voluntary eradication programs, which induce producers to voluntarily eliminate crops; and ii) involuntary eradication programs, which destroy the coca crops temporarily. Among the voluntary eradication interventions, before 2003 the government launched several initiatives with modest effects on the total amount of coca cultivation due to the small number of interested participants. In 2003, in an attempt for correcting past mistakes the government launched *Programa Familias Guardabosques* (PFGB) and *Programa Proyectos Productivos* (PPP). PFGB is a CCT program that gives cash in exchange of the elimination of illicit crops and on the reception of technical guidance on alternative agricultural initiatives. PPP gives support to rural producers organizations to generate new sources of income and commercialize alternative licit products.

In the last decade around 50% of the Colombian public expenditures in anti-drug policy have been directed to the involuntary eradication programs i.e.,-aerial spraying and manual eradication (Figure 2). In particular, the aerial spraying program accounted for around 40% of the public expenditures in anti-drug policy during most of the last decade. The manual eradication program was launched in 2006, but was effectively implemented in 2007.

Figure 2: Decomposition of Public Expenditures in Anti-drug Policy

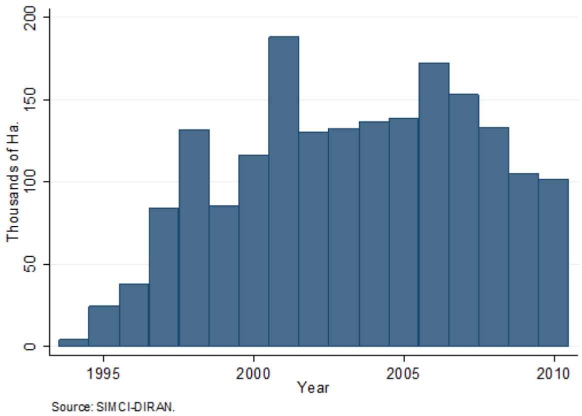


Source: Author's estimations with data from Departamento Nacional de Planeación.

2.1 Aerial Spraying

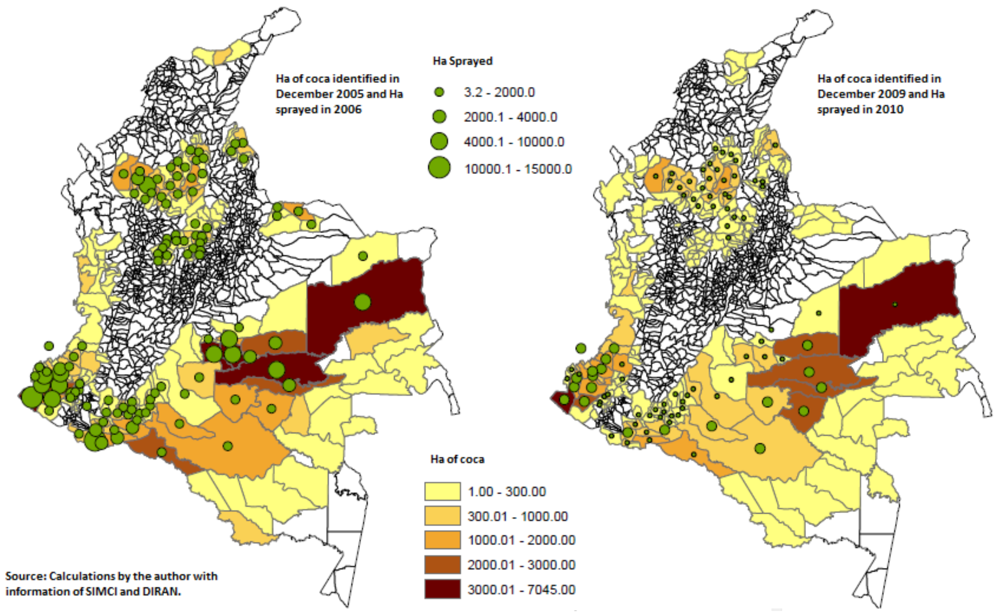
The program began since 1978 but fumigations were intensified in the country in the late 90s with the beginning of *Plan Colombia*–a cooperation agreement between Colombia and the US to fight drug production. Figure 3 presents the number of hectares sprayed between 1994 and 2010. As can be seen in the figure, the size of the program increased from 1994 to 2006, and from there on, it has been losing importance to return the levels it had in the year 2000.

Figure 3: Total Thousands of Ha Sprayed 1994-2010



Aerial spraying is coordinated by the *Dirección de Antinarcóticos* (DIRAN) of the National Colombian Police. DIRAN uses satellite images processes by SIMCI-UNODC each year to locate the areas where coca is being cultivated. Each year the images for the last December are used to target the program (for example to target the program in 2006 the satellite images correspond to December of 2005). Figure 4 presents the program's targeting for 2006 and 2010 (the period of analysis of this paper). The figure presents the geographical position of the hectares of coca identified through the satellite images in December of 2005 and the hectares sprayed in 2006, and the hectares of coca identified in December of 2009 and sprayed in 2010. Once the areas are identified in the satellite images, DIRAN confirms the exact location of the crops through airplane observations, and then aerial spraying is carried out. The fumigations are done with glyphosate, a herbicide that kills the plants by eliminating their capacity to generate aromatic amino acids. This herbicide is absorbed by the leaf instead of the roots of the plants.

