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Reyes, Luis Carlos

Michigan State University

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Estimating the Causal Effect of Forced Eradication on Coca Cultivation in Colombian Municipalities

Luis Carlos Reyes[1]

Michigan State University
Department of Economics
East Lansing, MI 49544
reyesher@msu.edu

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Abstract

Coca eradication has been aggressively pursued by the Colombian government to reduce the amount of land that agricultural households in the Andean country devote to this illegal crop. However, little work has been done to assess the causal effect of the policy on land allocation decisions. I use a six year panel of observations covering the entire country for the years 2001-2006 to estimate this effect at the municipality level, exploiting exogenous sources of variation in eradication and taking an IV approach to estimation. The instruments are derived from changes in the expected cost of coca eradication as crews get far from the zone where Antinarcotics Police helicopters can protect them from the illegal armed groups that try to shoot them down. IV estimation shows that the causal effect of a one percent increase in eradication is slightly less than a one percent *increase* in coca cultivation.

[1] Present address: Grand Valley State University, Department of Economics, Grand Rapids, MI 49504. E-mail: reyesher@msu.edu. Phone: 616-331-7231. Fax: 616-331-7445

I. INTRODUCTION

Colombia is the main supplier of cocaine to the United States. Because of the social costs resulting from production and consumption of the drug, both countries have made it a priority to put an end to illegal drug manufacturing and trafficking. In order to disrupt the flow of drugs, the governments of the two nations have targeted every step of this process, allocating billions of dollars to antinarcotics military units, border controls, interdiction of drug shipments, and the destruction of the laboratories and precursor chemicals used in the production of cocaine.

However, little empirical work has been done to assess the efficacy of drug control policies. This is particularly true in the case of coca eradication, which targets the farmers that produce coca leaf, the primary input of cocaine. Only Moreno et al. (2003) and Dion and Russler (2008) have attempted to estimate the effectiveness of coca eradication in Colombia at the national and departmental level, respectively.

It is widely acknowledged in the economic literature on crime that the empirical estimation of the effects of law enforcement and other government programs on illegal behavior is a task complicated by severe endogeneity of the policy variable (Johnson, R. S., S. Kantor and P. V. Fishback 2007, Levitt, S. D. 1997, 2002). Yet the available studies of the effect of eradication on coca cultivation do not address this issue. This is surprising, because endogeneity in this setting is a serious concern. The Colombian government has clear incentives to concentrate its antinarcotics efforts on specific regions of the country with an intensity that depends on the existing level of coca cultivation. It may, for example, choose to eradicate relatively more coca in areas where the production of the illegal crop is endemic and pervasive, or it may decide to devote more eradication resources to regions where coca cultivation is a recent arrival and locals can be most easily dissuaded from permanently adopting the new crop.

In this paper I use an Instrumental Variable (IV) approach to account for drug policy endogeneity. I choose instruments that enter the expected cost function of the government as it implements coca eradication programs, yet affect farmers' land allocation decisions through no channel other than their effect on drug policy. The instruments are derived from variations in the expected cost of coca eradication as crews get far from the zone where Antinarcotics Police helicopters can protect them from illegal armed groups on the ground that try to shoot them down. I find that there is a strong negative relationship between distance from this zone and the level of eradication that takes place. The location of coca eradication bases, in turn, is not determined by coca production levels in the vicinity, but by the presence of pre-existing commercial and military airports, which makes instruments derived from the distance to the safety zone surrounding the bases ideal to estimate the causal effect of eradication on coca production.

By evaluating the effectiveness of eradication in reducing the cultivation of coca, I contribute to answering the wider question of whether the current approaches to drug policy are succeeding. Eradication is a particularly good place to start because the outcome of the program - coca cultivation per municipality - can be observed directly. Six years of municipality level data on coca cultivation for the entire country are available from Project SIMCI II, a satellite survey of coca crops conducted by the United Nations Office on Drug and Crime (UNODC). I construct a panel that combines SIMCI II data with municipality level measures of eradication and the presence of illegal armed groups, as collected by entities such as the Antinarcotics Police and the Presidency of the Republic.

This paper is divided in seven sections. In Section II, I provide a comprehensive review of the relevant literature on crop choice, coca farming, and crime. In the third section I describe the data. Section IV describes the instrument and its correlation with Colombian antinarcotics policy. The estimates of the causal effect of eradication on coca cultivation are presented in section V. Section VI offers a discussion of the results and policy recommendations, and Section VII concludes.

II. LITERATURE REVIEW

Coca eradication seeks to reduce illegal crop cultivation by modifying the economic incentives faced by farmers, and there is evidence that coca farming households are sensitive to such changes. In particular, studies of coca farmers demonstrate that they respond to fluctuations in the profitability of their crops. Angrist and Kugler (2008), for example, analyze the impact of an exogenous rise in the price of coca resulting from the sudden interruption of coca imports from Bolivia and Peru, a consequence of heightened enforcement at the border in 1994. Using data from an annual survey of rural households, they find that after 1994 there was higher self employment income in regions where coca was traditionally grown. They attribute the rise in self employment to an increase in illegal crop farming. Furthermore, they were able to link higher coca prices to an increase in child labor. Additionally, they found a rise in violent deaths per capita in coca growing areas, suggesting that illegal crop farming results in conflict over coca profits. Using the same shift in coca production from Peru and Bolivia to Colombia, but focusing on its consequences for Peruvian farmers, Dammert (2008) shows that reduced coca earnings led to an increase in child labor. Her findings further demonstrate that coca farmers respond to economic incentives and that altering them is a viable approach to drug policy.

Whether eradication changes incentives in a way that will lead to a reduction in coca farming is a complex question. At issue is the mechanism through which policy intervention can reduce or eliminate production of illegal crops. One way eradication can make farmers switch from coca to other crops is by increasing the variability of coca yields. Morduch (Morduch, J. 1995) gives a review of the evidence that agricultural households in the developing world forego profitable economic activities when they have highly variable returns. This stems from the households' inability to buy insurance against annual fluctuations in harvest yields and the associated difficulty in smoothing consumption across years. Rosenzweig and Binswanger (1993) conclude that Indian farmers in environments with more weather variability choose less profitable but less risky crop portfolios. Kurosaki and Fafchamps' (2002) study of crop choices in Pakistan finds that agricultural production choices are similarly affected by price and yield risk. Yield variations in this literature are due to weather shocks, but the threat of government sponsored eradication in Colombia acts in the same way, making the returns from coca farming more uncertain. It is reasonable to assume that, just like their counterparts in other developing countries, coca farmers in Colombia cannot fully insure against harvest losses or smooth consumption across years. Consequently, they may diversify their crop portfolio and replace some coca with other crops.

In his study of opium production in Afghanistan, Clemens (2008) sketches a theoretical model of illegal crop farming that explores the mechanisms through which eradication and alternative development can lead to a reduction in illegal crop cultivation. In the model, farmers face the possibility of eradication and/or receive some kind of alternative development support. The farming household maximizes expected utility from consumption, which depends positively on the returns of a crop portfolio, and negatively on moral aversion to illegal crop cultivation.

Each crop has returns that vary across states of nature. By increasing the returns to legal crops through price support, cost reduction, or higher yields, or by using eradication to raise the probability that returns from illegal crop cultivation will be zero, and by finding ways to increase moral aversion to coca farming, policymakers could provide farmers with incentives resulting in the reallocation of resources from illegal crops to legal ones.

