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A Statistical Study of the Anti-Coca Aerial Eradication Policy in Colombia

I. Introduction

The production of the South American coca plant (*Erythoxylon coca*) has been a problem for Colombia since the 1980s. Cocaine, a popular stimulant that is the second most used illegal drug (after marijuana) in the United States, is derived from the coca plant commonly planted in Colombia, and to a lesser extent, in neighboring Bolivia and Peru. While the ways in which cocaine is trafficked in Colombia has undergone change in the 1980s, the mechanisms behind its farming has not.

Coca production is driven by impoverished families living in rural regions that farm the coca plant for drug traffickers; meanwhile, guerillas and rebels are in control of coca production and cocaine trafficking[1]. In Colombia, illegal drug production is usually a result of isolation/lack of access to capital centers, economic insecurity in rural regions, and political instability[1]. Recent surveillance show an increased concentration of crops in western regions of Colombia, areas generally controlled by right-wing paramilitary groups and disconnected from the central commercial areas of the country; despite being close to the Ecuadorian and Peruvian borders as well as having the country's most important sea port, the region has no exportable product--coca, it seems, alleviates some economic insecurity for those in the agricultural sector[1]. The eastern regions, on the other hand, have seen a general decrease after the landmark peace treaty signed between Colombia and the FARC (a left-wing military group), further suggesting that a lack of government control contributes to coca production[1]. However, illegal drug farming, though reducing some economic insecurity, still places farmers and their families at heavy risk to non-regulated market forces, in addition to unresolved issues in or lack of access to important human development factors including education and health care, due to the illicit nature of coca. It also perpetuates civil strife in Colombia, as it funds the paramilitary groups that are prevalent in the region and dominate the cocaine trade[2].

Colombia has launched government policies aimed at decreasing coca cultivation, mainly from the supply side of the issue. They have either aimed at (i) forceful cocaine eradication, which includes aerial spraying of pesticides on farms or manual uprooting of crops or plant/drug seizures, (ii) voluntary cocaine eradication, usually with subsidies and crop substitution programs to incentivize replacing coca crops with legal agricultural ones, and (iii) building infrastructure.

While forceful cocaine eradication--particularly aerial eradication--is the quickest method to destroy hundreds of thousands of hectares of coca crops while keeping costs low, it has massive negative externalities, such as destruction of the surrounding ecological systems, rendering the land unsuitable for *all* crops and poisoning the water systems[3]. Communities neighboring sprayed fields report increased health issues and reduction in crop quantity and quality. In addition, coca farmers have shown to overcompensate coca production when crops are destroyed either to recoup personal losses or forced by

[1] UNODC. (2017). Monitoreo de territorios afectados por cultivos ilicitos 2016.
[2] Kline, H. F., & McGreevey, W. P. (2020, May 5). The growth of drug trafficking and guerrilla warfare.
[3] Wola. (n.d.). The Costs of Restarting Aerial Coca Spraying in Colombia.

the buyers (those in control of the cocaine manufacturing process); they simply deforest more land and plant more coca[4].

Voluntary cocaine eradication programs include a government subsidy program that focuses on offering farmers higher prices on key alternative crops, such as plantains[5]. While some negative correlations have been shown (between increased plantain crop prices and coca cultivation), concerns arise over the ability for coca buyers to counteract these efforts by increasing the price of coca, as the coca crop is only a fraction of the final cocaine price[6]. Optimistically, previous subsidy programs in Thailand heavily reduced opium production. Colombia continues to pursue these programs, most recently with 2017's PNIS (*Programa Nacional Integral de Sustitución de Cultivos de Uso Ilícito*); the economic impact is yet to be determined. The aim of the project is to promote the voluntary eradication of cocaine production, offering various subsidies to support farmers as they transition to legal agricultural activities[7].

Given Ivan Duque's rebooting the aerial eradication program, our goal is to test the success of aerial eradication as the main anti-coca policy since 2002—where "success" is measured through a decrease in coca cultivation in hectares, as it directly lowers the potential volumes of cocaine produced and sold. We hope to evaluate the effectiveness of such a program, given the negative externalities associated.

II. Data

We collected data from 2002 to 2016 and over the 24 departments of Colombia for three variables. A description of them is given below:
Coca Production: measured in hectares over region and time.
Unemployment: measured as usual region and time.
Eradication: net eradication measured in hectares over region and time. Note that since this is net eradication and so the eradication for a time and region may be higher than the coca production for that same time and region.

