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THE WAR AGAINST DRUG PRODUCERS

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ABSTRACT

This paper develops a model of a war against the producers of illegal hard drugs. This war occurs on two fronts. First, to prevent the cultivation of crops that are the raw material for producing drugs the state engages the drug producers in conflict over the control of arable land. Second, to impede further the production and exportation of drugs the state attempts to eradicate crops and to interdict drug shipments. The model also includes an interested outsider who uses both a stick and a carrot to strengthen the resolve of the state in its war against drug producers. The results of the calibration of the model yield an estimate that from 2001 through 2003 subsidies from the United States to the Colombian armed forces under Plan Colombia caused a decrease in the exportation of drugs from Colombia to about 44 percent of what exportation was before Plan Colombia was implemented. The results of the calibration of the model also suggests that a more efficient allocation of the about $2 billion that the United States spent on Plan Colombia through 2003 would have involved larger subsidies to the conflict over control of arable land and smaller subsidies to eradication and interdiction efforts.

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1. Introduction

In many countries the state's control over much of the land within its recognized borders is tenuous and depends on the state's willingness to use armed force against challengers to its authority. This problem is especially acute in countries like Colombia in which the most profitable use of much arable land is the cultivation of crops that are the raw material for the production of illegal hard drugs — specifically, coca, which is the raw material for producing cocaine, and opium poppies, which are the raw material for producing heroin. The production of cocaine from coca base and the production of heroin from opium-poppy juice are relatively simple processes, requiring only the combining of the cultivated raw materials with a few chemicals in small scale local workshops.

Because almost all of the hard drugs produced in countries like Colombia are exported, the state typically faces international pressure — in the case of Colombia mainly from the United States — to make war against the organizations that organize and direct the production and exportation of hard drugs. These organizations are the residual claimants to the net revenues from this trade. We call these organizations for short the "drug producers".

This paper develops a model of a war against the drug producers. The war occurs on two fronts. First, to prevent the cultivation of coca and opium poppies the state engages the drug producers in conflict over the control of arable land. Second, to impede further the production and exportation of drugs the state attempts to eradicate crops of coca and opium poppies, mainly by aerial spraying of herbicides on arable land that the drug producers control, and to interdict shipments of drugs, mainly by raiding the workshops where drugs are produced and stored, by destroying landing strips from which drugs are exported, and by attacking airplanes that are transporting drugs.

Importantly, the model allows for an interested outsider who uses both a stick and a carrot to strengthen the resolve of the state in its war against the drug producers. The model shows how the efforts and successes of the state on the two fronts in this war depend on this stick and carrot as well as on the technology of conflict over land and on the technologies of eradication and interdiction.

We also calibrate the model for the well documented case of Colombia. In this calibration we take the state to be the Colombian government, the drug producers to be the two outlaw groups, Fuerzas Armadas Revolucionarias de Colombia (FARC) and the Autodefenses Unidas de Colombia (AUC),[1] and the interested outsider to be the government of the United States. Our calibration yields an estimate that from 2001 through 2003 subsidies from the United States to the Colombian armed forces under Plan Colombia caused a decrease in the exportation of drugs from Colombia to about 44 percent of what exportation was before Plan Colombia was implemented.[2,3] Our calibration also yields the estimate that the marginal cost to the United States of decreasing the exportation of drugs from

[1] According to many observers — see, for example, Rabasa and Chalk (2001), Echeverry (2004), Thoumi (2003), and UNODC (2003) — since the demise of the Medellín and Cali cartels in the 1990s, FARC and AUC, their historical origins as "leftist" guerrillas and "rightist" paramiltaries notwithstanding, have become the organizations that organize and direct most of the Colombian production and exportation of hard drugs, mainly cocaine and a relatively small amount of heroin. Bottía (2003) and Diaz and Sanchez (2004) use data from municipalities to confirm a high correlation between drug production and the control of arable land by the FARC and the AUC. Rangel Suárez (2000) tells us that at one time FARC only taxed and provided security for the various stages of drug production and exportation — the cultivation of coca, the manufacturing of cocaine from coca base, and the trafficking of cocaine — but that subsequently FARC began itself, as it does now, to organize and to direct the production and exportation of drugs. Rangel Suárez also discusses the other criminal activities, such as extortion and kidnaping, in which the Colombian outlaw groups engage. Our model abstracts from these activities. Naranjo (2003) analyzes a model in which FARC, as in former times, only taxes and provides security for production and exportation. Also, Naranjo focuses on eradication and interdiction, but he abstracts from conflict over control of arable land.

[2] Although appropriations for Plan Colombia began in 2000, we focus on 2001 through 2003 because Plan Colombia's gestation period seems to have lasted until the end of 2000. For example, a crucial component of subsidies to the Colombian armed forces has been the provision of helicopters. According to the General Accounting Office (GAO, 2003), these helicopters flew their initial missions only in December 2000.

[3] As Colombia is not the only source of importation of hard drugs into the United States, a relatively large decrease in exportation from Colombia does not necessarily imply that total importation of hard drugs decreased by a comparable amount.

Colombia was much smaller for subsidies for the conflict over control of arable land than for subsidies for eradication and interdiction efforts. This estimate suggests that a more efficient allocation of subsidies to the Colombian armed forces, on which the United States spent about $2 billion through 2003, would have involved larger subsidies for the conflict over control of arable land and smaller subsidies for eradication and interdiction efforts.[4]

2. The Model

2.1. Conflict over Arable Land

Assume that there are n drug producers, $n \in \{1, 2, 3, ...\}$, who, for simplicity, are identical in all relevant respects, and let area i, $i = 1, 2, ..., n$, denote the arable land that the state contests with the i^{th} drug producer. Also, assume that area i and area j, $j = 1, 2, ...n$, $j \neq i$, comprise disjoint sets, each consisting of L/n hectares. Hence, the total amount of arable land that the state contests with the drug producers is L hectares.