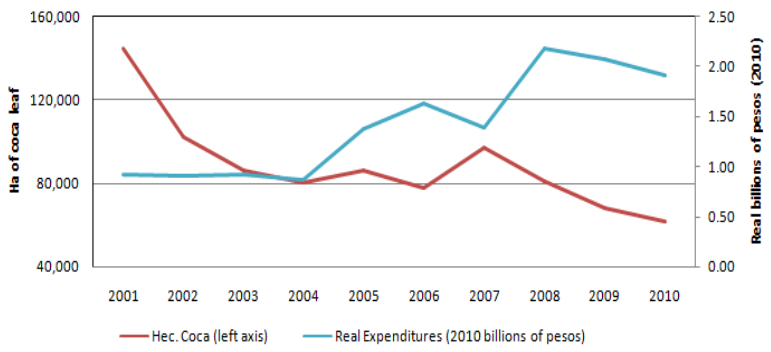
Figure 4: Aerial Spraying Targeting



2.2 General Results of Governmental Intervention

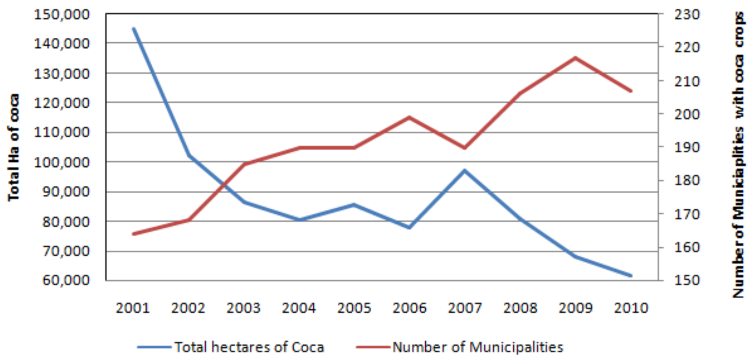
As a consequence of the governmental interventions the total hectares of coca cultivated in Colombia have been decreasing since 2000. According to the satellite data of UNODC between 2000 and 2010 the total hectares of coca went down by 57.3% from 144,807 ha to 61,811 ha, respectively (Figure 5). Yet, the governmental intervention has also spread coca cultivation to more municipalities. From 2000 to 2010 the number of municipalities with coca cultivation increased from 164 to 207 of the 1120 municipalities that conform the Colombian territory (Figure 6).

Figure 5: Ha of Coca and Public Expenditures in Anti-drug Policy



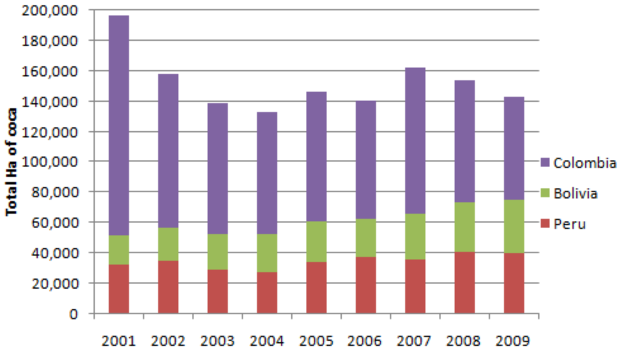
Source: Author's calculations with data from SIMCI, UNODC and Departamento Nacional del Planeación.

Figure 6: Number of Municipalities with Coca Crops



Source: Author's calculations with data from SIMCI, UNODC.

Figure 7: Total Hectares Cultivated in the Andean Region



Source: Author's calculations with data from UNODC

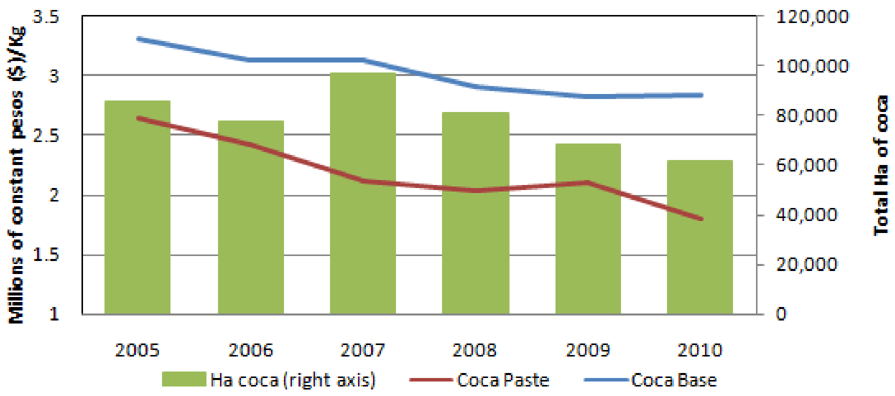
The reduction of hectares of coca cultivated has been coupled with an increase on the total hectares harvested in other Andean countries. Between 2001 and 2009 the total hectares cropped in Peru and Bolivia increased in 24.6% and 75.8%, respectively. However, even after taking into account this compensation the total hectares cropped in the whole Andean region has dropped in 27.3% (See Figure 7). Moreover, the total number of hectares of coca cultivated in the world decreased in 27% between 2000 and 2009.

2.3 The price puzzle

Although the evidence presented so far suggests that the total supply of coca production should be decreasing as a consequence of the reduction on total area cultivated, the prices of cocaine within Colombia have not presented any noticeable changes in the last decade. In particular, if the total area cultivated was traduced in lower supply of coca, prices should be increasing. Yet, national prices of coca paste or coca base–the main inputs exported to consumer countries–have not presented noticeable changes[4]. In addition, cocaine international prices in the US decreased between 2001 and 2005 and only recovered the levels of 2001 until 2009 (See Figure 8 and 9). This behavior casts doubts of the effectiveness of governmental interventions on total coca production and cocaine trafficking. This is specially true since according to the World Drug Report (2011) the observed consumption patterns have remained roughly constant in the world.