III. Model

We estimated a two-way fixed effects OLS regression. The response variable was coca production and the predictor variable was eradication. We also added unemployment as a control variable. Finally, we added two vectors each containing a fixed effect. One vector includes time fixed effects, for the years 2002 to 2016. The other vector includes the region fixed effects for 24 departments in Colombia. The specification for the model is given below:

[4] Moreno-Sanchez, R., Kraybill, D. S., & Thompson, S. R. (2003). An Econometric Analysis of Coca Eradication Policy in Colombia. World Development, 31(2), 375–383.
[5] Observatorio de Drogas de Colombia. (n.d.). Observatorio de Drogas de Colombia > Acuerdo de la habana. Retrieved from http://www.odc.gov.co/acuerdos_habana
[6] Moreno-Sanchez, R., Kraybill, D. S., & Thompson, S. R. (2003). An Econometric Analysis of Coca Eradication Policy in Colombia. World Development, 31(2), 375–383.
[7] Defensoria del Pueblo Colombia. (2017). Analisis de la fase inicial de diseno e implementacion del Programa Nacional de Sustitucion de Cultivos de Uso Ilicito.

$$Y = \beta_0 + \beta_1 X_{it} + \beta_2 X_{it} + \beta_3 Z_i + \beta_4 Z_t + e_{it}$$

Where,

B_1= eradication over region and time
B_2= unemployment over region and time
Z_i = a vector of time-invariant fixed effects for 24 departments
Z_t = a vector of time-variant fixed effects for each year between 2002 and 2016 inclusive

IV. Results

Results for the fixed-effects regression are reported below. Note that to make the regression results more compact, standard errors are in brackets next to the coefficient estimate; however, they are usually located in a row below the coefficient estimate. The standard errors reported are heteroskedastic robust.

Table 1.1: OLS Regression

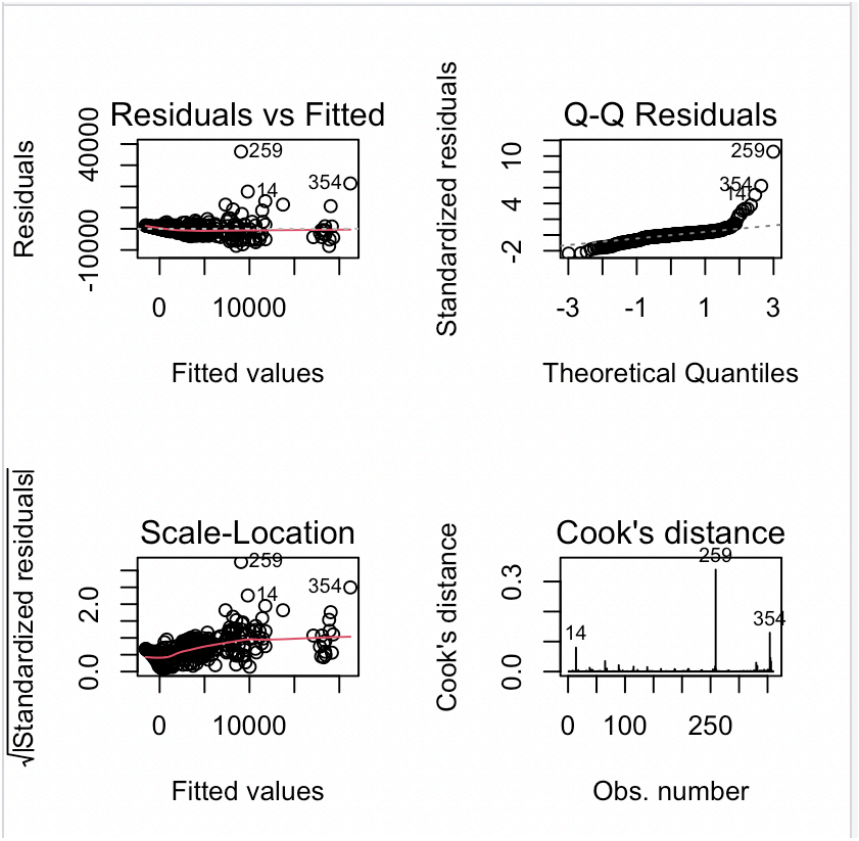
	Dependent variable:
	Cocaine Production
Intercept	208.33 (2,019.72)
eradication	-0.02 (0.03)
unemployment	6,872.30 (11,469.95)
2003	-560.06 (1,066.06)
2004	-929.87 (1,072.46)
2005	-143.71 (1,113.49)
2006	-835.22 (1,083.57)
2007	41.42 (1,087.65)
2008	-703.28 (1,094.03)
2009	-1,090.23 (1,082.58)
2010	-1,541.28 (1,086.26)
2011	-1,453.68 (1,113.62)
2012	-325.42 (1,133.10)
2013	-2,010.67* (1,164.27)
2014	-1,096.72 (1,189.33)
2015	67.68 (1,202.97)
2016	2,293.49* (1,185.60)
antioquia	4,481.16*** (1,360.51)
arauca	328.52 (1,334.91)
bolivar	2,791.35** (1,366.40)
boyaca	-142.90 (1,349.10)

