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Coca Leaves Production and Eradication: A General Equilibrium Analysis

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Abstract

Law enforcement against illegal drug markets like coca leaf production have created big debate about its consequences and effectiveness. Since this enfocerment does not only affect the illegal market but also the legal ones it is then necessary to study its effects and effectiveness within a general equilibrium framework. This is the first contribution of this note. Moreover, using a unique database on Colombia we make a robust econometric check for the main results: we show that standard erradication policy have counterintuitive effects and do not reduce the production.

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1 Introduction

For several years, Colombia has been one of the main countries producing the cocaine sold in the streets of many developed countries. Every year this industry moves millions of dollars, supports many types of illegal behaviors and changes the lives of many people who are displaced from where they live.

Moreover, since the fight against illegal drug markets is considered a priority at the international level scholars and policy makers should move from a pure descriptive exercise to a more analytical and econometric based approach in order to isolate the main forces driving their dynamics. This is the main goal of our paper.[1]

In addition, since coca production is a problem that affects several other markets, e.g. land markets and labor markets, the modeling of this industry has to be changed from a partial equilibrium approach to a general equilibrium framework. This is the second specific contribution of our paper. To our knowledge this is the first time this issue has been examined in this type of framework,[2]which reveals the informal and formal linkages in the economy.

With our model we show why simple enforcement policies like aerial spraying/eradication might be ineffective, namely due to the particular nature of the coca production, such as technological rigidity, oligopolistic structure and external demand. In this context, law enforcement policies affecting production costs do not work because there is no substitutability between factors of production, the market power stands on the supply side, and lastly, external demand is both not affected by the policy and poorly affected by the price changes (due to the well known rigidity of drug demand).

The next section presents the theoretical model, Section 3 describes the econometric strategy, the data and the results. The last section concludes.

[1]We use a unique database collected from several sources at the municipal level in Colombia during the years 2000 and 2008, which allows testing the main Proposition in our model.

[2]Moreover, the literature is rather thin, despite the large debate in the public opinion concerning the topic. Mejia (2010) uses a calibrated partial equilibrium model to criticized the benefits of the *Plan Colombia*; Ibañez and Carlsson (2010) use an experimental methodology in a remote area of an important producer province in Colombia to investigate the incentives behind farmers producing coca, suggesting that economic incentives can explain only a small part of the behaviour. Diaz and Sanchez (2004) uses spatial analysis to test the hypothesis that crop production is intensified by the armed conflict; finally, Moreno-Sanchez et al. (2003) use an econometric model to criticize the effectiveness of the eradication policy.

2 The Model

We want to capture the basic structure of the economy in a simple general equilibrium framework. Households set their consumption level between a formal economy good (f) and an imported good x. They provide inelastically labour and land and receive rental prices (respectively w and r). They are charged with taxes for the income they receive from the formal sector production. Taxes are lump sum and state budget is τ. The state raise taxes τ in order to fight coca producers.

Production occurs according to Leontief production function in both the formal (y) and the coca sector (Q_c). The latter has demand $p_c(Q_c)$ with homogeneous producers: we look at symmetric equilibria for simplicity, thus there will be n equal producers producing q_c each, with $Q_c = nq_c$ in equilibrium. In the coca sector there is a fixed entry cost F. Production of the formal economy is also exported in amount e together with the entire coca produced.

We set to one the price of the formal good.

The following assumptions hold.

Assumption 1. The production function of the formal sector is

$$y = \min_{K^f, L^f} \{\beta K^f,\ L^f\} \quad \beta > 0$$

Assumption 2. The production function of the coca sector is

$$q_c = \min_{K^c, L^c} \{\alpha(\tau) K^c,\ L^c\} \quad \alpha(\tau) > 0 \quad \alpha'(\tau) > 0$$

Unless we need to derive for τ, we will indicate simply α to avoid heavy notation. Entry cost is $F > 0$.

Assumption 3.

$$p_c'(Q_c) < 0 \quad p_c''(Q_c) < 0$$

Assumption 4. Formal goods export and supply of land are positive and exogenous, $e > 0$, $\bar{K} > 0$.