Let the outcome of the conflict over arable land between the state and the i^{th} drug producer be that, although the state can have more or less success over time, on average the state controls the fraction P_i of area i. Assume that the

[4]Despite some minor accounting discrepancies several sources agree that through 2003 the United States spent about $2 billion on Plan Colombia. See CIP (2004), GAO (2003), and Wood (2003). Initially subsidies to the Colombian armed forces were limited to eradication and interdiction efforts, but subsequently subsidies were made available for the conflict over control of arable land. "In response to increased violence in Colombia during early 2002 and the recognition that the insurgents and illicit drug activities are inextricably linked, the Congress provided 'expanded authority' for the use of the U.S. assistance to Colombia. This authority enables the government of Colombia to use the U.S.-trained and -equipped counternarcotics brigade, the U.S.-provided helicopters, and other U.S.-provided counternarcotics assistance to fight groups designated as terrorist organizations as well as to fight drug trafficking." (GAO, 2003, p. 10)

technology of conflict over arable land is such that P_i is determined, according to a standard contest-success function, by

$$P_i = \begin{cases} \dfrac{Z_i}{Z_i + \Phi X_i} & X_i > 0 \\ 1 & X_i = 0, \end{cases} \tag{2.1}$$

where Z_i and X_i denote the resources, valued in dollars, that the state and the i^{th} drug producer, respectively, allocate annually to their conflict over arable land.

The positive parameter, Φ, in equation 2.1 measures the relative effectiveness of the resources that a drug producer allocates to this armed conflict. Although the armed forces of the state have the advantage of better training and more advanced weaponry, the drug producers have the advantage of a cheaper pool of labor from which to recruit their fighters and the use of guerrilla tactics. If these advantages are approximately offsetting, then Φ is approximately equal to one. According to equation (1), if both Z_i and X_i are positive, then the state controls some, but not all of area i, with P_i being an increasing concave function of the ratio, $Z_i/\Phi X_i$.

The n drug producers also contest with each other the control of the arable land, consisting of $\sum_i (1-P_i)L_i$ hectares, that the state does not control.[5] Let the outcome of the conflict between the drug producers be that, although the i^{th} drug producer can have more or less success over time, on average the i^{th} drug producer controls the fraction p_i of $\sum_i (1-P_i)L_i$. Assume that the technology of conflict between the drug producers is such that p_i is determined, again according to a standard contest-success function, by

[5] As an example, the publication *Revista Cambio,* "Tiempo de muerte y de cosecha", 8/8/2004, reports that the FARC and the AUC are engaged in an armed conflict for control of land in the region of Catatumbo (northeast of Bogotá), where approximately 30,000 hectares of coca are planted. A major Colombian newspaper recently reported violent confrontations between FARC and AUC in the Sierra Nevada for the control of workshops where cocaine is produced and stored (see *El Tiempo*, 18/01/05).

$$p_i = \begin{cases} \dfrac{y_i}{y_i + \sum_{j \neq i} y_j} & y_i > 0 \\ 0 & y_i = 0, \end{cases} \tag{2.2}$$

where y_i and y_j denote the resources, valued in dollars, that the i^{th} drug producer and the j^{th} drug producer, respectively, allocate to the conflict between the drug producers.

Equation 2.2 assumes that the resources that the n drug producers allocate to conflict among themselves are equally effective. Hence, p_i is an increasing concave function of the ratio, $y_i / \sum_{j \neq i} y_j$. If both $\sum_i (1 - P_i) L_i$ and y_i are positive, then the i^{th} drug producer controls a positive amount of arable land.

2.2. Eradication and Interdiction

Let the outcome of the state's eradication and interdiction efforts be that, although these efforts can be more or less successful over time, on average the i^{th} drug producer successfully exports the fraction q_i of the drugs that potentially could be produced from crops grown on the land that it controls. Assume that the technologies of eradication and interdiction are such that q_i is determined, again according to a standard contest-success function, by

$$q_i = \begin{cases} \dfrac{\phi x_i}{\phi x_i + z_i} & z_i > 0 \\ 1 & z_i = 0, \end{cases} \tag{2.3}$$

where z_i denotes the value in dollars of the resources that the state allocates annually to its eradication and interdiction efforts against the i^{th} drug producer, and where x_i denotes the value in dollars of the resources that the i^{th} drug producer allocates annually to thwarting the state's eradication and interdiction efforts.

The positive parameter, ϕ, in equation 2.3 measures the effectiveness of the resources that a drug producer allocates to preventing eradication and interdiction relative to the resources that the state allocates to its eradication and interdiction efforts. As eradication and interdiction seem to be easier to avoid than to accomplish, ϕ is probably larger than one. According to equation 2.3, if both z_i and x_i are positive, then the state prevents the exportation of some, but not all, of the drugs that the i^{th} drug producer potentially could produce from crops grown on the land that it controls, with q_i being a decreasing convex function of the ratio, $z_i/\phi x_i$.

2.3. The Drug Producers

The i^{th} drug producer's average annual net revenue, denoted by R_i, is given by

$$R_i \;=\; q_i \; c \; p_i \; \sum_i (1 - P_i) L/n \;-\; (X_i + y_i + x_i), \tag{2.4}$$

where c denotes the potential annual profits in dollars from each hectare of contested land used to cultivate crops from which hard drugs are produced. According to equation 2.4 the i^{th} drug producer's average annual gross revenue is the product of the amount of land the i^{th} drug producer controls, $p_i \sum_i (1-P_i) L/n$, potential profits per hectare, c, and the fraction of its potential production that the i^{th} drug producer successfully exports, q_i. Equation 2.4 also assumes that the total value of the resources that the i^{th} drug producer allocates annually to its conflicts with the state and with the other drug producers equals the sum, $X_i + y_i + x_i$. This assumption abstracts from complementarities in the technology of conflict, such as might be associated with centralized command and control.

