The Economics of the War on Illegal Drug Production and Trafficking*

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Abstract

We model the war on drugs in source countries as a conflict over scarce inputs in successive levels of the production and trafficking chain, and study how policies aimed at different stages affect prices and quantities in upstream and downstream markets. We use the model to study Plan Colombia, a large intervention aimed at reducing the downstream supply of cocaine by targeting illicit crops and blocking the transport of cocaine outside this source country. The model fits the main patterns found in the data, including the displacement of the drug trade to other source countries, the increase in coca crops' productivity as a response to eradication, and the lack of apparent effects in consumer markets. We use a reasonable parametrization of our model to evaluate the cost-effectiveness of different policies implemented under Plan Colombia. We find that the marginal cost to the U.S. of reducing cocaine transacted in retail markets by one kilogram is $940,000, if it subsidizes eradication efforts; and $175,000, if it subsidizes interdiction efforts in Colombia.

Keywords: Hard Drugs, Conflict, War on Drugs, Plan Colombia.

JEL Classification Numbers: D74, K42.

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1 Introduction

Ever since Richard Nixon formally declared a war on drugs in 1971, different policies have been implemented in producer, transit and consumer countries with the goal of reducing illegal-drugs' consumption. Source and transit countries, such as Colombia (where about 70% of the cocaine consumed worldwide is produced), Afghanistan and Mexico, have played a mayor role, and in alliance with the U.S. and other developed countries, implemented several anti-drug strategies ranging from the eradication of illicit crops, the detection and destruction of processing labs and the interdiction of drug shipments en route to consumer markets.

In September 1999, the Colombian government announced Plan Colombia, a strategy which had two main objectives. The first was to reduce the production of illegal drugs (primarily cocaine) by 50% within six years; the second was to improve security conditions in Colombia by reclaiming control over large areas of the country held by illegal armed groups (see the U.S. Government Accountability Office - GAO, 2008). Since 2000, Plan Colombia has provided the institutional framework for a military alliance between the U.S. and Colombia in the war against drug production, trafficking and the organized criminal groups associated with these activities.

According to official figures from the Colombian government (see DNP, 2006), between 2000 and 2008, the U.S. disbursed about \$4.3 billion for the military component of Plan Colombia; while the Colombian government spent about \$7.3 billion on several anti-narcotic programs. Joint expenditures reached, on average, \$1.3 billion per year, which corresponds to about 1.2% of Colombia's GDP, making Plan Colombia on of the largest interventions in a drug producing country. Despite the financial efforts, the results have been mixed. While the number of hectares of coca crops cultivated in Colombia decreased by about half (from 161,700 hectares in 1999 and 2000 to 86,000 hectares on average from 2005 to 2008), potential cocaine production only decreased by about 24% (from 690 metric tons per year from 1998 to 2000, to 550 around 2008). This paradoxical outcome can be explained by a significant increase in yields per hectare, from roughly 4.3 kg of cocaine per hectare per year prior to 2000, to about 6.6 kg of cocaine per hectare per year in 2008. Furthermore, the wholesale price of cocaine in consumer countries remained relatively stable during this period.[1]

In this paper, we construct a model of the war on drugs in source countries to study the effects of such interventions in downstream and domestic markets. Our model helps us understand the mixed results of Plan Colombia and underscores the economic forces explaining the mixed results. The structure in our model allows us to surpass the inherent data limitations related to the study

[1]See Mejía and Posada (2008) for a thorough description of the main stylized facts related to cocaine markets, both in producer and consumer countries. Despite Plan Colombia, market prices at the wholesale and retail levels remained relatively stable from 2000 to 2008— the period in which we base our study. Recent data indicates an increase in wholesale prices since 2008, when Colombia redirected its efforts towards interdiction.

of illegal markets, and provides tractable expressions to calculate the cost effectiveness of different supply-side interventions. These are informative numbers in this context, given that the lack of good natural experiments and the general equilibrium effects of such large interventions, limit our ability to grasp the magnitude of such costs from traditional program evaluation analysis.[2]

We model the drug market as a vertical production chain composed of several stages (or nested production functions), starting with production in the source country and followed by trafficking to transit countries. Drugs are then transported and distributed in downstream markets, until reaching final consumers. Source country interventions take place in two fronts. First, the eradication front, where policies are aimed at reducing the cultivation of illicit crops (coca or opium poppy) required to produce hard drugs (cocaine or heroin, respectively). Second, in the interdiction front, where policies are aimed at blocking the routes required to transport the drugs from the source country to transit markets and interdicting drug shipments. Both policies affect downstream markets by curbing the net supply of drugs from the source country.

Our model incorporates several economic forces usually absent from formal analysis of illegal drug markets or policy discussions. First, we allow producers to combine land and complementary factors to produce cocaine, which creates the potential for substitution in response to eradication efforts. This force creates an endogenous increase in land productivity as a response to eradication campaigns, thus rendering these policies less effective at curbing drug production. Likewise, we allow traffickers to compensate for interdiction losses by demanding more cocaine. Second, our model allows other source countries to supply downstream markets when the price of Colombian cocaine increases. This renders supply reduction efforts in Colombia less effective in reducing downstream consumption and creates the possibility of displacement effects: Large shifts in cocaine production among different source or transit countries depending on the extent and effectiveness of different anti-drug anti-drug strategies implemented in each of these countries. Finally, our model takes into account that, at each stage, Colombian cocaine only represents a fraction of producers' costs, while a large chunk of the price is determined by other inputs, including labor used in distribution networks, bribes for government officials, airplanes or drug submarines, construction of drug-tunnels, etc. Since supply-reduction policies in Colombia do not directly affect the price or supply of these inputs, increases in the price of Colombian cocaine do not translate into equal changes in consumer prices, rendering source country interventions less cost effective.

Essentially, our model allows drug markets to adjust to reductions in coca crops and routes in a source country through margins other than an increase in consumer prices. The adjustment may occur through investments aimed at raising land productivity, displacement of production to

[2] Some recent exceptions include the papers by Mejía et al. (2014) and Rozo (2014), described in the related literature section. However, both papers only estimate partial equilibrium effects, and their general equilibrium implications require filtering the results through a model like the one we propose in this paper.

other countries, or a more intensive use of trafficking and distribution networks abroad. Our model disciplines these margins of adjustment by providing an explicit micro-foundation, and permits us to quantify them using reasonable parameter values.

Besides the above market structure, we follow the conflict literature (See Grossman and Mejía, 2008) and model supply-reduction policies in source countries as a conflict between the (Colombian) government and producers or traffickers. For instance, we model eradication as a conflict between the government and producers over the effective control of land suitable for coca cultivation. Likewise, we model interdiction as a conflict between the government and drug traffickers over the effective control of transportation routes. This modeling strategy incorporates another margin of adjustment; namely, investments by market participants to avoid eradication and interdiction efforts. As a result, the cost of eradication and interdiction depends on how valuable land and routes are for producers and traffickers, respectively, thus making interventions aimed at less valuable inputs less costly. However, these cost gains have to be weighed against the fact that such interventions have a smaller effect on downstream prices— given that the share of such inputs reflected in consumer prices is small— when computing their cost-effectiveness.