caldas	-395.34 (1,338.42)
caqueta	5,515.35*** (1,404.45)
cauca	4,608.62*** (1,352.19)
cesar	-342.87 (1,342.24)
choco	1,227.93 (1,336.52)
cordoba	1,216.36 (1,335.77)
cundinamarca	-367.42 (1,335.11)
guainia	15.80 (1,333.85)
guaviare	8,790.12*** (1,392.14)
guajira	-98.12 (1,370.42)
magdalena	-28.40 (1,366.86)
meta	7,509.88*** (1,354.09)
narino	18,645.82*** (1,631.83)
nortedesantander	8,372.61*** (1,340.97)
putumayo	10,788.60*** (1,416.79)
santander	333.52 (1,346.59)
valledelcauca	25.71 (1,346.75)
vaupes	173.93 (1,333.85)
vichada	3,152.47** (1,334.78)
Observations	360
R^2	0.65
Adjusted R^2	0.60
Residual Std. Error	3,652.89 (df = 320)
F Statistic	14.98*** (df = 39; 320)
Note:	*p<0.1; **p<0.05; ***p<0.01

Neither eradication nor unemployment were deemed significant in this regression. They did, however, have intuitive signs attached to the coefficients. The only variables deemed significant were some time and region fixed effects; however, we do not believe it is necessary to interpret the significance of these fixed effects as they are just control variables. The multiple-R^2 and adjusted-R^2 were 0.65 and 0.6, respectively. This is a low value, which suggests that the regression may be improved by adding more control variables. However, the F statistic was statistically significant at the 1% level, which implies that the R^2 is statistically significantly different than 0. Therefore, while the R^2 may be low, it is statistically significant.

Finally, let's run some diagnostic tests on this model.

Table 1.2: Model Diagnostics



On the top left, the flat horizontal line on the residuals vs. fitted values plot indicates that the relationship between dependent and independent variables is likely linear. The (mostly) linear relationship on the top right Q-Q plot indicates that residuals are (mostly) normally distributed. The bottom left plot has a slightly non-horizontal line, which indicates that the residuals exhibit some *heteroskedasticity*. The Cook's distance plot on the bottom right is used to identify outliers that may affect the regression. It appears there are some outliers, which could affect the fit of the linear regression. I will ignore this complication for now. Most of the assumptions for OLS appear to be met. However, the presence of heteroskedastic errors makes the estimation of coefficient standard errors erroneous. To correct for this, we need to estimate heteroskedastic robust errors for the coefficients. This was done using the HC1 method in the 'sandwich' package. The reported standard errors in the model results above are the heteroskedastic robust ones. The main conclusion we can make is that eradication through aerial spraying is not significant in reducing year-by-year coca production. This suggests that a different solution must be found to lowering coca production rather than forced eradication through aerial spraying.

V. Conclusion

We propose that future policy should emphasize the voluntary eradication program. The voluntary program should be structured as the PNIS has outlined: once a certified monitor has confirmed that cocaine farmers have eradicated their crops, the Colombian government will provide the family with a year-long stipend for basic necessities, a one-time subsidy to be used in new business ventures, and a one-time subsidy to buy durable goods that promote hygiene and food stability. This provides incentive to switch crops as well as aid to cash-strapped farmers (previous study in Kenya exhibited increased economic and psychological well-being in response to cash transfers). Following that, another one-time subsidy is given in the second year and technical assistance is provided by the government if the farmer needs help cultivating their new legal crop. This is intended to sustain the habit of keeping the new crop and discourage reverting back to coca.

To evaluate the effectiveness of subsidy programs, we would work on the hypothesis that greater participation rate would reduce the total coca production across regions and time. Since the program began in 2017, this hypothesis could be tested in the future, once more years of data have been collected. The test would use the same two-way fixed effects regression we estimated above, but now it would also add a variable to measure participation rate in PNIS. We could measure program participation rate through proxies such as pure acreage of farmland under the subsidy program or total government spending on the subsidy program. An additional consideration would be the long-term participation rate past year one (as another issue is the high recidivism farmers have with producing coca plants), though this variation could be accounted for through the previously mentioned measurement methods.

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