Assumption 2 is motivated by empirical evidence of the lack of technological alternatives in the coca sector. The same can be said over the oligopolistic assumption. Both are taken as a realistic description of existing market conditions and are also strictly related with the point that we want to make, namely that the fight against *narcos* should take into account the market structure, the availability of production factors and the poor technological alternatives.

The α is a reduced form treatment of the anti-drugs policy, as compared with some political economy setup. However, it is well known that there are geo-political factors behind policies such as the *Plan Colombia*, thus this exogeneity assumption is not particularly restrictive.

Assumption 3 is a standard assumption to guarantee that first order condition for maximization is also sufficient.

Formally the representative household maximizes

$$\max_{f,x} f^{\gamma}x^{1-\gamma} \ s.t. \ f + p_x x \leq [(w + r/\alpha)nq_c + (w + r/\beta)y - \tau] \qquad (1)$$

with $\gamma \in (0,\ 1)$.

In the coca sector, each producer maximizes profits:

$$\max_{q_c} p_c(Q_c)q_c - (w + r/\alpha)q_c \ s.t. \ Q_c = \sum_i q_{ic} \qquad (2)$$

in a standard Cournot setting with entry cost F.

In the formal sector, each producer maximizes profits:

$$\max_{y} y - (w + r/\beta)y \qquad (3)$$

under free entry condition.

A couple of remarks are in order.

Remark 1. If we look at the model, there is no justifying reason to prosecute coca producers. Efficiency-wise the only problem is the oligopolistic structure. Our approach is positive and not normative. The state decided to fight against coca production and we evaluate how this decision affects the environment and how effective can be, given the existing structure of the economy. By the same token our description of the state is more technocratic than grounded on political economy. Given the lack of studies, we preferred to start presenting the baseline stylized facts and try to provide a characterization of them.

Nevertheless, prosecution can be easily motivated because of the violence that is characteristic of this sector. One can add an externality in the utility of consumers without changing the fundamental properties. We omit it to avoid heavier notation

Remark 2. The use of Leontief production function also in the formal sector is motivated by empirical evidence of absence of short run substitutability between factors of production (Boldrin, 2009, stylized fact (9), p. 419). Needless to say, in the long run there is labor saving innovation in the formal sector, which generates interesting dynamics but which are not the focus of this analysis.

2.1 Solution

Proposition 1. *The equilibrium of the economy satisfying Assumption 1-4 is a n-tuple*

$$\{n,\ w,\ r,\ q_c,\ p_c,\ x,\ p_x,\ y,\ f\}$$

defined by the solution to the following system of equations.

$$f = \gamma[(w + r/\alpha)nq_c + (w + r/\beta)y - \tau] \tag{4}$$

$$p_x x = \gamma[(w + r/\alpha)nq_c + (w + r/\beta)y - \tau] \tag{5}$$

$$p_x x = p_c q_c n + e \tag{6}$$

$$f + p_c q_c n + e + \tau + nF = y + p_x x \tag{7}$$

$$\frac{nq_c}{\alpha} + \frac{y}{\beta} = \bar{K} \tag{8}$$

$$w + r/\beta = 1 \tag{9}$$

$$p_c - (w + r/\alpha) = \frac{F}{q_c} \tag{10}$$

$$p_c'(nq_c)q_c + p_c(nq_c) = w + r/\alpha \tag{11}$$

A couple of remarks are in order.

Remark 3. The eight equation for nine variables should not be thought to imply indeterminacy: given oligopolistic structure in the coca sector, the price is univocally determined once n and q_c are given.

Remark 4. Intentionally, we did not add an equation for the labour market. Given the Leontief production structure we can only by chance equalize the demand and supply of factors with positive prices. In practice we consider condition for equilibrium in the land market and set the price of labour according to free entry in the formal sector. Implicitly we are assuming that there is no excess labour supply or the rental price of labour cannot go below a certain threshold. Indeed we think that the latter is the most plausible explanation and that it captures part of the story, given the typical queuing of South American labour market and given the evidence that mobility is also determined by displacement. A simple extension is the use of efficiency wages in the formal sector, to weaken the assumption of equality of wages in the formal and informal sector. In this case a no shirking condition define the equilibrium wage in the former. Of course in equilibrium coca production should be positive because otherwise the no shirking condition cannot hold (Shapiro and Stiglitz, 1984) and everything else remains equal. Finally, linking the wage in the illegal sector to the fight against coca production does not have any impact, since in the informal sector workers are paid their reservation wage; this will only affect the relative price of wage and land, not the relative wage between formal and informal sector (which is determined by the No Shirking Condition).