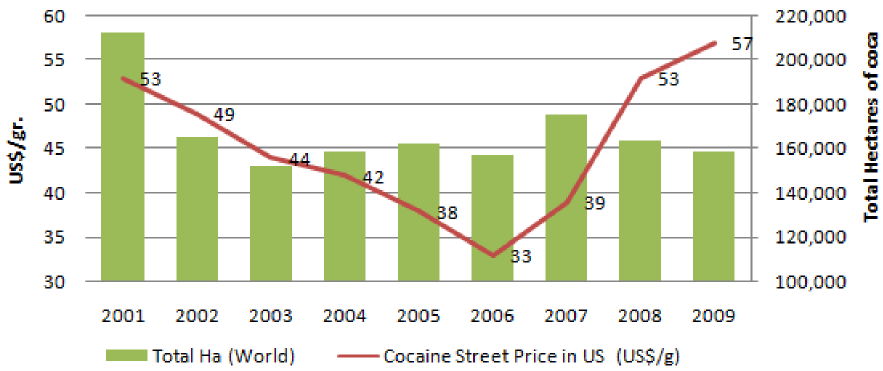
[4]This was also noticed in previous studies by Mejia and Posada (2008), Caulkins and Hao (2008) and UNODC.

Figure 8: Prices in Colombia



Sources: Author's calculation with data from SIMCI -UNODC. Constant prices of 2010.

Figure 9: Prices in the US



Source: World Drug Report (2011) and SIMCI-UNODC. Prices have been adjusted by inflation and purity.

3 The model

3.1 Exogenous productivity

Consider the static maximization problem faced by a representative producer located in region i, in which initially, the governmental interventions do not affect productivity. Assume that producers act as price takers in all markets and each period they choose between three mutually exclusive choices: producing coca (c), producing an alternative licit product, (a) or move to other area to produce coca (m). Assume these three productive alternatives use as inputs labor (l) and land (L), which are mobile across sectors. Let w denote the wage and r denote the price of land.

Also suppose that if the producer chooses to produce coca leaf in region i he will face a cost of aerial spraying of δ_i that varies with the size of the crop L. As in reality, here producers with higher extensions cropped are more likely to be affected by aerial spraying (since they are targeted through satellite images). If the producer chooses to produce the alternative licit product he will not receive the extra cost of aerial spraying but will only need to pay for the cost of inputs for production. Finally, if producers decide to move to other location j with lower costs of spraying δ_j they will have to incur on a fixed cost M. In sum, the producer's profit maximization problem can be written as:

$$Max_{m,c,a}(\pi_j^m, \pi_i^c, \pi_i^a) \qquad (1)$$

where $\pi_j^m, \pi_i^c, \pi_i^a$ denote the producer's profits under each of the three productive alternatives and:

$\pi_i^c = Max_{l_i,L_i} \left[p_c(f_i^c(l_i, L_i, A_i^c)) - wl_i - rL_i - \delta_i L_i\right]$ (2)
$\pi_i^a = Max_{l_a,L_a} \left[p_a(f_i^a(l_i, L_i, A_i^a)) - wl_i - rL_i\right]$
$\pi_j^m = Max_{l_j,L_j} \left[p_c(f_j^c(l_j, L_j, A_j^c)) - wl_j - rL_j - \delta_j L_j - M\right] \quad s.t. \ \delta_i > \delta_j \ for \ i \neq j$

where A_i^c, A_i^a, and A_j^c denote the productivity in coca bush cultivation in region i, the productivity in the alternative licit activity in region i, and productivity in coca bush in region j, respectively. Also p_c and p_a denote the price of coca leaf and the price of the alternative licit product, which are given by the producer.

Consider the producer that chooses to produce coca in region i. His optimal choice of inputs will be given by $l_i^*(A_i^c, w, r, \delta_i, p_c)$ and $L_i^*(A_i^c, w, r, \delta_i, p_c)$.Without doing any parametric assumption it is easy to observe in this model that:

$$\pi_i^{c^*} = \pi_i^{c^*}(A_i^c, w, r, \delta_i, p_c)$$

Hence, the effect of aerial spraying over coca profits in region i can be identified clearly. In particular, applying the envelop theorem changes in δ_i will not generate first order effects on l_i^* or L_i^*, and thus:

$$\frac{\partial \pi_i^{c^*}}{\partial \delta_i} = -L_i \leq 0,$$

In words, when the cost of aerial spraying is increased–for example because of the higher intensity in fumigations in the region- total profits of coca production will be lower in region i. If the effect is sufficiently high it will make the producer switch to the alternative licit product or move to other region j $(for\ i \neq j)$ in which $\delta_i > \delta_j$. Thus, when productivity of coca leaf producers in region i is exogenous to governmental anti-drug policies, these policies will at least leave coca production unchanged in region i but will also likely reduce it.

3.2 Endogenous productivity

What occurs when productivity is endogenous to aerial spraying? In particular, let the productivity of coca production in region i (A_i^c) be affected by the aerial spraying directly as well as indirectly:
$A_i^c = A_i^c(L_i, l_i, \delta_i), \forall i$

This for example this could be the case if aerial spraying not only affects the productivity of the plants (i.e., direct effect), but also affects the optimal choice of inputs (i.e. indirect effect). Under this situation the problem of the producer will still be given by (1) and (2) but the profit functions for coca production (c) in region i and region j will be given by:

$\pi_i^c = Max_{l_i,L_i}\left[p_c(f_i^c(l_i, L_i, A_i^c(L_i, l_{i,}\delta_i))) - wl_i - rL_i - \delta_i L_i\right]$, and
$\pi_j^m = Max_{l_j,L_j}\left[p_c(f_j^c(l_j, L_j, A_j^c(L_i, l_{i,}\delta_i))) - wl_j - rL_j - \delta_j L_j - M\right]\ s.t.\ \delta_i > \delta_j\ \ for\ i \neq j$