The i^{th} drug producer chooses X_i, y_i, and x_i to maximize R_i, taking c, Z_i, y_j, P_j, and z_i as given. Accordingly, in the conflict over arable land between the i^{th} drug producer and the state, the i^{th} drug producer's choice of X_i, assuming an interior solution, satisfies the following first-order condition:

$$\frac{\partial R_i}{\partial X_i} = -q_i \; c \; p_i \; \frac{\partial P_i}{\partial X_i} \; L/n \;-\; 1 \;=\; 0.$$

Using equation 2.1 to calculate $\partial P_i / \partial X_i$, this first order condition becomes

$$(\Phi X_i + Z_i)^2 \;=\; \Phi \; Z_i \; q_i \; c \; p_i \; L/n. \tag{2.5}$$

Turning to the conflict among the drug producers over the arable land that the state does not control, the i^{th} drug producer's choice of y_i, assuming an interior solution, satisfies the following first-order condition:

$$\frac{\partial R_i}{\partial y_i} \;=\; q_i \; c \; \frac{\partial p_i}{\partial y_i} \; \sum_i (1 - P_i) L/n \;-\; 1 \;=\; 0.$$

Using equation 2.2 to calculate $\partial p_i / \partial y_i$, this first-order condition becomes

$$(y_i + \sum_{j \neq i} y_j)^2 \;=\; q_i \; c \; \sum_{j \neq i} y_j \; \sum_i (1 - P_i) L/n. \tag{2.6}$$

Combining this first-order condition with the analogous first-order condition for the choice of y_j, we obtain

$$y_i \;=\; y_j \;= q_i \; c \; \sum_i (1 - P_i) L/4n.$$

Substituting $y_i = y_j$ into equation 2.2 we find that p_i equals $1/n$. Unsurprisingly, given that the resources that the two drug producers allocate to conflict between them are equally effective, each drug producer gains control of an equal amount of the contested land that the state does not control.

Finally, analyzing the drug producers' allocation of resources to thwarting the state's efforts at eradication and interdiction, the i^{th} drug producer's choice of x_i, again assuming an interior solution, satisfies the following first-order condition:

$$\frac{\partial R_i}{\partial x_i} \;=\; \frac{\partial q_i}{\partial x_i}\, c\, p_i\, \sum_i (1-P_i)L/n \;-\; 1 \;=\; 0.$$

Using equation 2.3 to calculate $\partial q_i/\partial x_i$, this first-order condition becomes

$$(\phi x_i + z_i)^2 \;=\; \phi\, z_i\, c\, p_i\, \sum_i (1-P_i)L/n. \tag{2.7}$$

2.4. The State and the Interested Outsider

The interested outsider uses both a stick and a carrot in an attempt to strengthen the resolve of the state in its war against the drug producers. The stick is the threat that the interested outsider will label the state a "narco-state," and as a result the state will be ostracized by the international community.

Assume that from the perspective of the state the decision of the interested outsider to apply the label "narco-state" includes a stochastic element. To allow for this stochastic element, let λ denote the number of kilograms of drugs that without eradication could be produced annually from the crops harvested on a hectare of land, and let D denote the total amount of hard drugs exported annually, measured in kilograms, where

$$D \;= \lambda \sum_i q_i (1-P_i)L/n. \tag{2.8}$$

Assume that the state perceives the probability of its being labeled a narco-state to be equal to the ratio, $D/\lambda L$, where λL is the amount of drugs that potentially could be produced and exported annually. In calibrating the model for the case of Colombia we assume, as seems historically accurate, that this perception existed before the implementation of Plan Colombia and was not affected by Plan Colombia.

Let h denote the annual cost in dollars that the state anticipates would result from its being labeled as a narco-state. Thus, the expected annual cost associated with the possibility of being labeled as a narco-state equals the product of h and the probability, $D/\lambda L$.

The carrot used by the interested outsider is a subsidy to the armed forces of the state. This subsidy consists of a fraction, $1-\Omega$, of the resources that the state allocates to its conflicts with the drug producers over control of arable land and a fraction, $1-\omega$, of the resources that the state allocates to its eradication and interdiction efforts.

Given this stick and carrot, the state's expected annual net payoff from its war against the drug producers, denoted by S, is given by

$$S \;=\; b\,\sum_i P_i L/n \;-\; hD/\lambda L \;-\; \Omega\,\sum_i Z_i \;-\; \omega\,\sum_i z_i, \qquad (2.9)$$

where b denotes the annual profit in dollars from each hectare of contested land that the state controls and uses to cultivate the most profitable benign crop. Given equation 2.9, the term, $hD/\lambda L$, which is the expected annual cost associated with the possibility of being labeled as a narco-state, equals $h\,\sum_i q_i(1-P_i)/n$.

Equation 2.9 assumes that the total value of the resources that the state allocates annually to its war against the drug producers over arable land is $\sum_i Z_i$ and that the total value of the resources that the state allocates annually to its eradication and interdiction efforts is $\sum_i z_i$. These assumptions accord with the assumption that area i and area j comprise disjoint sets and also abstract from complementarities in the technology of conflict. Equation 2.9 also assumes, for simplicity, that the state takes no account of the havoc that results from its war against the drug producers.

The state chooses Z_i and z_i to maximize S, taking b, X_i, x_i, h, Ω, and ω as given. Accordingly, the state's choice of Z_i, again assuming an interior solution, satisfies the following first-order condition:

$$\frac{dS}{dZ_i} = \frac{1}{n}(bL + hq_i)\,\frac{\partial P_i}{\partial Z_i} \;-\; \Omega \;=\; 0.$$

Using equation 2.1 to calculate $\partial P_i / \partial Z_i$, this first order condition becomes

$$(\Phi X_i + Z_i)^2 \;=\; (bL + hq_i)\ \Phi\ X_i\ /n\ \Omega. \tag{2.10}$$

Finally, turning to the state's efforts at eradication and interdiction, the state's choice of z_i, again assuming an interior solution, satisfies the following first-order condition:

$$\frac{\partial S}{\partial z_i} \;=\; -\frac{1}{n}\ h\ \frac{\partial q_i}{\partial z_i}\ (1 - P_i) \;-\; \omega \;=\; 0.$$