2.2 Comparative Statics

Our main aim is to compute the effect of state policies to fight coca production.

Proposition 2. *The equilibrium of the economy characterized by Assumption 1-4 satisfies the property* $\frac{dQ_c}{d\tau} > 0$.

Our main result justifies formally the intuition provided in the Introduction. In particular we show in details in the Appendix that the law enforcement affects negatively the individual quantity but increases the number of producers. The total effect is positive, namely an increase in eradication increases the total quantity.

3 Empirical evidence

3.1 Econometric Strategy

We provide a synthetic account of the determinants of coca production and state enforcing through aerial spray/eradication (*aspersion*). Our baseline equation will be:

$$q_{it}^c = \alpha_0 + \alpha_1 a_{it} + X_{it}\beta + \epsilon_i + u_{it} \qquad (12)$$

where q_{it}^c is the coca production, a_{it} is aspersión, X is a vector of prices (of equilibrium) and the last is an error component term.

We use a proxy for the formal economy y that adjust to price movement in the system, to control for unobserved prices change, but still we are dealing with two major causality problem: (a) the individual time effect may be correlated with the covariates and (b) (the most important) aspersión is by definition endogenous.

We address (a) by a within group transformation that eliminates fixed effects. To solve (b) we follow a double strategy. On the one hand, to soften the problem we use the lag: it is well known that under predetermined regressors, WG has a bias that is $O(T^{-1})$ (Wooldridge, 2001, p. 302) and thus very little with a significant time dimension as in our case. On the other hand we estimate a simultaneous system of equation where aspersion is a function of coca production, crime rate and internal desplacement.

The exclusion restrictions for the *Aspersión* equation are motivated as follows. The arrival of refugees or the high crime rate ask for an intervention by politicians (for electoral reasons). The use of some of the resources for eradication can be a rapid response. However, displacement and crime rate are not systematically correlated with coca production since they are linked with the political conflict, and at most with the commercialization phase, which is not systematically located where the production takes place.

As a result we estimate ($\dot{r}$ indicate the within group transformation of variable r):

$$\begin{aligned} \dot{q^c_{it}} &= \alpha_0 + \alpha_1 \dot{a_{it-1}} + \alpha_2 \dot{y_{it}} + \dot{u_{it}} \\ \dot{a_{it}} &= \beta_0 + \beta_1 \dot{q^c_{it}} + \beta_2 \dot{z_{it}} + \beta_3 \dot{d_{it}} + \dot{v_{it}} \end{aligned} \tag{13}$$

where z indicate crime rate and d internal refugees. If (u_{it}, v_{it}) satisfies standard assumptions, we can estimate (13) by three stage least squares.[3]

3.2 The Data

Data comes from different sources. The unit of analysis is the administrative municipality, covering the period 2000-2008.

The main variables are: coca production, aerial spray/eradication (*aspersión*), displaced population, municipality budget, crime rate.

The source for the coca production is the SIMCI project by the United Nations, whose database includes geographical coordinates of all the coca plot above the threshold of point five acres (one fifth of an hectar). We then

[3]We know that 3SLS is identified under homoschedasticity, thus we run separate regressions testing for it and we cannot reject it at 5 per cent in any of the two, so we proceeded to use this technique. Some details can be found in the Appendix.

plot the administrative coordinates to delimit the territory and we calculate the area at municipality level. Through the same source we extract the coca disruption.

By displaced population we mean in particular the *received* population. The number of internally displaced population varies a lot according to the various sources. Normally NGOs provide figures largely above those of the government, which are released by the *Vicepresidencia de la República*. We took the latter as a conservative estimate.

The figures for the municipality budget are taken from the Colombian National Planning Authority (DNP, *Departamento Nacional de Planeación*). We use it as a proxy for GDP, since income estimates are not available at municipal level. Since Colombia is not a federalist state, we use the data on receipt and not on the expenditure, which may be affected by subsidies and transfer.