Consider again the producer that chooses to produce coca in region i. Without assuming any parametric functional form for the production function it is no longer possible to identify anti-drug policies affect affect drug supply in this region. In fact, by applying the envelop theorem to derive the effect of fumigations on profits I obtain:

$$\pi_i^{c^*} = \pi_i^{c^*}(w, r, \delta_i, p_c) \Rightarrow \frac{\partial \pi_i^{c^*}}{\partial \delta_i} = p_c \frac{\partial f_i^c}{\partial A_i^c}\frac{\partial A_i^c}{\partial \delta_i} - L_i$$

Thus, given it is expected that $p_c \geqq 0$,and $\frac{\partial f_i^c}{\partial A_i^c} > 0$ without knowing the effect of the aerial spraying over productivity ($\frac{\partial A_i^c}{\partial \delta_i}$), it is no longer possible to infer how the profits of the producers in region i will respond to aerial spraying. This is precisely the issue that this paper wants to address. In particular if:

$$\frac{dA_i^c}{d\delta_i} \leq 0 \Rightarrow \frac{\partial \pi_i^{c^*}}{\partial \delta_i} \leq 0$$

and we will have the same conclusions as in the previous subsection. However, if:

$$\frac{dA_i^c}{d\delta_i} \geqq 0$$

the effect of aerial spraying over total profits for the producer will be ambiguous. The rest of the paper deals with identifying empirically whether or not aerial spraying have an effect over productivity, and if such an effect exists what is its direction.

4 Empirical Strategy

The main question this paper seeks to answer is if aerial spraying is affecting the productivity of coca leaf producers, and if so in which direction. This effect is by no means obvious. Although in principle the effect of herbicides should be negative over the plants that are affected, local authorities have realized that coca producers have figured out ways to reduce the effectiveness of the spraying. Among the most common methods are to intensively wash coca plants right after the fumigation, cutting the plant but leaving the roots planted, or spraying the coca plants with molasses to prevent the effect of herbicides (Mejía and Restrepo (2011a)). The first two techniques may be effective given the herbicides used in aerial spraying are absorbed through the leafs and not the roots of the plants. Moreover, it may the case that those producers that face aerial spraying are incentivized to innovate at a higher rate and in that sense aerial spraying increases productivity.

4.1 Data

I will use two unique cross section surveys collected and processed by SIMCI-UNODC. The surveys were gathered with the aim of characterizing the productivity levels of coca bush producers in Colombia, and thus, they are ideal for the question I want to answer. Each of the coca leaf producers interviewed in the survey was selected in the following way: one year before each survey's implementation the last available satellite images were used to identify the location of all the coca crops in the country. Given their location the country was divided into 5 regions according to the geographical characteristics of the territory and each of the regions was subdivided in smaller areas of 1 squared kilometer (henceforth called *grillas*). Among all the *grillas* the areas to be surveyed were selected randomly. The number of observations collected was selected to be representative for each of the regions and at the national level.

The first round of surveys was collected between 2005 and 2006, and the second round was collected in four steps by dividing the country in four regions between 2007 and 2010. The second round the surveys were done in each region in consecutive years. The north region was surveyed in 2007, the south-east part of the country (*Meta-Guaviare*) in 2008, the west region (*Pacífico*) in 2009, and the east region (*Orinoquia*) in 2010.

The questionnaire includes self-reported measurements of productivity and also for around half of the sample specific measurements of productivity were performed directly over the coca crops by the interviewer. To maximize the sample size I will focus on self-reported measures but it is worth noting that there are no statistically significant differences between these measurements for the observations that have both available. The surveys contain information on the socioeconomic characteristics of coca producers and fully characterize the coca production process. Since these crops are illegal in Colombia it was necessary to guarantee each of the interviewed producers that their answers were confidential and in no case may be used with fiscal or legal objectives.

The survey allows identifying if the producers were treated by any of the anti-drug governmental programs. Given that the voluntary eradication programs require the complete elimination of the coca crops and the survey targeted producers that had coca crops, in general, the surveyed producers were not affected by other voluntary eradication programs. However, some of them were affected by the manual eradication program in the second round of surveys (since for the first round manual eradication had not began). These producers were dropped of the sample[5]. Finally, the survey allows me to identify whether or not the producers were affected by aerial spraying between 2006 and the second round of surveys.

Table 1 presents the number of observations in the sample and treated individuals in each round. The total number of observations for the first round is of 1,389 and the total number for the second round of surveys is 1,106. As is shown, since aerial spraying began in Colombia in 1978 and the surveys are collected to be representative at the national level, 84 of the producers in the first round were treated by the program.

Table 1: Sample Description
Number of Observations

	2005-2006	2007-2010
Aspersed	84	303
Not aspersed	1305	803
Total	1389	1106

Source: Surveys were collected and processed by SIMCI-UNODC.

Table 2 presents the descriptive statistics for the most important variables for both rounds of surveys. The table shows that for 2006 most of the coca producers were men of age 40 years, with low education levels, who had been working in coca production for around 6 years. Yet, for the second round of samples more women and younger individuals entered coca production. Also, for the last round of surveys the years of education of the average individual is higher.

Moreover, the mean number of properties of coca producers is of around 1 and the mean number of employees in the coca crop was 11 for 2005-2006 and it decreased to 6.31 for the second round of surveys. This behavior is in line with previous findings by UNODC, which suggest that between 2000 and 2010 the size of the coca crops has been decreasing to avoid detection. Also, in line with the trends presented in the previous sections, the table shows that the average harvested area per producer has been decreasing from 1.25 to 1 hectare.