Using equation 2.3 to calculate $\partial q_i / \partial z_i$, this first-order condition becomes

$$(\phi x_i + z_i)^2 \;=\; h\ \phi\ x_i\ (1 - P_i)\ /n\ \omega. \tag{2.11}$$

2.5. The Outcome of the War Against Drug Producers

Given that the n drug producers are identical, an equilibrium exists in which the vector $\{x_i, z_i, X_i, Z_i\}$ equals $\{x, z, X, Z\}$ for all i and, accordingly, in which the vector $\{q_i, P_i\}$ equals $\{q, P\}$ for all i. Using these equalities, recalling that p_i equals $1/n$, and solving equations 2.5 and 2.10 and equations 2.7 and 2.11 we derive the equilibrium values for the allocation of resources to the war against drug producers:[6]

$$X \;=\; \frac{\Phi\ \Omega\ hq}{n\ \left(\Phi\ \Omega + n\dfrac{h}{cL}\right)^2}, \tag{2.12}$$

[6] For simplicity the following solutions assume that b equals zero. As long as b is small relative to the product of q and c, this simplification is innocuous. See the appendix for amended solutions that allow for a positive value of b.

$$Z = \frac{\Phi \dfrac{h^2}{cL} q}{\left(\Phi \, \Omega + n \dfrac{h}{cL}\right)^2}, \tag{2.13}$$

$$x = \frac{\phi \, \omega \, h \, (1 - P)}{n \left(\phi \, \omega + \dfrac{h}{cL}\right)^2}, \tag{2.14}$$

$$z = \frac{\phi \dfrac{h^2}{cL} (1 - P)}{n \left(\phi \, \omega + \dfrac{h}{cL}\right)^2}. \tag{2.15}$$

These solutions for resource allocations imply the equilibrium outcomes on the two fronts of the war against drug producers. Substituting equations 2.12 and 2.13 into equation 2.1 we obtain

$$1 - P = \frac{\Phi \, \Omega}{\Phi \, \Omega + n \dfrac{h}{cL}}. \tag{2.16}$$

According to equation 2.16 the fraction of the contested land that the drug producers control is an increasing function of Φ and Ω, an unsurprising result, and is also a decreasing function of n and of the ratio of h to cL. To understand the effect of n, recall that, because of the conflict over arable land among the drug producers, each drug producer retains control of only the fraction, $1/n$, of the land that the state does not control. Accordingly, the larger is n the smaller is the payoff to each drug lord from the resources allocated to conflict with the state over arable land and, hence, the smaller is the amount of resources that each drug producer allocates to this conflict.

Substituting equations 2.14 and 2.15 into equation 2.3 we obtain

$$q = \frac{\phi \, \omega}{\phi \, \omega + \dfrac{h}{cL}}. \tag{2.17}$$

According to equation 2.17 the fraction of potential drug production that the drug producers successfully export is an increasing function of ϕ and ω, another unsurprising result, and is a decreasing function of the ratio of h to cL.

Finally, from equation 2.8 we have

$$D = \lambda \; q \; (1 - P) \; L. \tag{2.18}$$

From equations 2.16, 2.17, and 2.18, we see that the interested outsider can effect a decrease in D, the annual exportation of drugs, either by decreasing Ω, and hence decreasing $1 - P$, or by decreasing ω, and hence decreasing q.

2.6. The Cost for the Interested Outsider

Let M denote the dollar amount of annual subsidies from the interested outsider to the armed forces of the state, where

$$M \; = n \; [(1 - \Omega) \; Z \; + \; (1 - \omega) \; z] \, . \tag{2.19}$$

From equation 2.19 the marginal cost for the interested outsider of decreasing Ω is given by $\partial M / \partial \Omega$, where

$$\frac{\partial M}{\partial \Omega} \; = \; n \; \left[-Z \; + \; (1 - \Omega) \; \frac{\partial Z}{\partial \Omega} + (1 - \omega) \frac{\partial z}{\partial (1 - P)} \frac{\partial (1 - P)}{\partial \Omega} \right] \; . \tag{2.20}$$

From equation 2.18 the marginal effect of decreasing Ω on the exportation of drugs is given by $\partial D / \partial \Omega$, where

$$\frac{\partial D}{\partial \Omega} \; = \; \lambda \; q \; \frac{\partial (1 - P)}{\partial \Omega} \; L. \tag{2.21}$$

Let $(\partial M/\partial D)_\Omega$ denote the marginal cost, measured in dollars per kilogram, for the interested outsider of decreasing the exportation of drugs by decreasing Ω. From equations 2.20 and 2.21, using equation 2.13 to calculate $\partial Z/\partial\Omega$, equation 2.16 to calculate $\partial(1-P)/\partial\Omega$, and equation 2.15 to calculate $\dfrac{\partial z}{\partial(1-P)}$, we have

$$\left(\frac{\partial M}{\partial D}\right)_\Omega = -\frac{h}{\lambda L}\left[1 + (1-\Omega)\frac{2\,\Phi}{\Phi\,\Omega + n\dfrac{h}{cL}} - (1-\omega)\frac{\dfrac{h}{cL}}{\omega\left(\phi\omega + \dfrac{h}{cL}\right)}\right] \tag{2.22}$$

Turning to subsidies to eradication and interdiction, from equation 2.19 the marginal cost for the interested outsider of decreasing ω is given by $\partial M/\partial\omega$, where

$$\frac{\partial M}{\partial \omega} = n\left[(1-\Omega)\frac{\partial Z}{\partial q}\frac{\partial q}{\partial \omega} - z + (1-\omega)\frac{\partial z}{\partial \omega}\right]. \tag{2.23}$$

From equation 2.18 the marginal effect of decreasing ω on the exportation of drugs is given by $\partial D/\partial\omega$, where

$$\frac{\partial D}{\partial \omega} = \lambda\,\frac{\partial q}{\partial \omega}\,(1-P)\,L. \tag{2.24}$$

Let $(\partial M/\partial D)_\omega$ denote the marginal cost, measured in dollars per kilogram, for the interested outsider of decreasing the exportation of drugs by decreasing ω. From equations 2.23 and 2.24, using equation 2.13 to calculate $\partial Z/\partial q$, equation 2.3 to calculate $\partial q/d\omega$, and equation 2.15 to calculate $\partial z/\partial\omega$, we have

$$\left(\frac{\partial M}{\partial D}\right)_\omega = -\frac{h}{\lambda L}\left[-(1-\Omega)\frac{n\dfrac{h}{cL}}{\Omega\left(\Phi\Omega + n\dfrac{h}{cL}\right)} + 1 + (1-\omega)\,\frac{2\,\phi}{\left(\phi\,\omega + \dfrac{h}{cL}\right)}\right]. \tag{2.25}$$

Under an efficient allocation of subsidies $(\partial M/\partial D)_{\Omega}$, as given by equation 2.22, and $(\partial M/\partial D)_{\omega}$, as given by equation 2.25, would be equal.