Finally, we also assume source-country interventions are implemented locally, with partial funding from consumer countries (the U.S.) in an effort to strengthen the resolve of the source country in curbing its drug supply. This creates the possibility of agency problems, and implies that source countries' preferences and objectives will also, from an outsider's perspective, determine the costs of eradication and interdiction. In particular, a larger misalignment among both countries' objectives makes schemes such as Plan Colombia more costly from the outsider's perspective. For instance, the Colombian government greatly emphasized eradication during our period of analysis, presumably because of internal political considerations or in an effort to affect the finances of large armed groups involved in cocaine production (guerrilla and paramilitary groups). From the U.S. perspective, such preferences imply that more subsidies will be used in the less efficient (but more appealing from the Colombian government point of view) eradication, than in interdiction.

After presenting our model, we turn to a quantitative exploration of its implications. Our model rationalizes several stylized facts of the war on drugs during Plan Colombia. For example, our model predicts an increase in land productivity following an intensification of eradication campaigns, as observed in the data. Our model also suggests that, despite large increases in eradication and interdiction efforts, there are only limited effects on retail quantities and prices. Consistent with this prediction, the wholesale and retail price of cocaine remained relatively stable during the years of our study. Our model also predicts a reallocation of cocaine production to other source countries. Indeed, following the implementation of Plan Colombia, cocaine production shifted considerably to Peru and Bolivia— the other two producers of cocaine in the Andean region.

In a more ambitious exercise, we turn to quantifying the cost-effectiveness of Plan Colombia using our model. We back up reasonable values for the parameters of our model based on the available data; these quantify the extent of different margins of adjustment in the cocaine market. We then compute measures of the cost-effectiveness of eradication and interdiction. Since we do not have enough data or a reliable identification strategy to estimate all parameters, these results are only suggestive of the broad quantitative implications of the margins of adjustment incorporated in our model, and are indicative of how they shape the costs and effectiveness of different policies. Our findings indicate the marginal cost to the U.S. of reducing consumption of cocaine in downstream markets by 1kg is about $940,000, if it subsidizes eradication efforts; and about $175,000, if it subsidizes interdiction efforts in Colombia. Both numbers are large and suggest source-country interventions are quite ineffective at curbing drug supply in consumer countries. To put these numbers in perspective, MacCoun and Reuter (2001) estimate that it would cost the U.S. $33 million per year to reduce consumption by 1% using treatment for addicts, and between $50 and $275 million per year using prevention policies. These figures imply marginal costs of reducing consumption by 1kg using treatment of $8,250; and between $12,500 and $68,750 using prevention, respectively. Eradication and interdiction in source countries are, at least, 13 and 3 times more costly than these alternative domestic policies, respectively. Taken at face value, these numbers suggest that, if the U.S. wants to reduce drug consumption, it is better off investing in treatment and prevention programs domestically than subsidizing source country interventions, as Plan Colombia, abroad.[3]

Our model is based on the case of Colombia and the cocaine trade. Thus, we refer to cocaine as the illegal drug being produced throughout, and to Colombia as the source country. Nevertheless, the model and its main insights apply more generally to other producing and transit countries, such as Afghanistan, where heroin is produced by processing opium poppy seeds and is then transported to primarily consumer markets in Europe and North America; or Mexico, where heroin and marijuana are produced and then shipped to final consumer markets in the U.S. In these countries, the U.S. has also funded anti-narcotic efforts similar to Plan Colombia, for which some the insights developed in this paper may apply.

2 Related Literature

There is a small but growing empirical literature on Plan Colombia relying on micro evidence. For instance, Mejía et al. (2014) estimate the impact of aerial spraying of coca crops (the biggest component of eradication policies during our period of analysis) on cultivation. The authors

[3]These numbers are silent about other potential costs or benefits from such source country interventions. While some commentators claim that Plan Colombia resources helped improve security and brought the professionalization of the army, other researches point out to some unintended consequences (See Dube and Naidu, 2015).

exploit the natural experiment created by Colombia's diplomatic compromise of not carrying out spraying campaigns since 2006 in a 10 km strip in the border with Ecuador. They find spraying campaigns have a statistically significant but small effect on coca cultivation, consistent with the large marginal cost computed in our paper using a different methodology. Rozo (2014) uses an IV strategy that exploits the location of natural and indigenous reserves— where spraying campaigns are forbidden by law— and estimates a negative effect of eradication on coca yields. There is also some empirical evidence for the effectiveness of the war on drugs on U.S. soil. Kuziemko and Levitt (2004) find that drug prices increase in states imprisoning more drug offenders, consistent with an inward shift in supply.

Other studies have focused on the unintended consequences of Plan Colombia, and the war on drugs in general. For example, Dube and Naidu (2015) examine the impact of U.S. military assistance on the intensity of conflict in Colombia, and find that it has led to an increase in the number of paramilitary attacks near military bases. Angrist and Kugler (2008) show the displacement of the coca trade from Peru to Colombia in the early 90s increased violence in the country side, consistent with our view that the war on drugs involves conflict over resources required for production (See also Mejía and Restrepo, 2013). For other countries, Dell (2011) uses a regression discontinuity approach in the election of Mexican mayors and documents that following the election of a PAN mayor (the party spearheading the war on drugs in the country), drug routes reallocated to neighboring places, increasing violence in these municipalities.

Most of the available applied-theory literature on the effects of anti-drug policies has focused on partial equilibrium analysis. Caulkins et al. (2001) and Rydell et al. (1996) use this approach in order to study the policy trade-off between treatment and enforcement policies in reducing the consumption of illegal drugs. Grossman and Mejía (2008) study the relative efficiency and effectiveness of eradication and interdiction efforts in a partial equilibrium game theory model.[4] However, the market for illegal drugs hides complex interactions that should be addressed using models that can account for general equilibrium effects, especially when evaluating large-scale policy interventions such as Plan Colombia. Some recent papers incorporating these effects include Becker et al. (2006), Naranjo (2007), Chumacero (2010), Costa Storti and De Grauwe (2009), and Mejía and Restrepo (2011).[5]

[4]For a thorough survey of the literature on the effects of control interventions in source countries versus the effects of treatment and prevention policies in consumer countries on reducing the demand for illegal drugs in the latter, see Caulkins (2004), Reuter (2008), and Mejía and Posada (2008).

[5]Relatedly, Jeff Miron analyzes the costs of drug prohibition and the budgetary consequences of drug legalization in the U.S. ((Miron, 2001) and (Miron, 2010)).

3 The Model

We model the drug market as a vertical production chain where all agents involved are price takers.[6] Figure 1 presents a diagram of the actors, markets and technologies involved in our model. It is useful for readers to keep the diagram in mind as they proceed through the description of our model.