The data allows estimating the average productivity as total kg of coca leaf produced per hectare and per harvest. As can be seen in Table 2 productivity declined from an average of 1,099 to 921kg/ha between the two rounds of surveys. Also, the number of harvests per year went down from 5.31 to 4.93. The reduction in total quantity produced per harvest and hectare is also traduced in a decrease of total production of coca leaf in the year from around 6,000 to

[5] It is worth mentioning that these only represented 20 observations of the total sample. In fact, all estimations were carried out with and without these observations and results are not sensitive to this change.

4,500 kg/ha each year. The best productive age of the crops is similar for both samples and is of around 2.5 years.

Finally, in 2006 around 30% of the coca leaf producers suffered a loss due to plagues, fungi or climate changes and when this occurred around 40% of the crops were lost. The percentage is smaller for the second round of surveys (33% of producers suffered a loss of around 35% of the crops).

Table 2: Descriptive Statistics

	2006		2007-2010	
Variable	Mean	St Dev	Mean	St Dev
Gender (=1 if men)	0.91	0.29	0.75	0.43
Age	38.34	11.36	29.45	20.11
Years of education	4.88	3.33	5.22	3.91
Experience in years producing coca	6.64	4.30	6.74	3.55
Size of farm	24.18	61.19	13.21	32.02
Number of Properties	1.27	0.58	1.10	0.91
N. of workers (within household)	11.02	9.00	6.31	4.25
Harvested area	1.25	0.86	1.09	0.96
Plants (per ha)	10890.55	5192.13	12176.74	6378.07
Quantity(kg)(per ha and harvest)	1099.86	401.20	921.99	405.84
N. of times harvested (per year)	5.31	1.67	4.93	1.15
Quantity (kg per ha and year)	5929.57	2973.75	4551.13	2171.25
Best productive age	2.64	0.60	2.50	0.59
Quantity at best productive age (kg per ha and year)	2066.41	503.70	1551.15	407.26
Suffered production loss(=1 if yes)	0.38	0.48	0.33	0.47
Percentage Loss**	42.04	18.09	35.22	14.75
Number of obs	1389		1106	

**:Different number of observations. Expansion factors produced by SIMCI-UNODC in the survey design were used.

4.2 The identification strategy

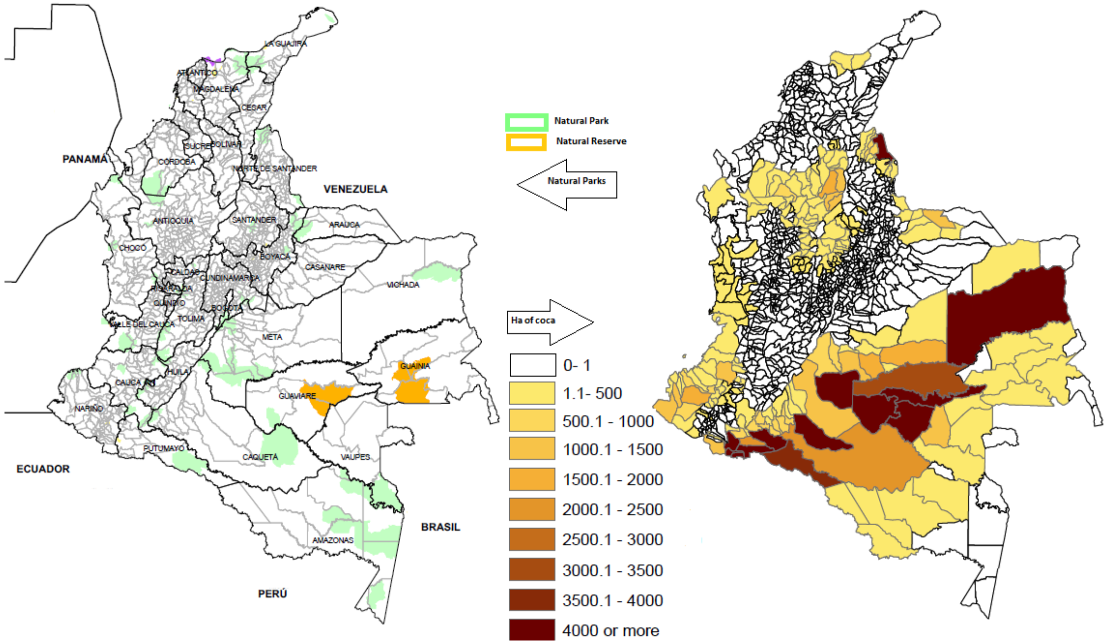
One of the main challenges for identifying the effect of aerial spraying over productivity is the endogeneity problem between productivity and treated producers. Since aerial spraying is targeted through satellite images, those places with higher number of hectares of coca will be treated more likely since they are more visible. If producers are choosing their location freely they will locate where they are more productive (absent the program). It naturally follows that those areas with the higher number of hectares of coca are also the most productive ones. In that sense by targeting the areas with the highest number of hectares of coca the government targets the most productive producers.

A plausible solution to the endogeneity problem is to use an instrument that is correlated with aerial spraying reception but not directly with the productivity levels of farmers. I use legal restrictions on the areas that can be fumigated in Colombia to instrument aerial spraying. In Colombia by explicit government mandate aerial spraying cannot be done over natural parks or natural reserves[6]. In this context, coca leaf producers that are located in natural parks or near them have lower probabilities of being sprayed relative to other producers.

According the Colombian local authorities –Ministry of Environment, Housing and Rural Development and *Instituto Geográfico Agustín Codazzi*– Colombia has 56 protected areas that account for more than 12% of the territory. Figure 10 shows the location of the natural parks and the location of coca cultivation for the year 2006.

[6] See governmental documents CONPES 3669 and 3218 produced by the Departamento Nacional de Planeación.