3. Calibration of the Model

3.1. Plan Colombia: How Successful?

To calibrate the model for the case of Colombia we begin with the following facts about Colombia provided by the United Nations Office for Drug Control (UNODC, 2004):

i. Opium poppies were cultivated only on a relatively small amount of land. Accordingly, we focus on the production and exportation of cocaine. The amount of land on which coca was cultivated, $(1-P)L$, decreased from about 163,300 hectares in the year 2000, before the implementation of Plan Colombia, to about 144,000 hectares in 2001, 102,000 hectares in 2002, and 86,000 hectares in 2003, for an average of about 110,900 hectares after the implementation of Plan Colombia. Thus, on average Plan Colombia has decreased the amount of land that the drug producers have controlled to about 0.68 of what it was before the implementation of Plan Colombia

ii. Without eradication on average the coca harvested on a hectare of land yields annually about 4.7 kilograms of coca base, and about one kilogram of cocaine can be produced from a kilogram of coca base. Hence, λ equals about 4.7 kilograms.

iii. During years 2000 through 2003 the drug producers paid the farmers who cultivate coca on average \$830 for a kilogram of coca base. Hence, for the product of each hectare of land on which coca is cultivated, the drug producers paid on average the product of 4.7 and \$830 per year, which is about \$3900.[7]

[7] Although during some months the drug producers paid as little as \$750 per kilogram of coca base and as much as \$965 per kilogram per kilogram of coca base, the amounts paid for coca base exhibit no trend.

Also, in calibrating the model we use the fact that for 2001 through 2003, M, average annual spending by the United States on subsidies to the Colombian armed forces under Plan Colombia was about \$2/3 billion, and we take n, the number of drug producers, to be two — FARC and AUC.

In order to reconcile these facts with our model we begin by assuming (in the median scenario of the calibrations, columns 1 and 2 of Table 1) that c, potential annual profits from each hectare of land used to cultivate coca, equals twice the average cost of production of a kilogram of cocaine. Assuming that the cost of converting a kilogram of coca base into cocaine (which includes a few chemicals, microwave ovens and the costs of operating the workshop) is about \$1000, then the total cost of producing a kilogram of cocaine is about \$5000. Hence, c equals about two times this cost, or about \$10.000. This assumption implies that in pricing cocaine the drug producers apply a mark-up of 200 per cent to the cost of producing one kilogram of cocaine.[8] Importantly, our main conclusions are robust to large variations in c. In Table 1 we also report the implications of assuming that c equals \$8000 (columns 7 and 8), and \$12000 (columns 9 and 10).

With regard to the technology of conflict over land and the technologies of eradication and interdiction, we begin by assuming in the median scenario that Φ, the relative effectiveness of the resources that the drug producers allocate to conflict with the state over control of land, equals one, and that ϕ, the relative effectiveness of the resources that the drug producers allocate to preventing eradication and interdiction, equals two. Our main conclusions are also robust to large variations in ϕ. In Table 1 we report the implications of assuming that ϕ

[8] Echeverry (2004) presents two estimates of the net income derived from the production of cocaine in Colombia during 2001 and 2002. These estimates are \$1.9 billion (2.3% of Colombian GDP in 2000) and \$3.3 billion (3.9% of GDP). Using these two estimates we calculate the net income of cocaine production (without interdiction costs) per hectare of land cultivated with coca to be between \$11000 and \$15000. These two numbers, although higher than the number we use in the median scenario, are not too far from our assumption about c, especially given the fact that his estimates are for the whole chain of cocaine exportation in Colombia.

equals 1.5 (columns 3 and 4), and 2.5 (columns 5 and 6).

In the median scenario of the calibrations we will use a value of h, the annual cost in dollars that the Colombian state anticipates would result from its being labeled as a narco-state, to be \$4 billion dollars (approximately 4.6% of GDP). In Table 1 we also report the implications of assuming that h equals \$2 billion (columns 11 and 12), and \$6 billion (columns 13 and 14).

Before the implementation of Plan Colombia, $(1-P)\ L$ was equal to $163,300$ hectares. With Ω and ω equal to one (before the implementation of Plan Colombia), n equal to two, and taking a value of h equal to \$4 billion, using equation 2.16 to solve for the equality $(1-P)\ L = 163,300$ implies that L, the amount of arable land that the state contests with the drug producers, has been about 450 thousand hectares. Table 1 reports the implied values of L if we assume different values of c (columns 7 through 10) and h (columns 11 through 14). Hence, before the implementation of Plan Colombia, equation 2.16 implies that $1-P$ was equal to 0.36 in the median scenario. In addition, with ϕ equal to two, equation 2.17 implies that before implementation q was about 0.69 in the median scenario.

Given that the ratio of $1-P$ after implementation to $1-P$ before implementation has been about 0.68, and given that before implementation Ω was equal to one, from equation 2.16 we have

$$\frac{\Phi\ \Omega}{\Phi\ \Omega + n\dfrac{h}{cL}} = 0.68\ \frac{\Phi}{\Phi + n\dfrac{h}{cL}}. \tag{3.1}$$

With Φ equal to one, n equal to two, h equal to \$4 billion dollars, and c equal to \$10000, equation 3.1 implies that after implementation Ω has been about 0.57. Table 1 reports the implied values of Ω for variations in c and h. Moreover, with the parameter values of the median scenario, equation 2.16 implies that after implementation $1-P$ has decreased from 0.36 to about 0.25.

The results of the calibration of the model in the median scenario imply that the probability of being labeled a narco-state perceived by the Colombian government decreased from 25% before the implementation of Plan Colombia to 11% after its implementation.