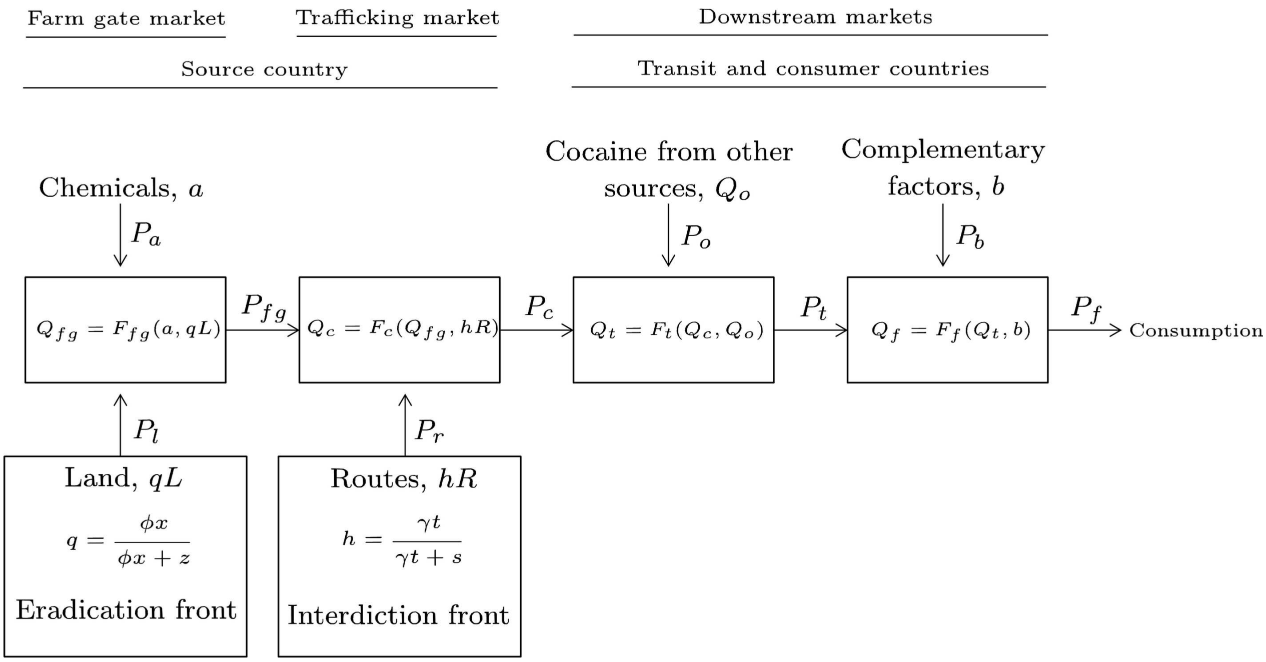

Figure 1: Cocaine market structure.

3.1 Description of the markets

The first stage in the production of cocaine is the farm gate market, indexed with the subscript fg and depicted at the left in Figure 1. At this stage, producers cultivate coca crops, harvest them, and combine the leaves with chemical precursors such as gasoline, cement, sodium permanganate and sulfuric acid in order to produce cocaine.[7] The cultivation and processing of coca crops into

[6]In our view, this is a better approximation than assuming that certain players have market power. The recent experience of countries such as Colombia, Peru and Mexico shows that although some groups have territorial and market control over specific areas, they still face competition from other producers and trafficking organizations located in other areas or even other countries. Even if some groups derive profits from market power (that is, profits beyond risk compensation or rents accruing to the control of scarce resources), these would not affect our conclusions as long as markups do not vary considerably with policies. Though some policies may affect markups, we believe such effects are second order compared to the broad economic forces examined in our model. Thus, we abstract from such possibilities in our analysis.

[7]For a thorough description of the different stages of production and trafficking of cocaine in Colombia, see Mejía and Rico (2010).

cocaine is carried out by farmers, with the protection and direct involvement of illegal armed groups, which have the capacity to confront the state over the control of the arable land necessary to cultivate coca crops.[8] We aggregate these agents and refer to them as the drug producer. The final product of this initial stage of production is cocaine at the farm gate (e.g., at processing facilities in the Colombian countryside). Farm-gate cocaine is purchased by a trafficker — or an aggregate *transportista*— who smuggles cocaine outside the source country.

Formally, we assume that the drug producer combines arable land, l, with complementary factors, a, to produce cocaine at the farm gate, Q_{fg}. Complementary factors are purchased at a price, P_a, which is assumed to be fixed and not affected by drug markets. Importantly, land is not obtained in regular markets, but its effective control is contested by the Colombian government. In particular, we assume that only a fraction, $q \in [0,1]$, of the available arable land, L, is effectively controlled by the drug producer. In the next sub-section we endogenize this fraction as the outcome of eradication policies and efforts by the drug producer to avoid them.

The drug production technology is given by a constant returns to scale function $Q_{fg} = F_{fg}(a, qL)$, with σ_{fg} the (local) elasticity of substitution among inputs; s_l the share of land; and $s_a = 1 - s_l$ the share of the factors complementary to land in the production of cocaine.[9] Price-taking behavior implies the producer problem is given by the following cost minimization problem:

$$\min_{l,a} P_l l + a \quad \text{s.t.} \quad F_{fg}(a,l) = Q_{fg}, \tag{1}$$

where the condition $l = qL$ fixes the amount of land used in cocaine production and determines its shadow price, P_l. The drug producer sells the total amount of farm gate production, Q_{fg}, to a Colombian trafficker at a price P_{fg} equal to its unit cost of production.

The second stage is the trafficking market, indexed with the subscript c, and depicted in the middle and to the left in Figure 1. At this stage, the trafficker transports the drugs, bought at the farm gate, outside the source country and towards transit countries, where he sells the drugs that survive interdiction efforts. For instance, we think of traffickers as *transportistas* in charge of moving cocaine out of the country and earning a price differential in return.

Formally, we assume the trafficker combines routes, r, with domestic drugs bought at the farm gate market, Q_{fg}, to "produce" Colombian cocaine in transit countries, Q_c, available for downstream distribution. As with land, we assume routes are not purchased in regular markets, but their effective control must be secured from the government interdiction efforts. In particular,

[8] Illegal armed groups such as the Fuerzas Armadas Revolucionarias de Colombia - FARC - and paramilitary groups have been actively involved during the last 20 years in the initial stages of coca cultivation and cocaine production in Colombia (See Rangel, 2000; Rabasa and Chalk, 2001; Villalon, 2004). In the case of Afghanistan, the Taliban has been the group that controls the cultivation of opium poppy.

[9] The constant returns to scale technology implies that, at the aggregate level, it does not make any difference whether there is just one or many drug producers.

we assume that only a fraction, $h \in [0, 1]$, of the possible routes used by the trafficker, R, is not disrupted (or blocked) by government interdiction efforts. In the next sub-section we endogenize this fraction as the outcome of interdiction policies and efforts by the trafficker to avoid them.

The drug trafficking technology is given by a constant returns to scale function $Q_c = F_c(Q_{fg}, hR)$, with σ_c the (local) elasticity of substitution among inputs in the trafficking technology; s_r the share of routes; and $s_{fg} = 1 - s_r$ the share of farm gate cocaine.[10] Price-taking behavior implies the producer problem is given by the following cost minimization problem:

$$\min_{Q_{fg}, r} P_{fg}Q_{fg} + P_r r \quad \text{s.t.} \quad F_c(Q_{fg}, r) = Q_c, \tag{2}$$

where the condition $r = hR$ pins down the shadow price of routes, P_r. The drug trafficker sells the total amount of Colombian cocaine (that survives the government's interdiction efforts) in the transit country, Q_c, at a price P_c equal to its unit cost of production, and depending on the equilibrium values of q and h— which determine the price of land and routes.

At this point we obtain the Colombian supply of cocaine in transit markets, $P_c^s(Q_c)$. Despite our constant returns to scale technologies, this supply is not flat, because land and routes are available in fixed quantities and at varying (shadow) prices. The structure of our model implies that supply-reduction policies in Colombia affect downstream markets only by shifting the curve $P_c^s(Q_c)$.