Finally, the crime rate is the number of homicides in a municipality per 100.000 inhabitants taken from the *Instituto Agustín Codazzy* con su proyecto de*Infraestructura Colombiana de Datos Espaciales* (SIGOT) from government source.

We take all variables in log form.

3.3 Results

In Table 1 we show the baseline regression. As a notational simplification we use the Spanish word aspersion to indicate aerial spray intervention and eradication to indicate the sum of aerial spray intervention and manual eradication.

As we can see, eradication is determined by coca area, and is positively correlated with crime and displacement. Our rationalization of these control variables is that the crime and the availability of cheap labor force are seen by the authority as factor fuelling production.

With regards to our main equation, we can see that the lag of aspersion is positively and significantly affecting coca area.

The coca area is also positively related with the level of formal production, capturing the availability of resources that can be used to finance the informal sector.

In Table 2 we run the regression using the sum of manual eradication and aerial spray intervention. The main results are confirmed.

In Appendix B we provide some descriptive statistics and a few diagnostic checks.

4 Concluding Remarks

In this paper, we use a collection of different data sources at the municipal level for Colombia between the years 2000 and 2008 to provide a descriptive and analytical account of the dynamics between coca leaf production and law enforcement. Moreover, we provide a general equilibrium treatment showing the linkages between the formal and the informal economy.

We show that due to technological rigidity, existence of market power, and external nature of drug demand, law enforcement is not effective in reducing coca leaf production. This is the main result we provide to policy makers and scholars.

We see this paper as a starting point of a new research line that tries to account for the effect of law enforcement on legal and ilegal markets, including violence.

A Proofs

A.1 Proof of Proposition 1

Proof. Equation (4) and (5) describe optimal consumption choice by the households, in standard Cobb Douglas setting, Equation (6) is the balance of payments equilibrium, (7) is the aggregate resource constraints, (8) is the land market equilibrium, (9) is the free entry condition in the formal economy, (10) is the zero net profit condition in the coca market (where oligopoly is preserved by the presence of a fixed cost) and finally (11) is the Cournot condition for profit maximising. Existence is guarantee by well behaviour of all the relevant objective function. QED □

A.2 Proof of Proposition 2

Proof. We reduce the system under Proposition 1 to the equations for n and q_c. Using (4), (5), (6), (7), and (9) by simple algebra we get:

$$\begin{gathered} \gamma[(w + r/\alpha)nq_c] + nF = (1-\gamma)(y-\tau) \\ \frac{nq_c}{\alpha} + \frac{y}{\beta} = \bar{K} \\ p_c - (w + r/\alpha) = \frac{F}{q_c} \\ p_c'(nq_c)q_c + p_c(nq_c) = w + r/\alpha \end{gathered} \tag{14}$$

solving from y from the first row and from $w+r/\alpha$ from the last two and replacing in the second and the last one, we get our function to do comparative statics

$$\Phi(n(\tau), q_c(\tau), \tau) = \begin{array}{c} \frac{nq_c}{\alpha} - \bar{K} + \left[\frac{\tau}{\beta} + \frac{\gamma}{\beta(1-\gamma)}\left(p_c - \frac{F}{q_c}\right) nq_c + \frac{nF}{\beta(1-\gamma)}\right] \\ -p_c'(nq_c)q_c - \frac{F}{q_c} \end{array} = 0 \tag{15}$$

We can now apply the Implicit Function Theorem

$$\begin{bmatrix} \frac{d\Phi_1}{dn} & \frac{d\Phi_1}{dq_c} \\ \frac{d\Phi_2}{dn} & \frac{d\Phi_2}{dq_c} \end{bmatrix} \begin{bmatrix} \frac{dn}{d\tau} \\ \frac{dq_c}{d\tau} \end{bmatrix} = \begin{bmatrix} -\frac{d\Phi_1}{d\tau} \\ -\frac{d\Phi_2}{d\tau} \end{bmatrix} \tag{16}$$

which can be written in compact form as

$$A \begin{bmatrix} \frac{dn}{d\tau} \\ \frac{dq_c}{d\tau} \end{bmatrix} = c \tag{17}$$

where a_{ij} and c_i represents the component of respectively the matrix A and the vector c.