Substituting equations 2.13, 2.15, 2.16, and 2.17 into equation 2.19, and setting M equal to \$2/3 billion, under the parameter values of the median scenario we calculate that after implementation ω has equaled about 0.37. In addition, with ϕ equal to two and ω equal to about 0.37, equation 2.17 implies that after implementation q has decreased from 0.69 to about 0.45, or to about 65 per cent of what is was before implementation.

Most importantly, given that λ equals about 4.7 and L equals about 450 thousand hectares in the median scenario, and given that before implementation $1-P$ equaled 0.36 and q equaled 0.69, equation 2.18 implies that annual exportation of drugs, D, was about 530 thousand kilograms before the implementation of Plan Colombia. In contrast, given that after implementation $1-P$ has equaled about 0.25 and q has equaled about 0.45, equation 2.18 implies that D has averaged about 237 thousand kilograms after implementation. Thus, the calibration of the model in the median scenario implies that the combined effect of the successes of the Colombian armed forces on these two fronts of the war against drug producers has been to decrease exportation of cocaine from Colombia to about 44 per cent of what it was before the implementation of Plan Colombia.

Finally, under the parameter values of the median scenario, we estimate that total expenditure by the Colombian government in the two fronts of the war against drug producers has been about \$580 million dollars (0.7 per cent of Colombian GDP).[9]

Table 1 presents all the results described so far using different values of $\phi, c,$ and h for the calibration of the model.

[9] Actual total defense expenditure in Colombia (includes National Police, the Defence Ministry, and other entities) has been, on average, 2.7 per cent of GDP in the last few years. The results of the calibration of the model imply that the Colombian state has spent 26% of its total defense budget in the two fronts of the war against the producers of illegal hard drugs.

3.2. Plan Colombia: How Efficient?

Given the values of λ and n, our assumptions in the median scenario that Φ equals one and that ϕ equals two, h equals \$4 billion, and our estimates of Ω, ω, and L, we calculate (using equation 2.22) that after the implementation of Plan Colombia $(\partial M/\partial D)_{\Omega}$ has equaled about \$800, and we calculate (using equation 2.25) that after the implementation of Plan Colombia $(\partial M/\partial D)_{\omega}$ has equaled about \$3770. In other words, we estimate that the marginal cost to the United States of decreasing the exportation of drugs from Colombia by subsidizing the Colombian armed forces in their conflict with the drug producers over the control of arable land has been about \$800 per kilogram, whereas the marginal cost to the United States of decreasing the exportation of drugs from Colombia by subsidizing the Colombian armed forces in their eradication and interdiction efforts has been about \$3770 per kilogram.[10]

These estimates suggest that the allocation of subsidies to the Colombian armed forces under Plan Colombia has not been efficient. The marginal cost of decreasing the exportation of drugs by subsidizing the Colombian armed forces in their eradication and interdiction efforts appears to have been, on average, almost five times as large as the marginal cost of decreasing the exportation of drugs by subsidizing the Colombian armed forces in their conflict with the drug producers over arable land. Note from Table 1 that in some of the cases (depending on the different assumptions on the parameter values) the marginal cost of reducing the exportation of cocaine by subsidizing the Colombian armed forces in their conflict with the drug producers over arable land is negative. In other words, under some parameter values, there is a net marginal benefit to the US of increasing the subsidies to the armed forces in their conflict with the drug producers over the control of arable land. Although this result seems paradoxical, a marginal increase in the subsidy from the interested outsider to the conflict over arable land causes $(1-P)$ to decrease, and as a result the optimal amount of resources spent

[10] As a point of reference, according to DEA (2003), the average price of a kilogram of cocaine in the U.S. in 2001 ranged between \$15000 (in Los Angeles) and \$25000 (in New York).

by the Colombian government in eradication and interdiction, z, also decreases (third term in the bracketed expression in equation 2.20). For a given subsidy to eradication and interdiction efforts, $1-\omega$, a decrease in z decreases the total costs to the interested outsider of subsidizing the war against the drug producers.

As we have pointed out, under an efficient allocation of subsidies $(\partial M/\partial D)_\Omega$ and $(\partial M/\partial D)_\omega$ would be equal. Equating expressions 2.22 and 2.25, an efficient allocation of subsidies would require that Ω and ω satisfy the relation

$$(1-\Omega)\frac{2\Phi\Omega+n\dfrac{h}{cL}}{\Omega\left(\Phi\Omega+n\dfrac{h}{cL}\right)}=(1-\omega)\frac{2\phi\omega+\dfrac{h}{cL}}{\omega\left(\phi\,\omega+\dfrac{h}{cL}\right)}. \tag{3.2}$$

The calibration of Ω and ω involves the solution of equation 3.2 together with equation 2.19 (after replacing for Z and z from equations 2.13 and 2.15 respectively), for given values of $c, \Phi, \phi, h, L, M,$ and n.

Using the assumptions in the median scenario that Φ equals 1, ϕ equals 2, c equals \$10000, h equal \$4 billion, our corresponding estimate of L, and taking M to be equal to \$2/3 billion, Table 2 presents the results of the calibration of the efficient subsidies and compares the results with the calibrated current subsidies. In the median scenario (columns 1 and 2 in Table 2) we find that an efficient allocation of \$2/3 billion in subsidies to the Colombian armed forces would have had Ω equal to 0.41, rather than 0.57 as we calibrate it was in fact, and would have had ω equal to 0.47, rather than 0.37 as we calibrate it was in fact. These calculations suggest that an efficient allocation of subsidies would have subsidized the Colombian armed forces more heavily in their conflict with the drug producers over the control of arable land than in their eradication and interdiction efforts, rather than vice versa as seems to have been in fact the case.