Though the Colombian supply curve is an interesting object, it is not useful when evaluating anti-drug policies. Instead, we are interested on how changes in eradication and interdiction efforts affect downstream markets, and consumers in the U.S. and other countries. To study this, we incorporate downstream markets (e.g., the wholesale trafficking from transit countries to the distribution of drugs at retail levels in consumer countries) by introducing a vertically integrated organization that demands cocaine from Colombia and other source countries (Peru and Bolivia), smuggles the drugs from transit into the consumer countries and distributes them to consumers in retail markets. For the sake of simplicity, we refer to this organization as "downstream markets." Its real vertical structure or identity does not matter for our purposes, so long as Plan Colombia, or the source country intervention more generally, does not target the workings of these markets or the organizations involved in the trade once cocaine leaves the Colombian borders. Downstream markets are depicted in Figure 1, in the two far right panels.

Formally, we model downstream markets using a nested production function which first allows them to substitute Colombian cocaine, Q_c, for cocaine from other sources, Q_o, depending on their

[10]In the late 80s and early 90s, Colombian traffickers controlled the whole trafficking chain in transit countries. With the demise of the Medellin and Cali cartels, and the rise of Mexican drug trafficking organizations, the ownership structure changed and Colombian traffickers started to play a more limited role. For the purposes of our model, it does not matter if there are several traffickers or if they are vertically integrated with agents in downstream markets, so long as they are all price takers and there are constant returns to scale.

prices, P_c and P_o, respectively. In particular, downstream markets aggregate cocaine from all sources into units in transit, Q_t, using a constant returns to scale technology $Q_t = F_t(Q_c, Q_o)$, with σ_t the (local) elasticity of substitution, s_c the share of Colombian cocaine and $s_o = 1 - s_c$ the share of drugs from other source countries. The elasticity σ_t captures the extent to which price increases in Colombia lead to a displacement of production towards Peru and Bolivia— the main regional competitors. We also assume that other sources supply cocaine with a price-elasticity $\varepsilon_o^s \geq 0$.

The aggregate Q_t is then combined with complementary factors, b, so as to "produce and distribute" drugs at the retail level in consumer countries, Q_f. Formally, this distribution technology is given by a constant returns to scale function $Q_f = F_f(Q_t, b)$. The complementary factors, b, can be thought of as the distribution networks, means of transportation, and the wage bill of drug dealers in U.S. retail markets, all of which are necessary inputs in the distribution technology. We assume that these complementary factors are supplied at a constant price, P_b. We denote the (local) elasticity of substitution between Q_t and b by σ_f; the share of Q_t by s_t; and the share of the complementary factors by $s_b = 1 - s_t$. Interdiction and enforcement in transit and consumer countries are already embodied in this technology, but are assumed constant and independent of interventions carried out in Colombia.

The competitive structure of our model implies that downstream markets price drugs at the retail level by solving the problem

$$P_f = \min_{Q_t', b'} P_t Q_t' + b' \quad \text{s.t.} \quad F_f(Q_t', b') = 1, \tag{3}$$

where Q_t' and b' are the inputs per unit of the final product. Here, P_t is the shadow price of Q_t, given by

$$P_t = \min_{Q_c', Q_o'} P_c Q_c' + P_o Q_o' \text{ s.t: } F_t(Q_c', Q_o') = 1, \tag{4}$$

where Q_c' and Q_o' are the respective quantities of drugs from Colombia and other source countries per unit of drugs in transit.

Equations 3 and 4 fully determine how changes in P_c induced by supply-reduction policies in Colombia affect downstream prices and quantities. In order to close the model, we assume that drugs at the retail level are sold to final consumers, whose demand for cocaine is denoted by $Q_f^d(P_f)$, with a corresponding price elasticity of $\varepsilon_f^d \geq 0$.

Though simple, this formulation of downstream markets captures their two most relevant features from the point-of-view of analyzing the effects of source country interventions: First, the possibility of obtaining cocaine from other source countries, embodied in the technology for Q_t; and second, the possibility of using other complementary factors to increase the amount of cocaine distributed in retail markets (for instance, by improving transportation and distribution networks), embodied in the technology for Q_f, and the complementary factors b. Moreover, this formulation takes into account that the share of Colombian cocaine in the drug trade is just a small fraction of the overall trade and that the price of Colombian cocaine represents a small share of the retail price.

3.2 Supply-reduction policies in source Countries

We model the war on drugs in Colombia as consisting of two main fronts: The eradication front and the interdiction front. Efforts in both fronts are conducted by the source country. We model the agency problem in the simplest way, by assuming that the source country has a motive of its own to fight producers and traffickers for the control of key inputs. However the U.S. may strengthen its resolve by subsidizing a fraction $1-\omega$ and $1-\Omega$ of eradication and interdiction efforts, respectively. The multiplicative structure for subsidies is consistent with the existence of complementarities between the expenditures of the two governments (the Colombian and U.S. governments). This, in our view, is an appropriate description of reality, as most of the subsidies granted by the U.S. government for the war on drugs under Plan Colombia have taken the form of in-kind support, such as training, aircraft, herbicides for aerial spraying, military intelligence, the use of satellites for detecting illegal drug shipments, etc.[11]

Formally, we assume that the Colombian government wants to minimize the social cost imposed by drug producers and traffickers upon civil society. A flexible and tractable way of introducing these costs is by assuming that the government faces a net cost per unit of income net of payments obtained by the drug producer, $c_1 > 0$, and a net cost per unit of income net of payments obtained by the local trafficker, $c_2 > 0$. This modeling assumption is motivated by the fact that in many source and transit countries— including Colombia, Mexico and Afghanistan— illegal armed groups engaged in the production and trafficking of illicit drugs use part of the proceeds from these activities to finance violent activities against the government, other competing drug trafficking organizations (DTOs) and civilians; to bribe corrupt politicians; and to weaken local institutions and the rule of law. In other words, this assumption implies that the objective of the Colombian government is not necessarily to minimize its supply of cocaine, but rather to target the sources of revenue of illegal armed groups involved in drug production and trafficking activities.[12]

On the eradication front, interventions are aimed at disrupting the production of cocaine. More precisely, we assume the Colombian government fights with drug producers over the effective

[11] Alternatively, one could abstract from this and simply assume that the U.S. directly invests in eradication and interdiction efforts, which is equivalent to assuming it provides additive subsidies. The insights and formulas developed here are quite similar, so this does not change any of the quantitative implications. However, we believe this omits important and relevant constraints related to the implementation of these programs that are discussed in the next section.

[12] This implicitly assumes that producer countries do not have a pressing consumption problem, which seems appropriate for Colombia. For instance, XX?

control of the land necessary to cultivate illegal crops. This fight often takes the form of aerial or manual eradication campaigns, where the Colombian government tries to destroy coca crops and disrupt the production of cocaine. In other cases, this front takes the form of direct confrontations between government forces and the illegal armed groups involved in coca cultivation and cocaine production. Formally, these efforts are aimed at reducing q, the fraction of land under the effective control of the drug producer in our model. Drug producers try to offset eradication efforts through various means, for instance, by planting land mines and other explosive devices aimed at preventing manual eradication teams from entering coca fields, or shooting airplanes used in aerial spraying campaigns. In other cases, they engage into direct confrontations against government forces in order to increase their territorial control in areas with coca crops.

Formally, q is endogenously determined by a standard context success function (CSF) of the following form:[13]

$$q(x, z) = \frac{\phi x}{\phi x + z}, \tag{5}$$

where, z denotes the resources allocated by the government to eradication efforts (aircraft for aerial spraying, herbicides, military personnel, etc.); x denotes the resources the drug producer invests in trying to avoid government eradication efforts (insurgents, land mines, etc.); and $\phi > 0$ captures the relative effectiveness of the resources invested by the drug producer in the conflict over the control of arable land.