We compute the following expressions:

$$a_{11} = \frac{q_c}{\alpha} + \frac{\gamma}{\beta(1-\gamma)}\left(p_c - \frac{F}{q_c}\right) q_c + \frac{F}{\beta(1-\gamma)} + \frac{\gamma q_c^2}{\beta(1-\gamma)} p_c'(nq_c) \tag{18}$$

$$a_{21} = -p''(nq_c)q_c^2 \tag{19}$$

$$a_{12} = \frac{n}{\alpha} + \frac{\gamma}{\beta(1-\gamma)}\left(p_c - \frac{F}{q_c}\right) n + \frac{\gamma nq_c}{\beta(1-\gamma)}\left(p_c'(nq_c)n + \frac{F}{q_c^2}\right) \tag{20}$$

$$a_{22} = -p''(nq_c)nq_c + \frac{F}{q_c^2} \tag{21}$$

$$c_1 = \frac{nq_c}{\alpha^2}\alpha'(\tau) - \frac{1}{\beta} \tag{22}$$

$$c_2 = 0 \tag{23}$$

Since $\frac{1}{\beta}$ is arbitrarily small, c_1 is positive.

Now let's start computing the discriminant of A; call it Δ:

$$\begin{aligned}\Delta = \tfrac{q_c}{\alpha}(-p_c''(nq_c)nq_c) + \tfrac{F}{\alpha q_c} + \tfrac{F}{\beta(1-\gamma)}(-p_c''(nq_c)nq_c) + \tfrac{F^2}{\beta(1-\gamma)q^2} \\ +\tfrac{\gamma}{\beta(1-\gamma)}q_c\left(p_c - \tfrac{F}{q_c} + p_c'(nq_c)q_c\right)(-p_c''(nq_c)nq_c) \\ +\tfrac{\gamma}{\beta(1-\gamma)}q_c\left(p_c - \tfrac{F}{q_c} + p_c'(nq_c)q_c\right)\tfrac{F}{q_c^2} \\ -\tfrac{q_c}{\alpha}(-p_c''(nq_c)nq_c) + \tfrac{\gamma n}{\beta(1-\gamma)}(p_c(nq_c) + p_c'(nq_c)nq_c)(-p_c''(nq_c)q_c^2)\end{aligned} \tag{24}$$

the first and the seventh terms canceled out. The only term that may be negative is the last one. Considering together the third, the fifth and the last term, we get:

$$\frac{(-p_c''(nq_c^2)nq_c^2)\gamma}{\beta(1-\gamma)}\left[\frac{F}{\gamma q_c} + \left(p_c - \frac{F}{q_c} + p_c'(nq_c)q_c\right) - p_c - p_c'(nq_c)nq_c\right] \tag{25}$$

which is positive since $\gamma < 1$. As a result $\Delta > 0$.

By Cramer's rule

$$\frac{dn}{d\tau} = \frac{c_1\ a_{22}}{\Delta} \tag{26}$$

$$\frac{dq_c}{d\tau} = \frac{-c_1\ a_{21}}{\Delta} \tag{27}$$

So the effect is positive on the number of producers and negative on the individual quantity. It is immediate to see from the above formulas that in case of linear demand or small concavity of the demand, the global effect is positive (namely quantity increases). However, we can now prove that it is the case also with constant elasticity of demand. Rewrite the system as a function of $(q_c,\ p_c)$.

$$\frac{Q_c(p_c)}{\alpha} - \bar{K} + \begin{bmatrix}\frac{\tau}{\beta} + \frac{\gamma}{\beta(1-\gamma)}\left(p_c - \frac{F}{q_c}\right)Q_c(p_c) + \frac{nF}{\beta(1-\gamma)} \\ -\frac{q_c}{Q_c'(p_c)} - \frac{F}{q_c}\end{bmatrix} = 0 \tag{28}$$