A serious problem with such policy interventions to force a change in the farmers' crop portfolio is that their effectiveness can be cancelled out by market forces. Eradication may increase income variability and raise the probability that the realized profits from coca cultivation turn out to be zero. But coca offers approximately double the expected profit of the next best legal crop (Ibanez, M., and Fredrik Carlsson 2010, Peterson, S. 2002, Thoumi, F. E. 2002), and it is quite possible that an inelastic demand causes prices to increase even further with eradication, as Vargas-Manrique (2004) has noted. Moreover, an inelastic demand could result in farmers responding to eradication programs that reduce expected yield by increasing the amount of land devoted to coca if coca leaf production is to remain at approximately the same level.

Because land allocated to coca can conceivably increase or decrease as a result of eradication, the question of whether drug control policies lead to a reduction in coca cultivation is ultimately empirical. Yet few empirical analyses of the effect of eradication and alternative development spending on coca cultivation exist.

An early study of the effect of eradication is Moreno-Sanchez et al. (2003). It uses national level data. Regressing hectares of coca cultivated in Colombia on hectares of coca eradicated, they find that eradication does not effectively control the supply of coca. Rather, it is associated with greater levels of cultivation. They attribute this outcome to farmers compensating for the destruction of their crops by cultivating greater extensions of land. Their specification accounts for the effects of coca cultivation in Bolivia and Peru and the prices of coca and plantain. Coca cultivation in Colombia is found to be unitary elastic to production in Bolivia and Peru, inelastic to its own price, and elastic to plantain price. Moreno-Sanchez et al. conclude that unilateral enforcement by one country does not work, because the unitary elasticity of coca production in Colombia to production in Bolivia and Peru suggests that production will simply move from country to country as levels of enforcement vary. Because they find that the elasticity of coca cultivation to the price of other crops seems to be higher than that to the price of coca, they take it as evidence that alternative development efforts may be more successful than eradication.

More recently, Dion and Russler (2008) have used panel data on Colombian departments (administratively equivalent to US states) to examine the effect of fumigation and other variables on coca cultivation. The dependent variable in their study is hectares cultivated per capita. The main independent variable is the percentage of department land area fumigated by the government. They find that aerial eradication, the size of the incoming population of displaced persons, department Gross Domestic Product, and corruption indicators do not have an effect on the level of coca cultivation. Government spending per capita, the number of outgoing persons displaced by violence and market access are associated with lower levels of coca cultivation. Poverty and legal agricultural output are correlated with increased coca production.

A weakness of the existing empirical studies is that they do not account for the endogeneity of enforcement. Ibanez and Carlsson (2010) try to circumvent this problem by conducting a survey-based choice experiment. Through a questionnaire, they pose several hypothetical scenarios to farmers from four Colombian municipalities of the department of Putumayo in 2005. By asking how many hectares of coca the farmers would grow conditional on different levels of subjective risk of eradication (ranked 1-5), and of profitability of coca cultivation (relative to the next best alternative), they find that farmers would grow less coca if the risk of eradication increased or if its relative profitability decreased. Furthermore, coca cultivation would be inelastic to both risk and relative profitability. Unfortunately, because they measure the farmers' subjective risk perceptions and not the incidence of eradication, their estimates do not allow for a precise calculation of the ceteris paribus effect of coca eradication. Moreover, because eradication is likely to simultaneously affect risk perceptions and relative coca prices, their estimates cannot be used to estimate the causal effect of eradication on coca cultivation.

Yet there is a substantial literature on the economics of crime that addresses this problem, whose approach I follow in order to obtain estimates of the causal effect of drug policy on coca cultivation.

The principal challenge is finding exogenous sources of variation in enforcement. A seminal paper is Levitt (1997), which uses a panel of US metropolitan areas to measure the effect of the size of police departments on crime rates. Levitt documents a previously unknown relationship between mayoral and gubernatorial elections and changes in the size of police departments that serves as a source of exogenous variation in enforcement. Then he uses election cycles as an instrument for police department sizes and finds a negative relation between the number of police officers and crime. In a follow-up to McCrary's (2002) challenge of his original results, Levitt replicates them using the size of firefighter forces as an instrument for the size of police departments (2002).

In the same vein, Klick and Tabarrok (2005) use terror alert levels as a source of exogenous variation in police levels in Washington D.C. They claim that more police are deployed when terror alert levels – which are considered exogenous to local crime - are high, therefore having a deterrent effect on crime. Regressing the daily number of crimes on terror alert levels, they find that a high level of terror alert has a negative effect on crime, which they attribute to the additional numbers of police officers on the streets. A final example is Johnson et al. (2007), which evaluates the effect of welfare spending per capita on crime rates during the Great Depression using panel data on major US cities. Because welfare spending was allocated in part with the goal of reducing the criminality that could spring from widespread unemployment, the government targeted federal aid to cities that were considered more likely to harbor crime. To make their estimates consistent in spite of the endogeneity of the application of the policy, the authors instrument spending with variables based on state size and federal land ownership.

I apply the insights of the crime literature to the problem of estimating the effect of drug policy on coca cultivation, finding exogenous sources of variation in coca eradication and taking an IV approach to estimation.

III. DATA

To measure coca production, I use a six year panel of the 257 Colombian municipalities that grew coca at some point between 2001 and 2006. The United Nations Office on Drug and Crime in Bogota conducts satellite surveys of coca crops in every municipality of the country since 2001[2]. The surveys use satellite photography and are designed to measure the number of hectares of coca in a given municipality on December 31st of each year.

57 percent of cultivation took place in the Colombian Amazon rainforest, 17 percent in the Pacific coast, 15 percent in the Andes Mountains, 8 percent in the eastern plains bordering Venezuela, and the remaining 3 percent in the Caribbean region[3]. Table 1 breaks down the eradication and cultivation data by year, showing that cultivation across the country fell by 46 percent, from 144,808 hectares in 2001 to 77,870 in 2006. The reduction came mainly from lower cultivation in the Amazonian and Andean regions (regional level data not shown).

The Colombian Antinarcotics Police maintain a national database of eradication and provided their data for this study. The number of hectares of coca eradicated is automatically recorded by GPS units on board of the fumigation planes. Eradication increased dramatically between 2001 and 2006: it more than doubled, going from roughly 94,000 hectares to 210,000. The number of hectares eradicated at the national level exceeded the number of hectares at the end of every year because the coca bush can regenerate in 6 to 8 months, and as a result the same coca field may be eradicated more than once per year.

The police locate coca crops using data from SIMCI II as well as less thorough aerial surveys conducted every six months, and the method of eradication has changed slightly over time. The government has used fumigation with glyphosate throughout the period covered by the data, and this continues to be the most widely used technique. Glyphosate kills coca leafs and

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[2] Cultivation data per municipality are publicly available at http://www.biesimci.org/Ilicitos/cultivosilicitos/cocampios.html

[3] Colombia is divided into five natural regions: Amazonian, Andean, Caribbean, Eastern Plains, and Pacific. These regions vary in socioeconomic conditions, climate, soil, flora, and fauna, and they provide different conditions for the cultivation of coca. When analyzing regional differences in coca cultivation, UNODC further subdivides the Amazonian region into Meta-Guaviare and Putumayo-Caquetá, and the Andean region into Catatumbo and Sur de Bolívar.

keeps the bush from producing another harvest for around six months. From 2005 onwards, manual destruction of coca bushes partially replaced fumigation in areas near the border with Ecuador and in national parks, primarily due to political pressure resulting from environmental concerns. As I describe below, the pattern of application of both methods is essentially the same. While I conduct the analysis using aerial fumigation as the measure of eradication, the results are robust to the inclusion of both manual and aerial eradication.