The optimal choice of the drug producer, x, can be easily characterized as:

$$\max_x P_l q(x, z)L - x \rightarrow P_l L \frac{\phi z}{(\phi x + z)^2} = 1. \tag{6}$$

Likewise, the government's problem at this stage is

$$\min_z C_P = c_1(P_{fg}Q_{fg} - a) + \omega z = c_1 P_l q(x, z)L + \omega z \rightarrow c_1 P_l L \frac{\phi x}{(\phi x + z)^2} = \omega. \tag{7}$$

The term ωz captures the budgetary cost of eradication efforts, since a fraction $1 - \omega$ of these expenditures is paid for by the U.S. government.

The equilibrium level of q^* is determined by the Nash equilibrium (z^*, x^*) derived from the simultaneous solution of problems 6 and 7. This equilibrium is described by the following equations:

$$x^* = (1 - q^*)s_l P_{fg}Q_{fg}, \quad z^* = \frac{c_1}{\omega}(1 - q^*)s_l P_{fg}Q_{fg}, \quad q^* = \frac{\phi\omega}{c_1 + \phi\omega}. \tag{8}$$

On the interdiction front, interventions are aimed at disrupting drug trafficking. We assume that the government of the producer country implements *interdiction efforts* by fighting the trafficker over the effective control of the routes necessary for transporting drugs from the producer

[13] A contest success function (CSF) is a technology wherein some or all of the contenders for resources incur costs as they attempt to weaken or disable competitors (See Hirshleifer, 1991; Skaperdas, 1996; Hirshleifer, 2001).

to transit countries. These efforts often take the form of crackdowns, surveillance flights, the use of fast boats and the installation of radars, all aimed at detecting and disrupting drug trafficking routes. Formally, these efforts are aimed at reducing h, the fraction of routes under the effective control of the trafficker in our model. Drug traffickers, for their part, try to offset interdiction efforts by adopting better and more efficient trafficking technologies so as to avoid the detection and disruption of drug shipments. There exists ample anecdotal evidence of drug traffickers reacting to anti-drug policies by adopting new technologies (semi-submersible vessels, small aircraft, etc.) in order to prevent radars from detecting illegal drug shipments.

Formally, h is endogenously determined by a standard context success function (CSF) of the following form:

$$h(t,s) = \frac{\gamma t}{\gamma t + s}, \tag{9}$$

where s denotes the resources allocated by the government to interdiction efforts (airplanes, radars, fast boats, etc.); t denotes the resources that the local trafficker invests in trying to avoid interdiction efforts (semi-submersible vessels, drug tunnels, fast boats, airplanes, pilots, drug mules, bribes to corrupt government officials and border patrol officials in order to avoid being captured, etc.); and $\gamma > 0$ captures the relative effectiveness of the resources invested by the drug trafficker in the conflict over routes.

The optimal choice of the producer, t, can be easily characterized as:

$$\max_t P_r h(t,s)R - t \rightarrow P_r R \frac{\gamma s}{(\gamma s + t)^2} = 1. \tag{10}$$

Likewise, the government's problem at this stage is

$$\min_s C_T = c_2(P_c Q_c - P_{fg} Q_{fg}) + \Omega s = c_2 P_r h(t,s) R + \Omega s \rightarrow P_r R \frac{\gamma t}{(\gamma t + s)^2} = \Omega. \tag{11}$$

The term Ωs captures the budgetary cost of interdiction efforts, since a fraction $1 - \Omega$ of these expenditures is paid for by the U.S. government.

The equilibrium level of h^* is determined by the Nash equilibrium (s^*, t^*) derived from the simultaneous solution of problems in equations 10 and 11. This equilibrium is described by the following equations:

$$t^* = (1 - h^*) s_r P_c Q_c, \quad s^* = \frac{c_2}{\Omega}(1 - h^*) s_r P_c Q_c, \quad h^* = \frac{\gamma \Omega}{c_2 + \gamma \Omega}. \tag{12}$$

Note that the equilibrium levels of expenditures in counteracting government eradication and interdiction efforts in equations 8 and 12 are proportional to the total market value of land and routes, respectively. This is a feature of the contest nature of enforcement in these markets, and holds in general if the contest success functions are homogeneous of degree 0. These formulas capture the important insight that the cost of reducing q or h depends on the value of land and routes, respectively, as these determine the willingness of producers and traffickers to counteract such efforts. Finally, note that q^* is lower when ω decreases, and U.S. subsidies constitute a higher share of eradication efforts. Likewise, h^* is lower when Ω decreases, and the U.S. subsidizes represent a larger share of interdiction efforts.[14]

4 Equilibrium and comparative statics

We now define an equilibrium in terms of the subsidies, which are the exogenous variables on which we focus in order to understand the consequences of the war on drugs. Given any pair of subsidies, (ω, Ω), the drug market equilibrium can be characterized by a vector of prices $(P_f^*, P_t^*, P_c^*, P_o^*, P_{fg}^*, P_r^*, P_l^*)$; quantities $(Q_f^*, Q_t^*, b^*, Q_c^*, Q_o^*, Q_{fg}^*, r^*, l^*)$; conflict-related expenditures (t^*, s^*, x^*, z^*) and equilibrium outcomes (h^*, q^*), such that markets clear, prices are equal to marginal costs, and the expenditures (t^*, s^*, x^*, z^*) correspond to the Nash equilibrium strategies given in equations 8 and 12.

The existence and uniqueness of our equilibrium follows by noting that Ω and ω uniquely determine q and h (a well known result from the conflict literature; see (Skaperdas, 1996)), and the market equilibrium is unique given that, for fixed values of q and h, technologies and preferences are jointly concave and standard.

Before moving to the propositions we introduce some notation. We denote by ε_l^d the elasticity of demand for land; ε_r^d the elasticity of demand for routes; ε_{fg}^d the elasticity of demand for farm-gate cocaine; ε_c^d as the elasticity of demand for Colombian cocaine in downstream markets; and ε_t^d as the elasticity of demand for the cocaine aggregate in transit markets. Using Hicks and Marshall's formula (provided in the Appendix), these endogenous elasticities can be computed recursively based on the consumers' demand elasticity, ε_f^d, and the (local) elasticities of substitution and current factor shares. Essentially, these formulas reveal that the elasticity of demand perceived in a given market is a weighted average of the possibilities to substitute for other factors in downstream markets and the consumer demand's elasticity.

The following proposition describes how the cocaine market adjusts to reductions in q and h

[14] One implicit assumption is that the Colombian government simultaneously plays against producers and traffickers, and does not play a-la Stackelberg, nor anticipates changes in prices. We make this simplifying assumption for several reasons. First, it imposes symmetry between both sides in the conflict. Second, it makes the model more tractable and easy to solve. Third, we are interested in the role of Colombia or the respective source country inasmuch as it helps us explain how U.S. subsidies translate into actual supply reduction efforts. Finally, even if we allow Colombia to anticipate effects on prices, this would just complicate the formulas for q^* and h^*, as they would now depend on the elasticities of demand and cross price elasticities, without providing any new insights. Moreover, this problem would be well defined only if σ_t is large enough, so that Colombia has the incentive to increase P_c and displace production, reducing quantities enough so that revenue falls.

caused by eradication and interdiction policies in Colombia. All the proofs are omitted from the main text and presented in the Appendix.