Figure 10: Location of Natural Parks and Hectares of Coca in 2006



The surveys collected by SIMCI-UNODC allow me to identify the exact geographical position of each of the coca producer that was interviewed. Using their location I calculate the minimum distance of each individual i to the centroid of the nearest protected area as follows:

$$Dist_i = Min_i\{d_{i1}, ...d_{i56}\},$$

where d_{ij} represents the distance of producer i to the centroid of the protected area j. Since there are 56 protected areas in the country the minimum distance for each producer i has to be chosen as the minimum distance of the producer with respect to each of the protected areas. This distance is denoted by $Dist_i$ and is measured in miles. Here d_{ij} is estimated as:

$$d_{ij} = \sqrt{(lat_i - lat_j)^2 + (long_i - long_j)^2}$$

where $(lat_i, long_i)$ represent the geographical coordinates that describe the location of the producer and $(lat_j, long_j)$ represent the geographical coordinates of the location of the centroid of protected area j.

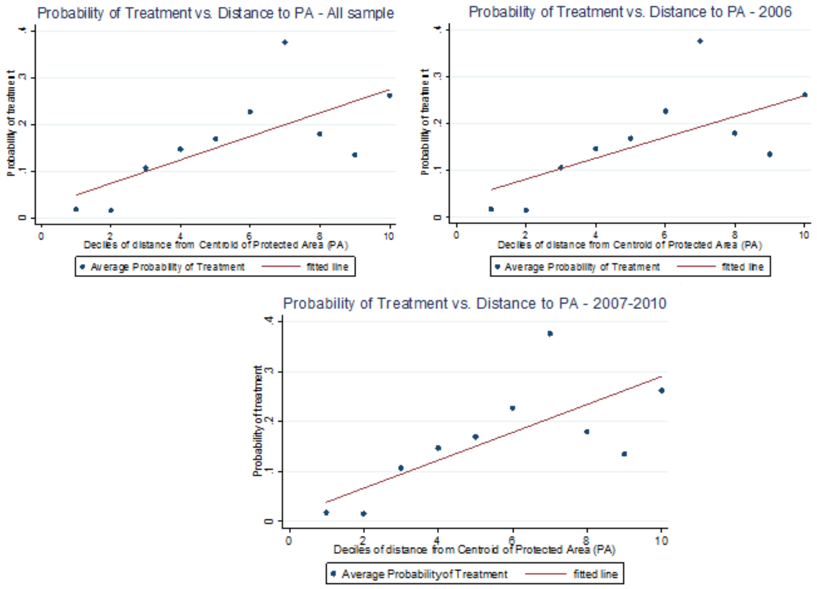
According to Imbens and Angrist (1994), and Abadie (2003) the validity of the 2SLS estimator relies on the satisfaction of the relevance assumption and the exclusion restriction. Moreover, if there are heterogeneous effects, instrumental variable estimates only identify the Local Average Treatment Effect (LATE) if monotonicity is also satisfied.

The relevance assumption requires that the covariance between aerial spraying and the instrument is different from zero. Although this will be assessed with the first stage results of the estimation in the next section, here I show some graphical evidence. I divided the variable $Dist_i$ in 10 deciles. Hence, lower deciles represent the individuals that are closer to the centroid of a protected area (or that are in a protected area) and vice versa. I also calculated for each of the 10 categories of distance the probability of receiving the treatment. It corresponds to the average of the treatment dummy. Figure 11 presents the probability of treatment and the deciles of distance to the nearest protected area. As can be seen for all the sample, as well as for each of the rounds or surveys in 2006 and 2007-2010 those individuals that are nearest to the centroid of a protected areas face lower probabilities of being sprayed.

The exclusion restriction is satisfied whenever the instrument only affects the dependent variable through the endogenous covariate. This occurs when the covariance between the instrument and the error term of the structural equation is zero. In this specific case, the condition will be satisfied if the distance of the producers to the nearest protected area ($Dist_i$) only affects the productivity of coca farmers through its effect over aerial spraying.

As usual, there is no formal proof to support this argument. However, the only other possible way–at least that I can think of so far–through which the

Figure 11: Probability of Treatment and Distance to the nearest Protected Area



instrument in question may affect productivity may be through the specific characteristics of the soil and the weather of protected areas. For example, it may be argued that producers located near natural parks or at them may also have higher probabilities of having more fertile soil or a climate that favors coca production. Yet, this generalization is imprecise since there is a huge variation in the geographical characteristics of the protected areas in Colombia. For instance, according to *Instituto Geografico Agustin Codazzi*–the local geographical authority–the standard deviation of the mean altitude of the 56 parks is 1322 meters, and the standard deviation of the maximum altitude of the parks is 2006.1 meters. In other words, the parks are formed by all types of climates and ecosystems with tremendous differences.

Finally, the monotonicity assumption rules out the existence of defiers. In other words, producers that are located at natural parks or located near them must be less exposed to aerial spraying and vice versa. Since the fumigation of natural parks is forbidden in Colombia, there is no reason to be concerned about a violation to this assumption.

5 Results

Using $Dist_i$ the reduced form estimation I will use to assess the effect of aerial spraying on coca leaf productivity is given by the triangular system of the form:

$$
\begin{array}{ll}
Yit = b_o + b_1 Spr_{it} + b_2 t + \gamma' X_{it} + \epsilon_{it} & (1)\\
Spr_{it} = a_o + a_1 Dist_{it} + +a_2 t + \gamma' X_{it} + u_{it} &
\end{array}
$$

where Y_{it} denotes the outcome of producer i in period t, Spr_{it} is a dummy variable that takes the value of one if the producer was sprayed in t (i.e., during the same year in which the survey was implemented), t is a dummy variable equal to one in the second round of surveys, X_{it} represents the exogenous covariates for producer i in period t ,and $Dist_{it}$ represents the instrument. The covariates included in X_{it} are: gender, age and years of education of the producer. All regressions include a constant term and fixed effects by region, method for harvesting (i.e., mixed with other licit agricultural products, mixed with other varieties of coca or only one type of coca), type of crop (i.e., variety of coca plant), and year[7]. The equations were estimated by clustering standard errors at the municipality level.