I obtained data on other covariates that are likely to affect coca cultivation levels from a variety of sources. Municipality level population data for the period under consideration are available from the National Administrative Department of Statistics (DANE). To control for the varying availability of land across municipalities, I used data on municipality areas and (legal) cultivated land per municipality collected by the Agustín Codazzi Geographical Institute in Bogota. Finally, UNODC provided data on the presence of illegal armed groups per municipality for the year 2005.

IV. DISTANCE TO A FUMIGATION BASE AND ANTINARCOTICS POLICY

According to the Colombian Antinarcotics Police, there is a strong link between distance from a fumigation base and the amount of coca eradication that goes on in a municipality. Fumigation of coca crops with glyphosate, the primary method of eradication, is conducted by police personnel flying various types of unarmed aircraft. They include OV-10 Bronco military planes, modified to carry modern fumigation equipment instead of weapons. There are also Air Tractor AT-802 and Turbo Thrush spraying planes, which are small aircraft widely used in agriculture that have no artillery (Luna, A. O. 2007). While the planes can fly to every region of the country, security as they perform their task is often at stake.

Armed attacks from the ground against fumigation planes are common. *El Tiempo*, the leading Colombian newspaper, reports that over the last decade ten pilots were killed and fumigation aircraft were hit from the ground 1,116 times[4]. Police protect from the attacks by escorting the planes with armed helicopters such as the Huey II and the UH-60 Black Hawk. According to Antinarcotics officers, the range of the helicopters is 80 miles from the base, a point after which they must return to the base they departed from. The map in Figure 1 shows which coca municipalities are within reach of a base[5]. Beyond the 80 mile range, fumigation planes must go unprotected, greatly increasing the expected cost of eradication missions. Being vulnerable to attack by disgruntled coca producers (or by the armed groups acting on their behalf), the planes are liable to being shot down, resulting in losses of lives and equipment.

The observed patterns of coca cultivation and eradication efforts across Colombian municipalities suggest that the lack of protection of fumigation planes results in major shifts in drug policy. A comparison of the mean number of hectares of coca grown per municipality for the years 2001 through 2006 shows that cultivation is roughly equal across locations within 80 miles of a base and outside of this range. The mean for the first group is 397.5 hectares, and 320.1 for the second group. The difference is statistically insignificant. Instead, fumigation within 80 miles of a base is significantly higher than beyond this distance. Mean fumigation per municipality within the safety zone is 669.2 hectares, but only 175.8 hectares outside of it. The trend of more intensive eradication in areas closer to the fumigation bases remains unaltered when manual eradication is included into the eradication calculations (see Table 2). Figure 2

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[4] "Policía Antinarcóticos lanza campaña para evitar muerte de pilotos de aviones fumigadores," March 22 2007 http://www.eltiempo.com/archivo/documento/CMS-3487812

[5] Distances are calculated from the fumigation bases to the centroids of the municipalities.

shows the relationship between distance from a fumigation base, coca cultivation, and eradication per municipality. The number of hectares of coca fumigated is greater than the number of hectares allocated to coca cultivation for the first 80 miles. At that point the relationship is turned around, with cultivation generally surpassing fumigation thereafter.

Naturally, the relationship I have presented does not take into consideration other factors that may affect coca eradication levels, such as the presence of illegal armed groups. For example, the police may want to pursue different levels of eradication in municipalities with left wing militias that seek to overthrow the government, such as the Revolutionary Armed Forces of Colombia (FARC) and the National Liberation Army (ELN), or where the right wing United Self-Defense Forces of Colombia (AUC) are present. A more thorough model of the effect of distance from a fumigation base on drug policy is given in Equation 1.1, which is the first stage equation for IV estimation of the effects of drug policy on coca cultivation:

$$(1)\ F_{it} = \alpha + \mathbf{D}_i'\beta + \mathbf{X}_{it}'\gamma + a_r + e_t + u_{it}$$

F_{it} is the policy in question, which can be either eradication or alternative development spending in municipality i in period t. $\mathbf{D}_i$ is a vector of variables that reflect cost variations in drug policy, $\mathbf{X}_{it}$ is a vector of control variables, and a_r and e_t are regional and year fixed effects. Finally, u_{it} is an error term with zero mean.

Table 3 shows OLS estimates of three different specifications of Equation 1. The dependent variable is hectares of coca eradicated per municipality per year. All regressions control for the number of illegal armed combatants belonging to FARC, ELN, and AUC, as well as for municipality area, population density, and hectares of legal crops cultivated in 2005, the year for which data were available. Indicators for year and regional fixed effects are also included.

Specification (1) includes one variable that proxies for the expected cost of drug policy, the distance of a municipality targeted for fumigation from the safety zone. The longer an eradication plane stays away from the safety zone, the more likely it is to get shot. Because unprotected exposure to potential attacks will last longer as distance to a destination increases, I take the probability of an attack on a fumigation plane to be increasing on distance. Therefore, the coefficient on this variable should take a negative value, reflecting lower levels of drug policy implementation as expected costs increase. The estimated coefficient on this cost proxy variable is negative and statistically significant. Specification (2) adds an indicator for whether a municipality is within the safety zone surrounding a fumigation base. As a result of the lower expected cost of fumigation in this area, the coefficient on the indicator should take a positive value. This would indicate that drug policies are implemented more intensively where they are comparatively cheaper. As predicted, the coefficient on this variable is statistically significant and positive.

Specification (3) adds interactions between distance from the safety zone and the number of combatants in illegal left wing (FARC and ELN) and right wing (AUC) armed organizations. These interactions exploit variation in the expected cost of drug policy implementation across municipalities that are equidistant from a base. Because the likelihood of an attack (and therefore the expected cost of drug policy) is increasing on the number of illegal group members at the destination, the sign of the coefficients on the interactions should be negative. The coefficients are indeed negative, and the one on the distance and left wing combatant interaction is statistically significant.

Finally, specification (4) includes three more regressors, intended to capture possible variations in expected drug policy costs within the safety zone. One is the interaction of the safety zone indicator with distance from the fumigation base, and the other two are interactions of this variable with the number of left and right wing combatants. For reasons analogous to those given above, the coefficients on these interactions should be negative if there are variations in the expected cost of fumigation within the safety zone. The estimates of two of these additional interaction terms are indeed negative, although none are statistically significant. This suggests that the expected cost of fumigation is uniformly low throughout the 80 mile radius of the fumigation bases.