Proposition 1 (Margins of adjustment inside the source country) *Suppose supply-reduction policies reduce q by $d\ln q$. Then:*

1. *The (shadow) price of land increases by $d\ln P_l = \frac{1}{\varepsilon_l^d} d\ln q > 0$. Holding all other factors constant, this would lead to an increase on Colombian prices of $s_l s_{fg} d\ln P_l > 0$. Thus, the share of the factor, $s_l s_{fg}$, determines the initial extent of the price adjustment required.*

2. *Once producers and traffickers are allowed to react, the Colombian market adjusts by investing more in complementary factors, a, per unit of land remaining, thus increasing land productivity by*
$$(1 - s_l)\sigma_{fg} d\ln P_l > 0. \tag{13}$$
Moreover, σ_{fg} makes the demand for land more elastic, reducing $d\ln P_l$.

3. *If $\varepsilon_c^d > \sigma_c$, the trafficker reduces its demand for routes, as these are highly complementary with the scarce farm-gate cocaine. This reduces the price of routes by*
$$d\ln P_r = \frac{s_{fg}(\sigma_c - \varepsilon_c^d)}{s_{fg}\sigma_c + (1 - s_{fg})\varepsilon_c^d} d\ln P_{fg} < 0,$$
further contributing to a lower effect on Colombian cocaine prices.

4. *The resulting net effect on Colombian cocaine prices is smaller than initially expected, and is given by*
$$d\ln P_c = \frac{s_{fg}\sigma_c}{s_{fg}\sigma_c + (1 - s_{fg})\varepsilon_c^d} \frac{s_l}{\varepsilon_l^d} d\ln q > 0.$$

Likewise, suppose supply-reduction policies reduce h by $d\ln h$. Then:

1. *The (shadow) price of routes increases by $d\ln P_r = \frac{1}{\varepsilon_r^d} d\ln h > 0$. Holding all other factors constant, this would lead to an increase in Colombian prices of $s_r d\ln P_r > 0$. Thus, the share of the factor, s_r, determines the initial extent of the price adjustment required.*

2. *If $\varepsilon_c^d > \sigma_c$, the Colombian market adjusts by investing less in farm-gate cocaine. In particular, the price of farm-gate cocaine falls by*
$$d\ln P_{fg} = \frac{s_r(\sigma_c - \varepsilon_c^d)}{s_r(\sigma_c + \varepsilon_{fg}^s) + (1 - s_r)(\varepsilon_{fg}^s + \varepsilon_c^d)} d\ln P_r < 0.$$
Here, $\varepsilon_{fg}^s = \frac{s_a}{s_l}\sigma_{fg}$ is the elasticity of farm-gate supply.

3. *If σ_{fg} is large, $d\ln P_{fg}$ falls mildly, but complementary factors, a, are considerably reduced, leading to a decrease in land productivity.*

4. This adjustment margin implies that a reduction in routes by $d \ln h$ *has a smaller effect on Colombian cocaine prices:*

$$d \ln P_c = \frac{s_r(\sigma_c + \varepsilon_{fg}^s)}{s_r(\sigma_c + \varepsilon_{fg}^s) + (1 - s_r)(\varepsilon_{fg}^s + \varepsilon_c^d)} \frac{1}{\varepsilon_r^d} d \ln h.$$

The main implication of the proposition is that, when σ_{fg} is large and σ_c smaller, the Colombian market responds to changes in q and h by adjusting its use of complementary factors, a. This adjustment always keeps Colombian prices from increasing by keeping the (shadow) price of land from increasing sharply.

Thus, policies like eradication, aimed at increasing the price (or the user cost) of land, will not be reflected in higher cocaine prices even if they successfully reduce the fraction of land with coca crops. Such policies fail to increase significantly the price of land and, in the case $\varepsilon_c^d > \sigma_c$, reduce the price of routes, thus making them highly inefficient at curbing the Colombian supply of cocaine. On the other hand, policies like interdiction, may be more successful at raising the price of routes, which cannot be easily substituted for other factors; while they only have a minor negative effect on the price of land.

The reason why the condition $\varepsilon_c^d > \sigma_c$ is required in the proposition is because traffickers face a scale and a substitution effect. The scale effect dominates in this case, and requires traffickers to cut down their demand for routes when farm-gate cocaine becomes scarce, or to cut their demand for farm-gate cocaine when routes are scarce. Thus, in this case, policies are complementary: Interdiction reduces the price of land (but only mildly if σ_{fg} is large); while eradication reduces the price of routes considerably. Incidentally, this makes policies less effective at raising cocaine prices, which in equilibrium reflects the price of land and routes— the inelastic factors. The substitution effect, on the other hand, creates a force in the opposite direction. We focus in the case in which the scale effect dominates, as it is the relevant one in our empirical exercise.

Finally, the proposition shows that policies aimed at more important factors, measured in terms of their share in total production, have larger effects on prices— even after taking into account the subsequent adjustments. The reason is that increases in the price of an unimportant factor can be easily accommodated by a small increase in consumer prices. This suggests that, if $s_l s_{fg} < s_c$— as is the case empirically, eradication is less effective at raising cocaine prices. Of course, as argued above, this has to be weighted against the fact that it may be cheaper to reduce q than h, given that routes are more valuable in this case.

As explained in the description of the model, the obtained effects on $d \ln P_c$ are sufficient to characterize the downstream effects of source country interventions. This is done in the following proposition.

Proposition 2 (Downstream market effects of source-country interventions) *Suppose $\sigma_t > \varepsilon_t^d$ and ε_o^s is large enough. Reductions in q and h increase Colombian cocaine prices by $d\ln P_c > 0$. This has the following effects in downstream markets:*

1. *Holding other factors constant, consumer prices would increase by $s_c s_t d\ln P_c$. Thus, the share of Colombian cocaine in the cocaine trade determines the initial extent of the price adjustment required.*

2. *Downstream markets react by demanding more cocaine from other source countries. In particular, quantities supplied by other sources increase by*

$$d\ln Q_o = \frac{s_c(\sigma_t - \varepsilon_t^d)\varepsilon_o^s}{s_c(\sigma_t + \varepsilon_o^s) + (1-s_c)(\varepsilon_o^s + \varepsilon_t^d)} d\ln P_c > 0.$$

3. *Downstream markets also react by increasing their investment in distribution and trafficking efforts, b, per unit of cocaine transacted. This adjustment margin implies that downstream markets may be able to keep final prices from falling by investing in their distribution networks.*

4. *Both adjustment margins reduce the effect of source country interventions on $d\ln P_c$, by making the demand for Colombian cocaine more elastic.*

5. *The resulting effect on quantities consumed is given by:*

$$\begin{aligned}\Lambda_q &= \frac{d\ln Q_f}{d\ln q} = \frac{d\ln P_c}{d\ln q}\frac{d\ln P_f}{d\ln P_c}\frac{d\ln Q_f}{d\ln P_f} \\ &= \left(\frac{s_l s_{fg}\sigma_c}{s_l\sigma_c\varepsilon_c^d + (1-s_l)\sigma_{fg}(s_{fg}\sigma_c + (1-s_{fg})\varepsilon_c^d)}\right)\left(\frac{s_t s_c(\sigma_t + \varepsilon_o^s)}{s_c(\sigma_t + \varepsilon_o^s) + (1-s_c)(\varepsilon_o^s + \varepsilon_t^d)}\right)\varepsilon_f^d > 0,\end{aligned}$$

and

$$\begin{aligned}\Lambda_h &= \frac{d\ln Q_f}{d\ln h} = \frac{d\ln P_c}{d\ln h}\frac{d\ln P_f}{d\ln P_c}\frac{d\ln Q_f}{d\ln P_f} \\ &= \left(\frac{s_r(\sigma_c + s_a\sigma_{fg}/s_l)}{s_r(\sigma_c + s_a\sigma_{fg}/s_l)\varepsilon_c^d + (1-s_r)(s_a\sigma_{fg}/s_l + \varepsilon_c^d)\sigma_c}\right)\left(\frac{s_t s_c(\sigma_t + \varepsilon_o^s)}{s_c(\sigma_t + \varepsilon_o^s) + (1-s_c)(\varepsilon_o^s + \varepsilon_t^d)}\right)\varepsilon_f^d > 0.\end{aligned}$$

The above proposition captures two forces making the effect of source-country interventions in retail prices negligible.