How much more would exportation of cocaine from Colombia have decreased, relative to what it was before the implementation of Plan Colombia, with an efficient allocation of \$2/3 billion in subsidies to the Colombian armed forces? From equations 2.16, 2.17, and 2.18 we find that, in the median scenario, the fraction of contested land on which coca has been cultivated, $1 - P$, would have decreased to about 0.19, as compared to the actual outcome of 0.25, which would have implied an "extra" decrease of about 17 per cent relative to what it was before the implementation of Plan Colombia. We also find that the fraction of potential drug production and exportation that avoided eradication and interdiction, q, would have increased to about 0.51, as compared to the actual outcome of 0.45, an increase of about 9 per cent relative to what it was before the implementation of Plan Colombia. Finally, we find that average annual exportation of cocaine from Colombia would have decreased to about 205 thousand kilograms, as compared to the actual outcome of about 237 thousand kilograms, an "extra" decrease of about 6 per cent of what exportation was before the implementation of Plan Colombia.

This estimate suggests that inefficiency in the allocation of subsidies has not had a big effect on the success of Plan Colombia. This conclusion, however, is sensitive to the assumed values of c, h, and ϕ. For example, as indicated in Table 2, given the assumptions that Φ equals one and that ϕ equals two, h equal \$4 billion, we estimate that an efficient allocation of subsidies would have resulted in an additional decrease in the exportation of cocaine from Colombia, relative to what it was before the implementation of Plan Colombia, by only about 0.03 if c equals \$12000, by about 0.06 if c equals \$10000, but by about 0.16 if c equals \$8000.

4. Summary

In this paper we develop a model of a war against the producers of illegal hard drugs. The first front of this war is the conflict between the state and the drug producers over the control of arable land that is suitable for cultivating the crops that constitute the raw material for producing cocaine. In the second front, the state attempts to eradicate the crops (for instance, by the aerial spreading of herbicides), to interdict drug shipments, and to destroy the workshops where cocaine is produced and the landing strips from which drugs are exported. We label this front the "eradication and interdiction" front of the war against drug producers. Importantly, the model includes an interested outsider who uses both a stick and a carrot to strengthen the resolve of the state in its war against the producers of illegal hard drugs.

According to the results of the calibration of the model, the implementation of Plan Colombia has decreased the exportation of cocaine from Colombia, on average, from 532 thousand kilograms before the implementation to 237 thousand kilograms after the implementation. Also, we estimate the marginal cost to the United States of reducing the exportation of cocaine by one kilogram by subsidizing the Colombian armed forces in the conflict over arable land to be, on average, $800, and the marginal cost of reducing the exportation of cocaine by one kilogram by subsidizing the eradication and interdiction efforts of the Colombian armed forces to be, on average, $3770. Efficiency in the allocation of subsidies would imply that these two marginal costs should be equal. Hence, our estimates suggest that the allocation of subsidies between the two fronts of the war against drug producers in Colombia has not been efficient.

An efficient allocation of subsidies would imply an increase in the subsidy to the Colombian state in its conflict with the drug producers over the control of arable land, and a decrease in the subsidy to eradication and interdiction efforts. The results of the calibration of the efficient subsidies implies that the fraction of land controlled by the drug producers would have been 19 per cent lower than it actually was, the fraction of drugs that could have been exported successfully would have been 9 per cent higher then they actually were, and, most importantly, total drug production and exportation would have been, on average, 6 per cent lower than it actually was. Depending on the assumed parameter values used in the calibration of the model, the extra decrease in total drug production and exportation that an efficient allocation of subsidies would have implied can be as low as 3 per cent, but as large as 16 per cent. Finally, under an efficient allocation of subsidies we estimate that the marginal cost to the United States of decreasing the exportation of cocaine by one kilogram would be, on average, $1900.

Appendix

Allowing for a positive value of b, the annual profit from each hectare of land used to cultivate the most profitable benign crop, we have

$$X = \frac{(bL + hq)\ \Phi\ \Omega}{n\left[\Phi\ \Omega\ + n\ \left(\frac{b}{qc} + \frac{h}{cL}\right)\right]^2}$$

$$Z = \frac{(bL + hq)\left(\frac{b}{qc} + \frac{h}{cL}\right)\ \Phi}{\left[\Phi\ \Omega\ + n\ \left(\frac{b}{qc} + \frac{h}{cL}\right)\right]^2}$$

$$1 - P = \frac{\Phi\ \Omega}{\Phi\ \Omega\ + n\ \left(\frac{b}{qc} + \frac{h}{cL}\right)}.$$

Assuming that Φ equals one, that ϕ equals two, and that c equals \$10000, if b is about \$400,[11] then our estimates of $1 - P$ before implementation and after implementation would be about 0.35 and 0.24, rather than 0.36 and 0.25, as we calculated under the assumption that b equals zero, and our estimates of D before implementation and after implementation would be about 536 thousand kilograms and about 245 thousand kilograms, rather than 532 thousand kilograms and 236 thousand kilograms, as we calculated under the assumption that b equals zero. The results of the calibration of the model under the median parameters scenario are presented in Table 3 (columns 3 and 4). Columns 1 and 2 in Table 3 reproduce the results obtained in Table 1 under the median scenario.

[11] Agricultural GDP per hectare of arable land in Colombia is about \$800. To calibrate the model for the case where $b > 0$ we make the (standard) assumption that half of this number is the remuneration to land holders. That is, b is about \$400. Results are very similar if we use the profits per hectare of land in the coffee sector in Colombia.

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Table 1

Facts

$[(1\text{-}P)L]_{\text{after implementation}} = 110900$ ha

$[(1\text{-}P)L]_{\text{before implementation}} = 163300$ ha

$\longrightarrow \dfrac{(1\text{-}P)_{\text{after imp.}}}{(1\text{-}P)_{\text{before imp.}}} = 0.68$