To verify that these correlations do not arise randomly or because of unaccounted factors related to a municipality's distance from a major urban area, I estimate Equation 1.1 again, replacing the location of the eleven fumigation bases with the location of the eleven largest Colombian cities without an established fumigation base. Predicted fumigation is shown in Table 4. Across specifications, the coefficients on distance beyond 80 miles from a city and the indicator for location within the vicinity of a major city are statistically insignificant and generally of the "wrong" sign. In specifications (3) and (4), the interactions between distance beyond 80 miles of a major city and the number of illegal group combatants in the fumigated municipality are significant but positive, again the "wrong" sign. Finally, two of the three additional instrument interactions in (4) also have a sign that is significant but the opposite of what is expected when distances are calculated from a fumigation base and not from a city. The weakness of these alternative specifications is reassuring, demonstrating that the measures of variation in the implementation of eradication I use are indeed picking up the effect of expected cost variations.

V. THE EFFECT OF ERADICATION AND ALTERNATIVE DEVELOPMENT ON COCA CULTIVATION

The previous section documents the negative relationship between Colombian drug policy and the ability of the Antinarcotics Police to protect its coca eradication crews. I now take advantage of the exogenous variation in drug policy costs demonstrated by this correlation to estimate the causal effect of eradication on coca production in Colombian municipalities.

If distance from the zone where eradication aircraft can fly safely is to be used as an instrument for drug policy, distance from this zone cannot itself be related to a municipality's propensity to produce coca. The exclusion restriction is not satisfied if the second stage regression does not account for variables that are correlated with distance to the safety zone and with coca production levels. The most obvious violation of this condition would occur if the bases had been intentionally located in areas with high levels of production of coca. However, the bases were not built with this criterion. Rather, they made use of preexisting structures such as airports in large cities that made them suitable to host a fleet of airplanes and helicopters.

The location of the bases being exogenous, the issue becomes whether there are systematic differences between the more urban areas where the bases are located and the rural regions out of their reach. To account for this, I control for a number of variables. More rural municipalities are larger and have greater availability of land, as well as lower population densities, so I control for municipality area and population density. Coca tends to be produced in agricultural frontier lands where legal agricultural output is lower than in the traditional farming areas located in the proximity of major population centers, so I account for this by including a measure of legal agricultural output per municipality in the regression. I also include the number of FARC, ELN, and AUC combatants present in each municipality, because they concentrate in rural areas and benefit from the drug trade.

I use regional fixed effects to control for the impact of variations in climate, local institutions, and history, on coca cultivation decisions. For example, regional variations in growing conditions result in significant differences in annual yields per hectare that could affect land allocation choices. Moreover, the existence of trading routes, markets, and experience in coca cultivation and processing may also be better developed in parts of the country like the Amazonian region, where illegal crop farming has taken place for decades, than in others such as the Pacific region, where coca production is of more recent date (UNODC 2006). Finally, year fixed effects account for shocks affecting all municipalities in a given year, such as changes in the world demand for cocaine, shocks to US funding for the war on drugs, and changes in the central government resulting from the transition between the Pastrana and the Uribe administrations. With these controls, distance from the safety zone of fumigation planes should be an appropriate instrument for Colombian anti-coca policies.

I estimate the effect of coca eradication and alternative development programs using an Instrumental Variables (IV) regression. The empirical specification is the following:

$$(2) \qquad H_{it} = \delta + \varphi F_{it} + \mathbf{X}_{it}'\theta + b_r + f_t + v_{it}$$

where H_{it} is the number of coca hectares per municipality at year end, F_{it} is fumigation per year per municipality, and $\mathbf{X}_{it}$ is a vector of exogenous covariates. b_r and f_t represent regional and year effects, and v_{it} is a zero mean error term. While OLS estimates may be biased because of a correlation between the policy variables and the error term, if distance from the safety zone is uncorrelated with v_{it} the IV estimation should result in accurate estimates of the causal effect of eradication and alternative development on coca cultivation.

In all regressions, I use standard errors that are robust to heteroskedasticity and clustered by municipality. Clustering is essential because some regressors, as well as the instrument, are fixed at the municipality level. Moulton (1986) shows that when a regressor does not vary within groups of observations, the conventional standard errors underestimate the variance of the coefficients, and Shore-Sheppard (1996) demonstrates that an analogous downward bias exists when an instrument takes the same value for clusters of observations. Fortunately, as long as the number of clusters is large, this concern can be put aside by clustering at the level of aggregation of the regressors. With 257 municipalities in the sample, there are enough clusters to ensure the asymptotic validity of the estimates of the standard errors.

IV and OLS estimates of Equation 1.2 are presented in Table 5. The policy variable is hectares of coca fumigated per municipality. All specifications control for regional and year fixed effects, municipality area, population density, legal crop cultivation, and number of combatants belonging to illegal armed groups.

The OLS estimate in column (1) shows a positive effect of coca eradication on coca production that is significant at the one percent level. It suggests that a one percent increase in coca eradication will lead to an increase in cultivation of around 0.33 percent. However, the following IV estimates show that the OLS estimator is downward biased and that eradication results in an even greater increase in cultivation than suggested by OLS.

The IV estimates of the coefficient on coca fumigation are all significant at the one percent level. The just identified regression in column (2), where the instrument is distance beyond the 80 mile radius of a base, shows that a one percent increase in fumigation results in a 0.92 increase in coca cultivation. Column (3) adds as an instrument an indicator for whether a municipality is less than 80 miles from a fumigation base, and the resulting IV estimate implies that a one percent increase in fumigation leads to a 0.80 percent increase in cultivation. In column (4), where interactions between distance beyond 80 miles of a base and the number of right wing/left wing combatants are added to the instrument set, a one percent increase in fumigation is estimated to increase coca cultivation by 0.76 percent. Finally, specification (5) further adds to the instrument set an interaction between the indicator for distance from a base being less than 80 miles and distance from the base, plus interactions between this variable and the number of right and left wing combatants. The coefficient on eradication is of the same order as in previous specifications: a one percent increase in eradication results in a 0.71 percent increase in cultivation. For specifications (3) - (5), the Sargan-Hansen test of the overidentifying restrictions cannot reject the null that the instruments are exogenous, even at the 10 percent level.

The coefficient on municipality area is always positive and statistically significant, a natural result if the availability of more land results in greater production of coca. The coefficient on a municipality's cultivated agricultural area is negative and significant across specifications, reflecting the geographical concentration of coca crops in agricultural frontier areas. All the other exogenous variables have coefficients that are statistically insignificant. A one percent increase in the number of FARC combatants is associated with an increase in coca cultivation of less than one tenth of a percent in all specifications. Because the presence of illegal armed combatants is generally thought to be linked to greater levels of production of coca, it is interesting that specifications (2) – (5) show that increases in the number of ELN and AUC combatants are associated with a reduction in levels of coca cultivation. This may be explained by these organizations having strong historical links with certain areas of the country, tending to stay in those regions for reasons other than coca production levels. At any rate, the estimated effects are small, and in all specifications a one percent increase in ELN combatants leads to changes in coca cultivation of less than one tenth of a percent. In the case of the coefficient on the number of AUC combatants, the effect of a one percent increase in AUC members on coca cultivation ranges between a reduction of 0.13 percent and an increase of 0.03 percent. However, none of these coefficients is statistically different from zero.

While all the coca fumigation bases are located in urban areas that have the major airports required for their operation, there are three locations where building projects were undertaken to make the bases suitable for aerial fumigation. As a robustness test, I drop from the sample the municipalities that are located within an 80 mile radius of those bases in case the location was endogenously chosen. Table 6 shows estimates of equation (1) analogous to the ones in Table 5, but where observations near the bases of Larandia, Villagarzón, and San José del Guaviare are not included. The statistical significance, sign, and magnitude of the coefficients on coca fumigation remain essentially unaltered.