First, the fact that the source country represents only a share of the whole trade implies that retail prices only have to increase mildly to cover the increase in the price of Colombian cocaine. Again, this has to be weighted against the fact that source country interventions may be cheaper precisely because they target less valuable stages of the production chain.

Second, the possibility to substitute for other factors in downstream markets makes the demand for Colombian cocaine more elastic, and reduces the effect of source- country interventions on prices. In particular, the possibility to substitute for cocaine from other source countries (i.e., when σ_t is greater), or later for other complementary factors (i.e., when σ_f is greater), implies downstream markets will react to a price increase in Colombian cocaine by moving away from that source and towards using more cocaine from other source countries, Q_o, or using more intensively distribution and trafficking networks— by increasing b per unit of cocaine transacted— in order to satisfy demand. Thus, markets are likely to adjust through changes in the quantities of these inputs without requiring an increase in consumer prices.

In the particular case of substitution for cocaine from other source countries, the above mechanism requires other sources' supply to be sufficiently elastic, so that the adjustment occurs through a considerable displacement of production and not simply through a sharp increase in prices in all source countries.

A by-product of the possibility of substitution for cocaine from other source countries are the so-called displacement effects. These arise when pressure against illegal-drug production pushes the problem to other countries or regions without reducing the aggregate trade. Our framework suggests that these displacement effects are in fact a key determinant of the cost effectiveness of source country interventions. Displacement effects may also have implications that go beyond our model. For instance, source country interventions in one source country increase the value of land and routes in others, creating social costs associated with an increase in trafficking and drug production elsewhere. This negative feedback between policies in different source countries implies that the level of enforcement may be inefficiently high from a regional perspective.

A final noteworthy feature of Proposition 2, is that it provides a formula for the elasticities Λ_q and Λ_h in terms of parameters that can be obtained from the data or estimated by researchers. These elasticities summarize the way in which our market structure adjusts to policies in source countries.

5 Determinants of the cost-effectiveness of supply reduction policies

In the previous section, we characterized the effects on prices and quantities of source-country interventions. In this section, we compute the marginal cost of reducing retail quantities via such policies, and characterize their determinants.

Let $TC_{US} = (1-\omega)z + (1-\Omega)s$ be the total cost to the U.S. of partially funding the producer country in the war against illegal drug production and trafficking. Recall from equations 12 and 8, that the two subsidies are defined implicitly as functions of q and h, respectively.[15] Thus, the

[15]We focus on the cost of these interventions from the U.S.'s point-of- view, but our analysis can easily be extended to include the component of the cost covered by Colombia.

marginal cost of reducing q by increasing subsidy $1-\omega$ is given by

$$\begin{aligned} C_q = -\frac{\partial TC_{US}}{\partial q} &= c_1 P_l L + 2(1-\omega)\phi(1-q)P_l L + (1-\omega)\phi(1-q)^2 P_l L \frac{1}{q\varepsilon_l^d} \\ &\quad + (1-\Omega)\gamma(1-h)^2 P_r R \frac{1}{q}\frac{d\ln P_r}{d\ln q}. \end{aligned} \quad (14)$$

Likewise, the marginal cost of reducing h by increasing subsidy $1-\Omega$ is given by

$$\begin{aligned} C_h = -\frac{\partial TC_{US}}{\partial h} &= c_2 P_r R + 2(1-\Omega)\gamma(1-h)P_r R + (1-\Omega)\gamma(1-h)^2 P_r R \tfrac{1}{h\varepsilon_r^d} \\ &\quad + (1-\omega)\phi(1-q)^2 P_l L \frac{1}{h}\frac{d\ln P_l}{d\ln h}. \end{aligned} \quad (15)$$

These costs capture two interesting features: first, they are proportional to the market value of the total amount of the input being targeted ($P_l L$ and $P_r R$), as anticipated in the introduction. Second, these costs already incorporate all potential distortions arising from the agency problem between the U.S. and the source country implementing the two policies; these correspond to the terms c_1 and c_2 appearing in the formulas.[16]

These expressions yield simple formulas for the marginal costs, presented in the following proposition.

Proposition 3 (The marginal costs of reducing cocaine consumption) *The marginal cost of reducing the amount of cocaine transacted in retail markets by 1 unit by increasing subsidies for eradication is given by*

$$\begin{aligned} MC_\omega &= \tfrac{qC_q}{Q_f\Lambda_q} = P_f \frac{s_l s_{fg} s_c s_t}{\Lambda_q}\left(c_1 + 2(1-\omega)\phi(1-q) + (1-\omega)\phi\frac{(1-q)^2}{q}\frac{1}{\varepsilon_l^d}\right) \\ &\quad + P_f \frac{s_r s_c s_t}{\Lambda_q}(1-\Omega)\gamma\frac{(1-h)^2}{h}\frac{d\ln P_r}{d\ln q}. \end{aligned} \quad (16)$$

The marginal cost of reducing the amount of cocaine transacted in retail markets by 1kg by increasing subsidies for interdiction is given by

$$\begin{aligned} MC_\Omega &= \tfrac{hC_h}{Q_f\Lambda_h} = P_f \frac{s_r s_c s_t}{\Lambda_h}\left(c_2 + 2(1-\Omega)\gamma(1-h) + (1-\Omega)\gamma\frac{(1-h)^2}{h}\frac{1}{\varepsilon_r^d}\right) \\ &\quad + P_f \frac{s_l s_{fg} s_c s_t}{\Lambda_h}(1-\omega)\phi\frac{(1-q)^2}{q}\frac{d\ln P_l}{d\ln h}. \end{aligned} \quad (17)$$

The proposition provides a sharp characterization of the marginal costs in terms of parameters that can be estimated by researchers, or for which we can make reasonable guesses.

The formulas deserve some comment. The first term in equations 16 and 17 captures the fact that the U.S. is now paying for a greater fraction of expenditures in each front. The second term

[16] These costs are calculated on the assumption that the other subsidy remains constant. Thus expenditure in the other front must necessarily change depending on the value of the input being targeted. This does not affect any of our conclusions, but simplifies the algebra and presentation.

reflects the extra expenditure incurred in outbidding the producer or the trafficker in order to reduce q or h enough so as to induce a marginal reduction in the quantity of drugs transacted in retail markets. The third term is always positive and captures the fact that targeting an input increases its price, and makes armed groups contesting it more motivated to avoid enforcement, thus increasing the cost of the policy. The last term captures the feedback effects between eradication and interdiction efforts that arise in general equilibrium, inasmuch as any policy will affect the price of both land and routes. As explained in Proposition 1, when $\sigma_c < \varepsilon_c^d$, eradication reduces the marginal cost of interdiction and *vice versa*.