The system given by (1) was estimated for seven outcomes including: i) kgs of coca leaf produced by hectare and per year, ii) kgs of coca leaf per hectare and per harvest, iii) number of harvests collected per year, iv) density of crops measured as distance between plants in meters, v) productive age of coca plants in years, vi) number of workers in coca crop, and vii) total harvested area in hectares. The first four variables are proxies of productivity.

Table 3 presents the Davidson and McKinnon test for endogeneity for each of the outcomes. This test is equivalent to the Hausman test for endogeneity. It consists of estimating the first stage regression of 2SLS, predicting the errors and testing for their statistical significance in the structural equation. The null hypothesis for the test states that both OLS and 2SLS estimators are consistent but only OLS is efficient (there are no endogeneity issues), whereas the alternative hypothesis suggests that OLS is inconsistent (and so IV should be used). The estimations reject the null hypothesis of consistency of OLS for all of the outcome variables and hence 2SLS are estimated for all of the outcomes.

[7] All estimations were runned with and without the covariates for methos of harvesting and type of crop due to concerns of endogeneity of these variables. The results for b_1 are not sensitive to the inclusion of these variables suggesting they are not endogenous to aerial spraying.

Table 3: Durbin-Wu-Hausman Test

	Kg (/Ha /Year)	Kg (/Ha/Harvest)	N. Harvest (/Year)	Density
Residuals	-1974.33***	-308.12**	-0.77**	0.24***
SE	887.24	158.2	0.39	0.06
R2	0.41	0.4	0.5	0.2
N	2020	2020	2025	2025
	Productive Age (years)	N. Workers	Harvested Area (Ha)	
Residuals	-0.89**	-15.7***	-0.86**	
SE	0.39	3.04	0.39	
R2	0.11	0.21	0.11	
N	2022	1015	2022	

Note: All regressions include a constant term and fixed effects by region, method of crop, type of crop, and year. Clustered errors by municipality are presented in parenthesis. The covariates included are: gender, age and years of education of the producer. Expansion factors provided by UNODC-SIMCI were used for the estimation.

Table 4 presents the first stage results. The R^2 is 0.29 and the F-test for excluded instruments rules out the possibility of weak instrument. As expected those producers who are located at higher distances from protected areas are more exposed to the program. In particular, the coefficient is significant an equal to 0.0048. If we interpret this coefficient as a linear probability model it indicates that for every additional mile between the centroid of the nearest protected area and the location of the individual the probability of being treated increases by 0.48%.

Table 4: First Stage Results: Dependent variable Aerial Spraying

Dependent var:	Aerial Spraying
Distance	0.0048***
SE	0.0008
F	28.8
R2	0.29
N	2020

Note: All regressions include a constant term and fixed effects by region, method of crop, type of crop, and year. Clustered errors at the municipality level are presented in parenthesis. The covariates included are: gender, age and years of education of the producer. Expansion factors were used for the estimation.

Table 5 present the results of the structural equation by OLS and 2SLS. All of the coefficients of interest are statistically significant but once the treatment variable is instrumented the effect of aerial spraying grows in absolute value. This finding is in line with the idea that OLS was biased downwards in absolute value. In particular, I found a negative effect of aerial spraying on all of the outcome variables.

The results suggest that those producers that were fumigated produced 2868.9 less kgs of coca leaf per hectare and per year, and 433 less kgs of coca leaf per hectare and per harvest relative to the other producers. Moreover, the number of harvests collected each year is reduced in 1, the productive age of coca plants decreases in 1.12 years, the number of workers is reduced by 12 and the harvested area decreases in 1.09 hectares when the producer is exposed to the fumigations. All of these results reject the view that aerial spraying increased productivity of coca producers, at least for the period 2005 and 2010.

Table 5: Structural equation results

Dependent var:	Kg (/Ha /Year)		Kg (/Ha/Harvest)		N. Harvests		Density	
	OLS	2SLS	OLS	2SLS	OLS	2SLS	OLS	2SLS
Sprayed	-990.45***	-2868.92***	-139.9***	-433.06***	-0.23**	-0.97**	0.079***	0.31***
SE	230.27	826.36	39.703	142.68	0.1	0.393	0.017	0.07
R2	0.41	0.36	0.39	0.33	0.5	0.47	0.19	0.17
N	2020	2020	2020	2020	2025	2025	2020	2025
Dependent var:	Productive age		N. Workers		Harvested Area			
	OLS	2SLS	OLS	2SLS	OLS	2SLS		
Sprayed	-0.27***	-1.12***	-1.14**	-12.29***	-0.28***	-1.09***		
SE	0.094	0.37	0.6	3.26	0.096	0.37		
R2	0.42	0.4	0.19	0.16	0.19	0.17		
N	2022	2022	1015	1015	2020	2020		

Note: All regressions include a constant term and fixed effects by region, method of crop, type of crop, and year. Clustered errors by municipality are presented in parenthesis. The covariates included are: gender, age and years of education of the producer. Expansion factors were used for the estimation.

To check whether the results of Table 5 are driven by measurement error I ran a placebo test. The specification is the same of equation (1) but the dependent variables in the structural equation are now age and gender[8]. There should not be any effect of aerial spraying over these variables. Table 6 presents the results of the estimations. The results are not significant for the OLS or 2SLS estimation for any of the outcome variable that were analyzed, as expected.