Finally, I change the measure of coca eradication to include both fumigation and the manual destruction of coca bushes. Manual eradication has similar risks to those of aerial eradication and its implementation follows roughly the same geographical trend. *El Tiempo* reports that over a period of eight months during 2008, FARC members killed eleven manual eradicators, more than the number of fumigation aircraft pilots who were killed in a decade[6].

[6] "Once erradicadores manuales de coca han muerto por explosión de minas en lo corrido del año" http://www.eltiempo.com/archivo/documento/CMS-4460262

Because of the high cost of manual eradication in terms of potential casualties, over the period covered by the data manual eradication accounted for only 8 percent of total eradication. Moreover, its application followed the same geographical pattern as fumigation, with around three fourths of all manual eradication occurring within 80 miles of a fumigation base. The common pattern is not surprising, because several kinds of antinarcotics operations are coordinated from the bases, and manual eradication crews require protection from the Antinarcotics Police. This makes the instruments I use for fumigation suitable predictors of an eradication variable that is the sum of aerial and manual eradication. Table 7 shows estimates of (1) that prove to be basically the same as those in the original specifications of Table 5, further demonstrating the robustness of the results.

VI. DISCUSSION AND POLICY RECOMMENDATIONS

The results reported above have substantial implications for policymakers seeking to reduce coca production in Colombia. In government reports and in the popular media, the discussion of the effectiveness of drug policy is carried out largely in terms of comparisons between national trends of coca production and levels of eradication. Every year, when UNODC publishes its annual cultivation report (UNODC 2005, 2006a, 2006b, 2009a, 2009b), a reduction in the number of hectares of coca cultivated at the national level is taken by proponents of eradication as a demonstration of the success of the policy. By the same token, when there is an increase in cultivation, it is taken by detractors as proof of the failure of eradication. For example, in 2006 an editorial piece in the leading weekly *Semana* strongly dismissed the effectiveness of coca fumigation in view of an increase in cultivation over the previous year:

> "In 2005, Colombia got straight "A"s in all areas: it attained record levels of coca eradication, historical levels of cocaine confiscation, and of captures and extraditions of drug traffickers. Nevertheless, this year was once again a failure in the war on drugs, as evidenced by the latest report on coca cultivation in the Andean region published yesterday by UNODC. In 2005, coca crops increased in the region by 1% compared to 2004. We went from 158,000 to 159,600 hectares of coca. While coca production fell in Bolivia (by 8 percent) and Peru (by 4 percent) in Colombia it increased by 8% […] These results reveal once again the failure of an anti-drug strategy based on aerial spraying [a policy not adopted by either Bolivia or Peru]."[7]

By contrast, after a decrease in national cultivation levels, the 2010 World Drug Report (UNODC 2010) attributed it primarily to the success of (the ever increasing) eradication efforts, aerial and otherwise:

> "While Colombian traffickers have produced most of the world's cocaine in recent years, between 2000 and 2009, the area under coca cultivation in Colombia decreased by 58%, mainly due to eradication […]"

While these correlations and aggregate trends are of interest, they are needless to say poor indicators of the causal effect of eradication on coca cultivation. By providing estimates of the effect of this policy on coca cultivation at the municipality level and exploiting only exogenous variations in eradication, this paper shows a clearer picture of what is ultimately of interest to policymakers and the public: the causal effect of a one percent increase in eradication is to *increase* the area cultivated with coca - by slightly less than one percent. More eradication leads to more coca cultivation.

The difference between the OLS and IV estimates shows OLS to be downward biased. The cause of the bias can be readily understood as the result of conducting relatively more eradication in areas where the Antinarcotics Police know, based on observed cultivation levels and institutional knowledge, that their efforts will be most effective at reducing the expansion in the national levels of cultivation of coca.

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[7] From "Further proof of the failure of the war on drugs" (Una prueba más del fracaso de la lucha contra las drogas), *Revista Semana*, June 21 2006, http://www.semana.com/noticias-on-line/prueba-del-fracaso-lucha-contra-drogas/95385.aspx, accessed December 15 2010

That coca cultivation in Colombian municipalities increases as a result of eradication demonstrates the strength of the incentives to produce this crop. They are able to counteract government policies against illegal crop cultivation.

An adjustment of coca leaf prices is the most probable explanation for the increase in cultivation. An inelastic demand can ensure that prices rise to maintain coca leaf production at (or near to) pre-eradication levels. Because eradication reduces the expected annual productivity of any given coca plot in a targeted municipality, maintaining a steady supply of coca leaf will require an increase in the amount of land allocated to coca.

If eradication increases coca cultivation and has little effect on the supply of coca leaf, the results obtained here suggest that the policy ought to be abandoned. Aside from being ineffective, crop eradication is costly and has negative externalities. For example, there is some evidence that aerial fumigation is detrimental to the environment. The area of the country targeted by the spraying campaign is very biologically diverse and it is home to several unique and endangered species, making the potential damage caused by herbicides severe (Peterson, S. 2002). Peterson contends that glyphosate has "well documented deleterious effects on soil micro-organisms, mammalian life (including humans), invertebrates, and aquatic organisms." Such assertions are vigorously contested by the Colombian government and the U.S. Department of State (USDS 2004). But while the environmental impact of glyphosate remains controversial, there is no question that large amounts of rainforest continue to be cleared to make way for new coca fields (Bigwood, J. and P. Coffin 2005). Governmental intervention may thus encourage the destruction of valuable environmental resources without having much to show in return in terms of a reduction in coca leaf production.

Recommending that eradication be stopped is not a call for abandoning other types of drug policy, because the production of coca itself has negative externalities. Taxation of the drug trade is thought to account for around half the revenue of FARC, ELN, and AUC, organizations that attack and weaken the Colombian state by bombing the country's oil pipelines, electrical, and telecommunications infrastructure; forcefully displacing the rural population; and causing excess defense spending and human losses from the combat deaths of members of the armed forces (Pinto Borrego, M. E., A. Vergara Ballen and Y. Lahuerta Percipiano 2005). If a reduction in the size of the profitable cocaine industry were to result in the weakening of these organizations, the government would have strong reasons to pursue the reduction of coca and cocaine production by other means. Furthermore, concern for drug consumption at home and abroad, as well as a desire to comply with the international treaties banning the production of narcotics can be invoked as reasons to seek new ways to reduce coca cultivation.

Alternative methods of reducing coca production exist and have been implemented, but they have not received nearly as much funding, and even less systematic evaluation than eradication. Most programs offer one type or another of alternative development for coca farmers, and the variety of the strategies used is remarkable. They include providing training for farmers, subsidizing inputs for the production of alternative crops, introducing new agricultural techniques, helping to commercialize farm products, providing technical assistance, and building processing facilities and various types of infrastructure. Yet data provided by UNODC show that funding for alternative development programs fell by 81 percent between 2001 and 2006, at the same time that eradication efforts were being intensified.

A carefully planned reallocation of government spending from eradication to alternative development may be a first step toward finding effective ways to reduce coca production in

Colombia. Ideally, a series of randomized experiments that allow for the systematic evaluation of program effectiveness should be used. Otherwise, the implementation of multiple types of endogenously targeted interventions that is currently the rule (UNODC 2008) will make it difficult to identify successful coca cultivation reduction programs.