$\lambda = 4.7$ kg/ha

$M = \$\ 2/3$ billion

$n=2$

	Median scenario		Variations in ϕ				Variations in c				Variations in h			
	after (1)	before (2)	after (3)	before (4)	after (5)	before (6)	after (7)	before (8)	after (9)	before (10)	after (11)	before (12)	after (13)	before (14)
Assumptions														
Φ	1	1	1	1	1	1	1	1	1	1	1	1	1	1
ϕ	2	2	**1.5**	**1.5**	**2.5**	**2.5**	2	2	2	2	2	2	2	2
c	\$ 10,000	\$ 10,000	\$ 10,000	\$ 10,000	\$ 10,000	\$ 10,000	**\$ 8,000**	**\$ 8,000**	**\$ 12,000**	**\$ 12,000**	\$ 10,000	\$ 10,000	\$ 10,000	\$ 10,000
h	\$4 billion	\$4 billion	\$4 billion	\$4 billion	\$4 billion	\$4 billion	\$4 billion	\$4 billion	\$4 billion	\$4 billion	**\$2 billion**	**\$2 billion**	**\$6 billion**	**\$ 6 billion**
Results														
Ω	0.57	1.00	0.57	1.00	0.57	1.00	0.59	1.00	0.56	1.00	0.53	1.00	0.59	1.00
ω	0.37	1.00	0.32	1.00	0.39	1.00	0.30	1.00	0.42	1.00	0.24	1.00	0.46	1.00
L (has.)	452,200	452,200	452,200	452,200	452,200	452,200	493,920	493,920	421,550	421,550	349,950	349,950	531,790	531,790
1-P	0.25	0.36	0.25	0.36	0.25	0.36	0.22	0.33	0.26	0.39	0.32	0.47	0.21	0.31
q	0.45	0.69	0.35	0.63	0.53	0.74	0.38	0.66	0.52	0.72	0.46	0.78	0.45	0.64
q_{after}/q_{before}	0.65		0.56		0.71		0.57		0.72		0.59		0.70	
D (kgs.)	236,640	532,151	183,700	482,800	274,090	566,921	195,550	509,582	269,660	550,038	239,540	596,924	234,130	490,693
D_{after}/D_{before}	0.44		0.38		0.48		0.38		0.49		0.40		0.48	
$(\partial M/\partial D)_{\Omega}$ (\$)	-798	-1,882	14	-1,882	-1,183	-1,882	197	-1,723	-1,513	-2,019	149	-1,216	-1,532	-2,401
$(\partial M/\partial D)_{\omega}$ (\$)	-3,770	-1,882	-3,638	-1,882	-3,896	-1,882	-3,741	-1,723	-3,712	-2,019	-3,962	-1,216	-3,636	-2,401

Table 2
Efficient Subsidies

Facts

$\lambda = 4.7$ kg/ha
M = $ 2/3 billion
n=2

	Median scenario		Variations in ϕ				Variations in c				Variations in h			
	current subsidies	efficient subsidies	current subsidies	efficient subsidies	current subsidies	efficient subsidies	current subsidies	efficient subsidies	current subsidies	efficient subsidies	current subsidies	efficient subsidies	current subsidies	efficient subsidies
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Assumptions														
Φ	1	1	1	1	1	1	1	1	1	1	1	1	1	1
ϕ	2	2	**1.5**	**1.5**	**2.5**	**2.5**	2	2	2	2	2	2	2	2
c	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000	$ 10,000	**$ 8,000**	**$ 8,000**	**$ 12,000**	**$ 12,000**	$ 10,000	$ 10,000	$ 10,000	$ 10,000
h	$4 billion	$4 billion	$4 billion	$4 billion	$4 billion	$4 billion	$4 billion	$4 billion	$4 billion	$4 billion	**$2 billion**	**$2 billion**	**$6 billion**	**$ 6 billion**
Results														
Ω	0.57	0.41	0.57	0.33	0.57	0.44	0.59	0.29	0.56	0.46	0.53	0.24	0.59	0.49
ω	0.37	0.47	0.32	0.37	0.39	0.51	0.30	0.33	0.42	0.52	0.24	0.29	0.46	0.55
L (has.)	452,200	452,200	452,200	452,200	452,200	452,200	493,920	493,920	421,550	421,550	349,950	349,950	531,790	531,790
1-P	0.25	0.19	0.25	0.16	0.25	0.20	0.22	0.12	0.26	0.23	0.32	0.18	0.21	0.18
$(1\text{-}P)_{eff.}/(1\text{-}P)_{current}$	0.77		0.65		0.81		0.55		0.86		0.56		0.86	
q	0.45	0.51	0.35	0.39	0.53	0.59	0.38	0.40	0.52	0.57	0.46	0.51	0.45	0.49
$q_{eff.}/q_{current}$	1.13		1.10		1.12		1.06		1.10		1.10		1.10	
D (kgs.)	236,640	205,090	183,700	130,420	274,090	248,900	195,550	114,700	269,660	254,970	239,540	146,800	234,130	221,930
$D_{eff.}/D_{current}$	0.87		0.71		0.91		0.59		0.95		0.61		0.95	
$(\partial M/\partial D)_{\Omega}$ ($)	-798	-1,867	14	-1,147	-1,183	-2,094	197	-714	-1,513	-2,291	149	-1,092	-1,532	-2,303
$(\partial M/\partial D)_{\omega}$ ($)	-3,770	-1,867	-3,638	-1,147	-3,896	-2,094	-3,741	-714	-3,712	-2,291	-3,962	-1,092	-3,636	-2,303

Table 3

Facts

$\left[(1\text{-}P)L\right]_{after\ implementation} = 110900\ ha$

$\left[(1\text{-}P)L\right]_{before\ implementation} = 163300\ ha$

$\longrightarrow \dfrac{(1\text{-}P)_{after\ imp.}}{(1\text{-}P)_{before\ imp.}} = 0.68$

$\lambda = 4.7$ kg/ha

$M = \$\ 2/3\ billion$

$n=2$

	Median scenario with b=0		Median scenario with b= $500	
	after (1)	before (2)	after (3)	before (4)
Assumptions				
Φ	1	1	1	1
ϕ	2	2	2	2
c	$ 10,000	$ 10,000	$ 10,000	$ 10,000
h	$4 billion	$4 billion	$4 billion	$4 billion
b	0	0	$ 400	$ 400
Results				
Ω	0.57	1.00	0.60	1.00
ω	0.37	1.00	0.37	1.00
L (has.)	452,200	452,200	466,610	463,720
$1\text{-}P$	0.25	0.36	0.24	0.35
q	0.45	0.69	0.46	0.70
q_{after}/q_{before}	0.65		0.67	
D (kgs.)	236,640	532,151	244,955	536,235
D_{after}/D_{before}	0.44		0.46	