Table 6: Placebo Test - Structural Equation

Dependent var:	Gender		Age	
	OLS	2SLS	OLS	2SLS
Sprayed	-0.028	-0.014	-0.13	-1.44
SE	(0.03)	(0.11)	(0.37)	1.66
R2	0.018	0.018	0.2	0.18
N	2025	2025	2025	2025

Note: All regressions include a constant term and fixed effects by region, method of crop, type of crop, and year. Clustered errors by municipality are presented in parenthesis. The covariates included are: gender, age and years of education of the producer. Expansion factors were used for the estimation.

5.1 Long-term Effects?

So far this paper has found a negative effect of the program over productivity. However, the dummy used in the previous estimations to measure the treatment reception only allows me to identify the effect of aerial spraying in the short run (i.e., one year). This occurs since the observed treatment variable measures whether or not a coca leaf producer was sprayed in the same year that the survey was collected. Hence, it may well be the case that aerial spraying has

[8] Gender is a dummy variable equal too 1 for men.

a different effect in longer periods of time. For example, coca producers may be innovating in their production techniques as a result of being treated by the program but this may only be visible over productivity in longer periods of time.

Although the question of whether individuals were aspersed in the past is not available for all of the sample, it is available for a small subsample of producers. In particular, UNODC gathered this information for the observations collected between 2007 and 2008 which add up to a total of 687 producers. I use this subsample to asses the effects of aerial spraying over productivity in the long run (i.e., 1 or 2 years).

Let $I(Sprayed\_t-1)$ and $I(Sprayed\_t-2)$ represent the indicator functions that take the value of 1 when the producer was aspersed 1 or 2 years before the survey was implemented, respectivelly. I ran the reduced form given by (1) replacing the treatment variable by $I(Sprayed\_t-1)$ or $I(Sprayed\_t-2)$. This time standard errors were not clustered since the number of municipalities was smaller than 50. Thus, the regressions were runned with robust standard errors. The Hausman endogeneity test rejects the null hypothesis of consistency of OLS for all of the outcome variables and hence 2SLS are used for the estimation. Panel A of Table 7 presents the first stage regression confirming the streght of the instrument. Moreover, Panel B of the same table presents the results of the structural equation for the most relevant measurement of productivity: kgs produced per hectare and year. As can be seen in the table the coefficient for aerial spraying is not statistically different from zero for any of the estimations. These results suggest that the aspersions have no effect over productivity in the long term. This results are also true for any of the other six proxies of productivity used in the previous subsection.

Table 7. Long-term Effects
Panel A. First Stage Results: Dependent variable Sprayed

Dependent Varible	Aerial Spaying (t-1)	Aerial Spaying (t-2)
Distance (miles to centroid)	0.00231**	0.0013***
SE	0.0012	0.0003
F (excluded instrument)	13.57	11.2
R2	0.16	0.12
N	687	687

Panel B. Structural Equation Results

Dependent variable:	Kg (/Ha /Year)	
	OLS	2SLS
Sprayed t-1	-320.42	-979.12
SE	(223.04)	(680.4)
R2	0.21	0.19
N	687	687
Dependent variable:	Kg (/Ha /Year)	
	OLS	2SLS
Sprayed t-2	149.51	1438.41
SE	(263.69)	(1120.87)
R2	0.21	0.19
N	687	687

Note: All regressions include a constant term and fixed effects by region, method of crop, type of crop, and year. Robust standard errors are presented in parenthesis. The covariates included are: gender and age. Expansion factors were used for the estimation.

6 Conclusions

This paper aimed at identifying the effect of aerial spraying over productivity of coca leaf producers in Colombia. Although in principle the effect of herbicides should be negative over the plants that are affected, local authorities have realized that coca producers have figured out ways to reduce the effectiveness of the spraying. Moreover, it may the case that those producers that face aerial spraying are incentivized to innovate at a higher rate and in that sense aerial spraying increases productivity. This hypothesis is well known in the literature, but never has been tested. In fact, it aims at explaining the *price puzzle* of cocaine markets: the fact that although the total hectares of coca cropped has decreased in the world, the prices of coca paste, coca base or cocaine have not changed as a consequence. In addition, the availability of cocaine in consumer countries has remained roughly stable. In other words, even if the total area cropped is lower if productivity per hectare has increased as a response to anti-drug policy programs total supply of cocaine may not be affected. This paper tested the validity of this hypothesis for coca leaf production in Colombia.

One of the main challenges for identifying the effect of aerial spraying over productivity is the endogeneity problem between productivity and treated producers. I use legal restrictions on the areas that can be fumigated in Colombia to instrument aerial spraying. In particular, by explicit governmental mandate, protected areas cannot be fumigated in Colombia. Thus, coca leaf producers that are located in natural parks or near them have lower probabilities of being sprayed relative to other producers.

The effect of the program was analyzed for seven outcomes including: i) kgs of coca leaf produced by hectare and per year, ii) kgs of coca leaf per hectare and per harvest, iii) number of harvests collected per year, iv) density of crops measured as distance between plants in meters, v) productive age of coca plants in years, vi) number of workers in coca crop, and vii) total harvested area in hectares. The results for all of the estimations suggest there is a strong and negative effect of aerial spraying in coca leaf productivity. These results contradict the hypothesis that aerial aspersions are increasing productivity of coca producers, an thus, the price puzzle of cocaine markets cannot be explained by changes in productivity of coca leaf production. Yet, it may be the case that innovations to production processes further up in the production chain explain why cocaine supply remains roughly stable despite the reductions in total hectares of coca in the world. This alternative hypothesis should be studied in the future.

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