VII. CONCLUSION

The data collected by the United Nations Office on Drug and Crime provide an excellent opportunity to shed light on the efficiency of the Colombian government's antinarcotics policies. I evaluate its flagship initiative, coca crop eradication. The principal challenge is to accurately estimate the effectiveness of this program given the endogeneity of the policy variable. I address it using an IV strategy, exploiting exogenous sources of variation in the ability of the Colombian government to implement drug control policies.

The social cost of coca and cocaine production and consumption is thought to be high, giving the government good reasons to fight drug production. Yet the findings I present show that the appropriate course of action to reduce this cost remains unclear, because a one percent increase in coca eradication results in an increase of about one percent in the amount of land cultivated with coca.

If the negative externalities of coca production to Colombia and to the international community warrant a high level of investment in antinarcotics efforts, resources from eradication should be allocated to new programs. The main option is alternative development, by which farmers are given incentives and a wide array of tools to switch from growing coca to producing legal crops and agricultural products. It remains a challenge for policymakers to design, implement, and identify efficient alternative drug policies by facilitating future program evaluation studies.

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Figure 1: Distance from a Coca Fumigation Base

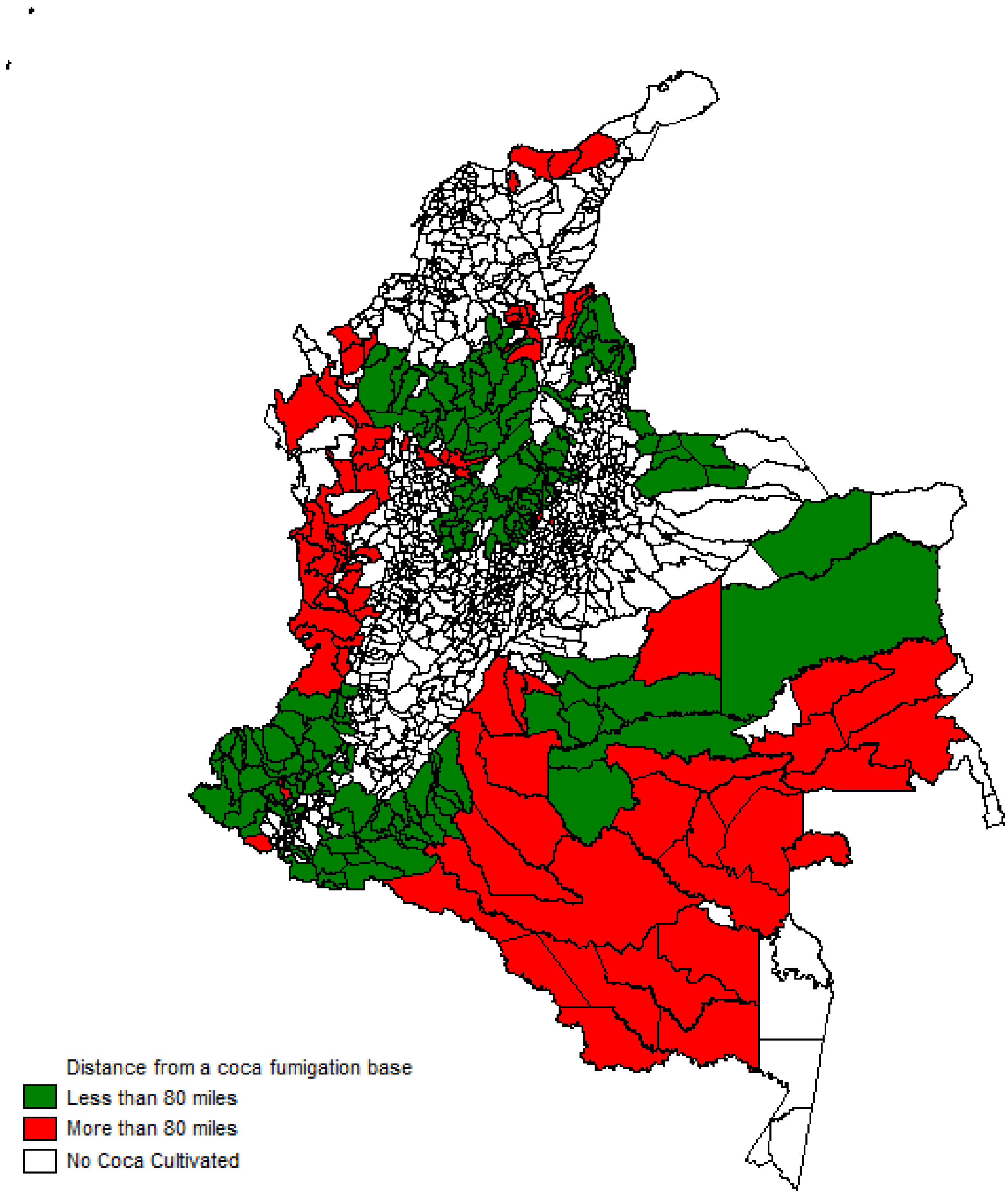

Figure 2: Coca cultivation and fumigation by distance to a fumigation base

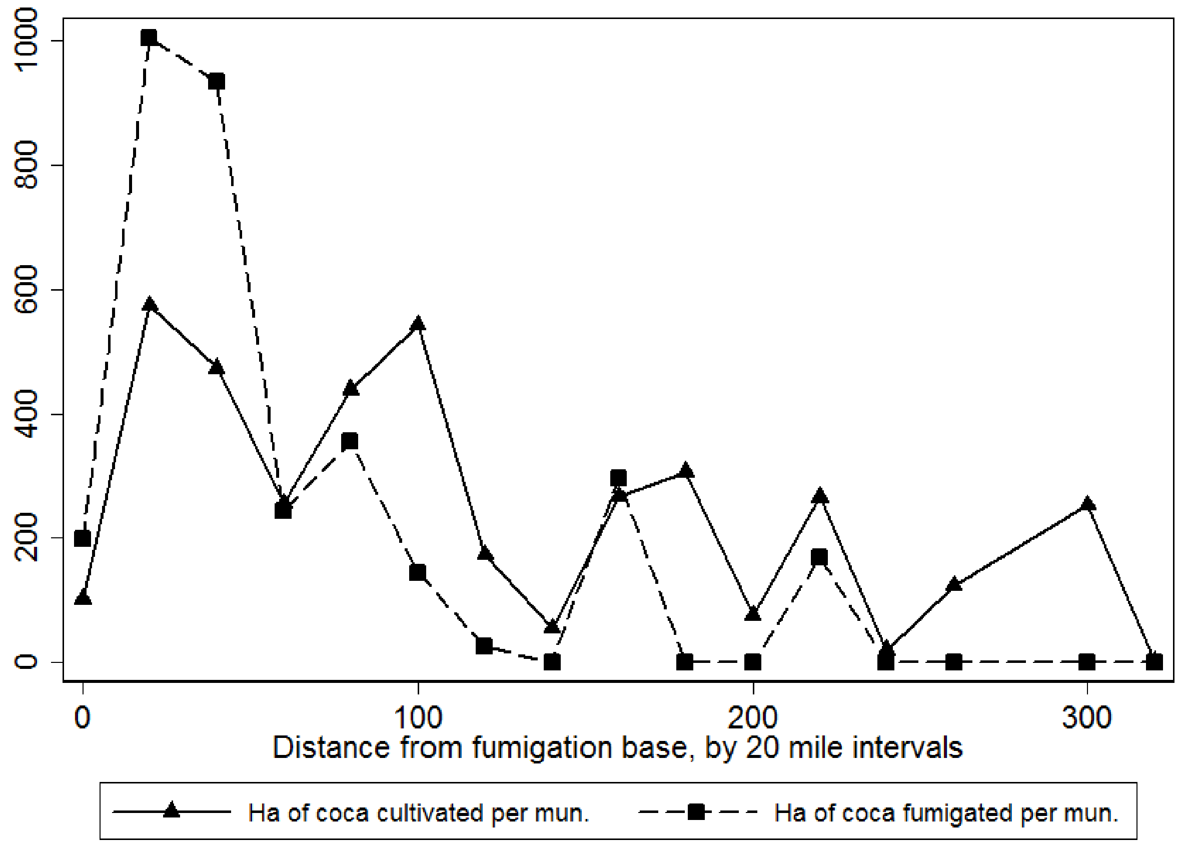

Table 1: Average Coca Cultivation, Fumigation, and Manual Eradication per Municipality

Year	Mean number of hectares cultivated per municipality	Mean number of hectares fumigated per municipality	Mean number of hectares manually eradicated per municipality
2001	563.45	366.35	0
	(1709.19)	(1572.04)	
2002	397.16	507.25	0
	(1273.80)	(2496.13)	
2003	335.92	516.80	0
	(880.41)	(2020.36)	
2004	312.64	531.04	8.89
	(762.41)	(1598.477)	(33.38)
2005	333.66	539.14	117.19
	(871.03)	(2061.02)	(476.63)
2006	303.00	667.87	150.46
	(778.312)	(1835.82)	(493.79)

Source: Author's calculations from data provided by the United Nations Office on Drug and Crime and the Antinarcotics Police.

Table 2: Mean annual cultivation, fumigation, eradication, and alternative development spending by location within 80 miles of a fumigation base.

	Coca hectares per municipality	Fumigated coca hectares per municipality	Manually eradicated coca hectares per municipality	Alternative development spending per municipality in millions of pesos
Distance to a fumigation base is less than 80 miles (N=1020)	397.5 (33.0)	669.2 (67.7)	57.0 (10.1)	169.6 (29.4)
Distance to a fumigation base is 80 miles or more (N=522)	320.1 (53.2)	175.8 (46.7)	20.5 (5.9)	31.6 (11.2)

Table 3: First Stage Estimates

	Dependent Variable is Eradicated Coca Hectares			
	(1)	(2)	(3)	(4)
Distance beyond 80 mile radius of a base	-12.52***	-8.160***	-3.982	-3.966*
	(2.815)	(2.584)	(2.883)	(2.382)
Municipality is less than 80 miles from a fumigation base		496.4***	329.0**	539.2*
		(174.4)	(159.5)	(289.6)
Distance beyond 80 miles of a base * Number of left wing combatants			-0.263***	-0.259**