Applying again the Implicit Function Theorem and using the definition above:

$$\begin{bmatrix} a_{12} & \frac{Q_c'(p_c)}{\alpha} + \frac{\gamma}{\beta(1-\gamma)}[Q_c + Q_c'(p_c)p_c] \\ a_{22} & -\frac{q_c}{(Q_c'(p_c))^2 Q_c''(p_c)} \end{bmatrix}\begin{bmatrix}\frac{dq_c}{d\tau} \\ \frac{dp_c}{d\tau}\end{bmatrix} = \begin{bmatrix} c_1 \\ c_2 \end{bmatrix} \tag{29}$$

where $\frac{Q'_c(p_c)}{\alpha} + \frac{\gamma}{\beta(1-\gamma)}[Q_c + Q'_c(p_c)p_c]$ is negative because the terms into bracket is negative (the elasticity is greater than one by definition). By the same token $a_{12} > 0$. Call Δ' the determinant, $\Delta' > 0$ holds.

The comparative static result is then:

$$\frac{dp_c}{d\tau} = \frac{-c_1 \ a_{22}}{\Delta'} < 0 \tag{30}$$

which proves that Q_c increases in equilibrium. □

B Econometric Appendix

In this Appendix we provide some basics descriptive statistics and some diagnostics for the estimation. In particular, in Table 3 we provide mean and standard deviation for the main variables, decomposing the latter in the within and between component. from this Table we can see that the within component is important, thus by using a within transformation we are not losing too much information. Moreover, the average T is in general close to the maximum, so attrition can be neglected.

In Table 4 we show the regression for the individual equations using WG estimator. We report also the Breusch Pagan test for heteroschedasticity and the variance inflation factor to control the risk of multicollinearity. As we can see from the Table, the null hypothesis of homogenous variance cannot be rejected and the VIF is negligible.

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Variable	**(1)** **Log(Coca)**	**(2)** **Log(Aspersión)**
Log(Coca)		7.449
		[2.239]***
Log(Aspersión)$_{t-1}$	0.019	
	[0.010]*	
Log(Displacement)		0.176
		[0.104]*
Log(Crime)		0.225
		[0.116]*
Log(Y)	0.033	
	[0.007]***	
const	-0.001	0.206
	[0.026]	[0.175]
Obs	929	929
Chi-2	18.90	13.68
(p-value)	(0.00)	(0.00)
RMSE	1.03	1.03

Table 1: Three Stage Least Squares

Standard error in parenthesis. One, two and three stars represent respectively significativity at ten, five and one percent.

Variable	**(1) Log(Coca)**	**(2) Log(Aspersión)**
Log(Coca)		5.162
		[1.162]***
Log(Eradication)$_{t-1}$	0.040	
	[0.011]***	
Log(Displacement)		0.088
		[0.072]
Log(Crime)		0.135
		[0.070]*
Log(Y)	0.032	
	[0.008]***	
const	0.010	0.154
	[0.025]	[0.129]
Obs	996	996
Chi-2	24.36	21.93
(p-value)	(0.00)	(0.00)
RMSE	0.80	4.38

Table 2: Three Stage Least Squares

Standard error in parenthesis. One, two and three stars represent respectively significativity at ten, five and one percent.

Variable	**Mean**	**Standard Deviation**			**Average T**
		Overall	**Between**	**Within**	
Log(Coca)	4.32	1.96	1.92	0.82	5.34
Log(Aspersión)	2.15	3.15	2.26	2.06	6.76
Log(Eradication)	1.68	2.58	2.03	1.58	8.61
Log(Displacement)	3.93	1.81	1.54	0.97	6.70
Log(Crime)	2.94	1.70	1.23	1.17	9
Log(Y)	8.39	1.61	1.04	1.22	6.97

Table 3: Descriptive statistics for the main variables.

Variable	**(1) Log(Coca)**	**(2) Log(Aspersión)**
Log(Coca)		0.332
		[0.075]***
Log(Aspersión)$_{t-1}$	0.030	
	[0.010]***	
Log(Displacement)		0.190
		[0.057]***
Log(Crime)		0.227
		[0.060]***
Log(Y)	0.007	
	[0.015]	
Obs	1056	1208
Breusch-Pagan	0.13	2.99
(p-value)	(0.72)	(0.08)
Vif	1.03	1.03

Table 4: WG Estimation and diagnostic test.

Separate regression. Standard error in parenthesis. One, two and three stars represent respectively significativity at ten, five and one percent.