			(0.100)	(0.108)
Distance beyond 80 miles of a base * Number of right wing combatants			-0.246	-0.401
			(0.169)	(0.338)
Municipality is less than 80 miles from a fumigation base * Distance from base				-3.449
				(3.975)
Municipality is less than 80 miles from a fumigation base * Distance from base * Number of left wing combatants				0.00681
				(0.0720)
Municipality is less than 80 miles from a fumigation base * Distance from base * Number of right wing combatants				-0.278
				(0.364)
FARC guerrilla combatants	1.527	1.763	7.037**	7.035**
	(2.298)	(2.321)	(3.059)	(3.234)
AUC paramilitary combatants	17.34	16.79	18.63	30.03
	(10.72)	(10.62)	(11.75)	(24.21)
ELN guerrilla combatants	20.78*	22.03**	16.76	16.38
	(10.82)	(10.51)	(10.25)	(11.21)
Area in square kilometers	0.0186	0.0229	0.0179	0.0161
	(0.0165)	(0.0156)	(0.0148)	(0.0155)
Cultivated agricultural area	0.000738	0.000660	0.000481	0.000627
	(0.000628)	(0.000597)	(0.000506)	(0.000550)
Population density	-1.230*	-1.467**	-1.187*	-1.599*
	(0.700)	(0.733)	(0.700)	(0.841)
Observations	1,530	1,530	1,530	1,530
R-squared	0.149	0.157	0.190	0.196
F statistic of excluded instruments	19.78	13.85	9.93	5.92

Robust standard errors clustered by municipality in parentheses. All regressions include a constant, year indicators, and indicators for each of the 7 UNODC coca growing regions.

*** p<0.01, ** p<0.05, * p<0.1

Table 4: First Stage Estimates Replacing Fumigation Bases with Largest Cities

	Dependent Variable is Fumigated Coca Hectares			
	(1)	(2)	(3)	(4)
Distance beyond 80 mile radius of 11 largest cities	1.116	0.366	-1.526	-2.341
	(1.655)	(1.780)	(1.544)	(1.497)
Municipality is less than 80 miles from one of the 11 largest cities		-216.2	-174.3	-95.35
		(134.4)	(136.8)	(210.1)
Distance beyond 80 miles of 11 largest cities * Number of left wing combatants			0.0774**	0.104***
			(0.0344)	(0.0383)
Distance beyond 80 miles of 11 largest cities * Number of right wing combatants			0.370**	0.477**
			(0.182)	(0.205)
Municipality is less than 80 miles from 11 largest cities * Distance from city				-5.699*
				(3.260)
Municipality is less than 80 miles from 11 largest cities * Distance from city * Number of left wing combatants				0.155*
				(0.0913)
Municipality is less than 80 miles from 11 largest cities * Distance from city * Number of right wing combatants				0.336*
				(0.172)
FARC guerrilla combatants	2.157	2.148	-4.106	-6.956*
	(2.611)	(2.617)	(3.208)	(3.904)
AUC paramilitary combatants	18.40*	18.16*	-5.333	-14.61**
	(10.79)	(10.82)	(4.965)	(7.405)
ELN guerrilla combatants	21.41**	20.07*	31.05**	22.29**
	(10.85)	(11.44)	(13.58)	(10.72)
Area in square kilometers	0.0169	0.0182	-0.00509	-0.0254
	(0.0183)	(0.0181)	(0.0219)	(0.0198)
Cultivated agricultural area	-0.000403	-0.000323	-3.01e-05	0.000327
	(0.000582)	(0.000575)	(0.000653)	(0.000639)
Population density	-0.533	-0.476	-0.0148	0.199
	(0.739)	(0.739)	(0.802)	(0.841)
Observations	1,530	1,530	1,530	1,530
R-squared	0.124	0.125	0.172	0.185
F statistic of excluded instruments	0.45	1.95	2.72	3.55

Robust standard errors clustered by municipality in parentheses. All regressions include a constant, year indicators, and indicators for each of the 7 UNODC coca growing regions. Distances are calculated from the 11 most populated cities that do not have fumigation bases: Bogotá, Medellín, Cali, Barranquilla, Cartagena, Bucaramanga, Ibagué, Soledad, Pereira, Santa Marta, and Soacha.

*** p<0.01, ** p<0.05, * p<0.1

Table 5: Second Stage Regressions

	Dependent Variable is Hectares of Coca Detected at the End of the Year in a Municipality				
	(1)	(2)	(3)	(4)	(5)
	OLS	IV	IV	IV	IV
Hectares of coca fumigated	0.238***	0.664***	0.576***	0.544***	0.510***
	(0.0359)	(0.109)	(0.0748)	(0.0706)	(0.0653)
FARC guerrilla combatants	0.932	0.0373	0.221	0.290	0.360
	(0.811)	(0.795)	(0.639)	(0.566)	(0.536)
AUC paramilitary combatants	1.645	-6.221	-4.601	-4.000	-3.383
	(1.641)	(4.176)	(3.056)	(2.523)	(2.157)
ELN guerrilla combatants	5.198	-3.807	-1.952	-1.264	-0.558
	(3.224)	(3.882)	(2.997)	(2.896)	(2.634)
Area in square kilometers	0.0761***	0.0673***	0.0691***	0.0698***	0.0705***
	(0.0162)	(0.0132)	(0.0134)	(0.0136)	(0.0138)
Cultivated agricultural area	-0.000808*	-0.000678*	-0.000705*	-0.000715*	-0.000725*
	(0.000412)	(0.000397)	(0.000384)	(0.000379)	(0.000378)
Population density	-0.0925	0.122	0.0776	0.0613	0.0445
	(0.170)	(0.251)	(0.196)	(0.178)	(0.164)
Observations	1,530	1,530	1,530	1,530	1,530
R-squared	0.451	0.000	0.135	0.193	0.246
F statistic of excluded instruments	-	19.78	13.85	9.93	5.92

Instrument in (2) is distance beyond the 80 mile radius of a base. In (3) the instruments are distance beyond the 80 mile radius of a base and an indicator for whether a municipality is less than 80 miles from a fumigation base. In (4), interactions between distance beyond 80 miles of a base and the number of right wing/left wing combatants are also included. Specification (5) further adds an interaction between the indicator for distance from a base being less than 80 miles and distance from the base, plus interactions between this variable and the number of right wing/left wing combatants. All regressions include a constant, year indicators, and indicators for each of the 7 UNODC coca growing regions. Robust standard errors clustered by municipality are shown in parentheses.

*** p<0.01, ** p<0.05, * p<0.1

Table 6: Second Stage Regressions Dropping Observations Near Larandia, Villagarzón and San José del Guaviare

	Dependent Variable is Hectares of Coca Detected at the End of the Year in a Municipality				
	(1)	(2)	(3)	(4)	(5)
	OLS	IV	IV	IV	IV
Hectares of coca fumigated	0.254***	0.826***	0.613***	0.528***	0.487***
	(0.0365)	(0.234)	(0.121)	(0.0954)	(0.0812)
FARC guerrilla combatants	0.284	0.620	0.494	0.444	0.420
	(0.904)	(0.565)	(0.617)	(0.662)	(0.690)
AUC paramilitary combatants	1.483	-11.14	-6.432	-4.557*	-3.648*
	(1.455)	(7.993)	(4.314)	(2.524)	(1.915)
ELN guerrilla combatants	5.873*	-8.142	-2.913	-0.832	0.178
	(3.232)	(7.130)	(3.735)	(2.923)	(2.345)
Area in square kilometers	0.0784***	0.0624***	0.0684***	0.0707***	0.0719***
	(0.0146)	(0.0162)	(0.0143)	(0.0141)	(0.0140)
Cultivated agricultural area	-0.000585	-0.00104**	-0.000873**	-0.000805*	-0.000772*
	(0.000577)	(0.000413)	(0.000423)	(0.000443)	(0.000460)
Population Density	-0.134	0.564	0.303	0.200	0.149
	(0.165)	(0.407)	(0.233)	(0.196)	(0.184)
Observations	1,254	1,254	1,254	1,254	1,254
R-squared	0.474	0.000	0.175	0.300	0.349
F statistic of excluded instruments	-	9.00	6.24	4.82	2.94

All observations from municipalities that are 80 miles or less from the fumigation bases of Larandia, Villagarzón, and San José del Guaviare have been dropped. The instrument in (2) is distance beyond the 80 mile radius of a base. In (3) the instruments are distance beyond the 80 mile radius of a base and an indicator for whether a municipality is less than 80 miles from a fumigation base. In (4), interactions between distance beyond 80 miles of a base and the number of right wing/left wing combatants are also included. Specification (5) further adds an interaction between the indicator for distance from a base being less than 80 miles and distance from the base, plus interactions between this variable and the number of right wing/left wing combatants. All regressions include a constant, year indicators, and indicators for each of the 7 UNODC coca growing regions. Robust standard errors clustered by municipality are shown in parentheses.

*** p<0.01, ** p<0.05, * p<0.1

Table 7: Second Stage Regressions Using Fumigation plus Manual Eradication by all Methods as the Policy Variable

	Dependent Variable is Hectares of Coca Detected at the End of the Year in a Municipality				
	(1)	(2)	(3)	(4)	(5)
	OLS	IV	IV	IV	IV
Hectares of coca fumigated and manually eradicated	0.221***	0.647***	0.549***	0.509***	0.476***
	(0.0299)	(0.108)	(0.0714)	(0.0638)	(0.0596)
FARC guerrilla combatants	0.934	-0.0205	0.198	0.289	0.363
	(0.820)	(0.825)	(0.637)	(0.556)	(0.528)
AUC paramilitary combatants	1.550	-7.084	-5.110	-4.284*	-3.620*
	(1.677)	(4.660)	(3.307)	(2.593)	(2.199)
ELN guerrilla combatants	5.501*	-3.587	-1.510	-0.640	0.0586
	(3.254)	(3.954)	(2.952)	(2.763)	(2.522)
Area in square kilometers	0.0766***	0.0681***	0.0700***	0.0708***	0.0715***
	(0.0163)	(0.0131)	(0.0134)	(0.0137)	(0.0139)
Cultivated agricultural area	-0.000806*	-0.000663	-0.000696*	-0.000709*	-0.000720*
	(0.000416)	(0.000406)	(0.000389)	(0.000383)	(0.000383)
Population density	-0.107	0.0962	0.0498	0.0304	0.0148
	(0.170)	(0.279)	(0.211)	(0.186)	(0.170)
Observations	1,530	1,530	1,530	1,530	1,530
R-squared	0.446	0.000	0.113	0.191	0.245
F statistic of excluded instruments	-	19.60	14.10	10.14	6.06

The policy variable is hectares of coca fumigated plus hectares of coca manually eradicated. The instrument in (2) is distance beyond the 80 mile radius of a base. In (3) the instruments are distance beyond the 80 mile radius of a base and an indicator for whether a municipality is less than 80 miles from a fumigation base. In (4), interactions between distance beyond 80 miles of a base and the number of right wing/left wing combatants are also included. Specification (5) further adds an interaction between the indicator for distance from a base being less than 80 miles and distance from the base, plus interactions between this variable and the number of right wing/left wing combatants. All regressions include a constant, year indicators, and indicators for each of the 7 UNODC coca growing regions. Robust standard errors clustered by municipality are shown in parentheses.
*** p<0.01, ** p<0.05, * p<0.1