The following propositions characterize the main determinants of these marginal cost. For the sake of exposition, we assume that when doing our comparative statics all other variables remain fixed. All the proofs follow through differentiation of the above formulas and we omit them to save space.

Proposition 4 (The role of substitution and scale effects in Colombia) *Suppose $\sigma_c < \varepsilon_c^d$. The marginal costs MC_ω and MC_Ω, have the following properties:*

- *The elasticity of substitution between land and complementary factors, σ_{fg}, always increases MC_ω. However its effect on MC_Ω is ambiguous, but becomes positive when expenditures in eradication are large relative to expenditures in interdiction.*
- *The elasticity of substitution between routes and farm gate cocaine, σ_c, always increases MC_Ω and reduces MC_ω.*

These results are in line with our discussion of Proposition 1. As argued there, a combination of a large value of σ_{fg} and a low value for σ_c implies that eradication fails to increase sufficiently the price of land and actually reduces the price of routes. Both effects make MC_ω large.

On the other hand, a lower σ_c favors interdiction, as it targets a factor that cannot be easily substituted. The ambiguous effect of σ_{fg} arises because this elasticity keeps land prices from falling in response to the scale effect created by interdiction. This makes interdiction more effective at raising prices and curbing supply. However, this has to be weighted against the fact that, in this case, interdiction generates fewer savings in the cost of eradication.

The following proposition characterizes how different margins of adjustment in downstream markets affect the marginal costs of reducing cocaine in retail markets.

Proposition 5 (Displacement effects and substitution in downstream markets) *Suppose σ_t and ε_o^s are large enough. Then*

- *MC_ω and MC_Ω increase with σ_t and ε_o^s. In particular, ε_o^s increases both marginal costs when $\sigma_t > \varepsilon_t^d$, and σ_t increases both marginal costs when $\varepsilon_o^s > \underline{v}$.*

- *MC_ω and MC_Ω increase with σ_f.*

Again, the results in this proposition are in line with the intuitions developed in Proposition 2. When $\sigma_t > \varepsilon_t^d$, source-country interventions have a large substitution effect, redirecting the demand fpr cocaine towards other source countries. This results in lower consumer prices so long as prices in other sources do not increase considerably (this is why we require $\varepsilon_o^s > \underline{v}$). In this case, downstream markets adjust by increasing the quantity of cocaine produced in other source countries without increasing consumer prices significantly. This adjustment makes source-country interventions in Colombia less effective at reducing cocaine in consumer markets.

Likewise, a larger σ_f allows downstream markets to compensate for a fall in cocaine production by improving their trafficking and distribution capabilities, whose prices are fixed, thus rendering supply reduction programs in source countries less effective.

Importantly, in the previous propositions we have emphasized forces that affect the market adjustment, but that do not change the cost of supply-reduction policies. In the next proposition we describe the role of shares, which, as argued above, affect both costs and benefits.

Proposition 6 (The role of factor shares) *An increase in the share of land in the cocaine trade has two opposing effects. On the one hand, an increase in the price of land, P_l, induced by eradication, has a larger effect on consumer prices. However, the cost of eradication is larger, as producers are more willing to avoid eradication and hold on to the valuable land. An analogous discussion applies for interdiction efforts.*

Overall, both effects cancel out when computing the marginal costs. In our model, shares only affect marginal costs by determining substitution patterns, or the adjustment margins, in downstream markets (that is, by shaping the demand and supply elasticities derived from Hicks and Marshall's formulas).

The key new insight in this proposition is that shares have ambiguous effects. We want to emphasize these findings, because previous analysis claimed it was more cost effective to target inputs with a large share in the drug trade. In fact, Propositions 1 and 2 shows that this intuition is partially right, in the sense that targeting such inputs increases retail prices more. But proposition 6 clarifies that this cancels out exactly with the fact that such policies are also more costly. Targeting relatively unimportant crops may have only a small effect on retail prices, but by the same token, producers will not fight back as hard. On the other hand, targeting distribution networks may have a large effect on retail prices, but drug traffickers value them more, so this is also more costly. Instead, what matters for cost-effectiveness in our model is how markets adjust to changes in the price of land and routes; not their shares.

Proposition 7 (The role of consumers' demand) *MC_ω and MC_Ω have the following properties.*

- *Both increase when the demand for cocaine at the retail level is more inelastic; that is,* $\varepsilon_f^d \to 0$.
- *Both increase when the overall demand for cocaine increases (leaving its elasticity fixed).*
- *Both are of the same order of magnitude as retail prices.*

A more inelastic consumers' demand causes price increases to have a smaller effect on quantities, as has already been pointed out by Becker et al. (2006) and others. In our model, a more inelastic demand feeds back into upstream markets, making the demand for all inputs more inelastic. This implies that eradication and interdiction have greater effects on land and routes' prices, but these effects are dominated by the fact that these price increases lead to a smaller reduction in consumed quantities.

Interestingly, in our model, the consumers' demand elasticity also affects the cost side of supply-reduction interventions. More precisely, a more inelastic demand implies that P_l and P_r increase sharply with eradication and interdiction, respectively, thus raising the cost of reducing q or h, since producers and traffickers value these inputs more. This particular channel arises only when we model enforcement as a conflict.

Finally, our model implies that both marginal costs are proportional to the retail price. This is because prices determine the willingness of producers and traffickers to avoid eradication and interdiction. This has important implications. For instance, policies in consumer countries that reduce retail demand (e.g., prevention, treatment or rehabilitation) or make it more elastic, have the extra benefit of lowering the marginal cost of implementing source country interventions(See Mejía and Restrepo, 2011, for a similar insight). By the same token, demographic, taste or legal changes in consumer countries that increase consumption raise the marginal cost of curbing supply in source countries.

Finally, the dependence of costs on prices has another interesting implication; namely, that the war on drugs becomes more and more expensive as source countries make important advances.[17] The reason is that supply reductions increase consumer prices, and by doing so, raise the value of land and routes. Thus, producers and traffickers are more willing to avoid eradication and interdiction effort. As explained above, this effect becomes stronger when the consumers' demand is more inelastic so that prices rise sharply. This result suggests the war on drugs cannot be won abroad: As subsidies increase, and q and h become smaller, the marginal cost of reducing the amount of drugs transacted in retail markets by one extra unit becomes arbitrarily large.

[17] The concavity of the contest success function and the fact that the U.S. pays a larger share of the costs create similar effects in the same direction. We find the effect of prices more interesting and novel, and this is the reason we emphasize this channel here.

The previous propositions characterize the behavior of the marginal costs MC_ω and MC_Ω without taking a stand on how the U.S. allocates these subsidies. If the U.S. objective was simply to reduce supply, and Colombia had no say in the allocation of subsidies, it would do it in such a way as to guarantee that $MC_\omega = MC_\Omega$. The following proposition characterizes which levels of observed expenditure are consistent with such allocation rule.

Proposition 8 (Efficient allocation of subsidies) *Let TC^{ω}_{US} and TC^{Ω}_{US} be the observed expenditures by the U.S. on subsidizing eradication and interdiction efforts respectively. The allocation is efficient— from the viewpoint of supply reduction— if and only if $\frac{TC^{\omega}_{US}}{TC^{\Omega}_{US}} = \overline{m}$. The threshold $\overline{m}$ can be computed from the data as*

$$\overline{m} = \frac{\Lambda_q}{\Lambda_h} \frac{\frac{\Omega}{(1-\Omega)(1-h)} + 2\frac{h}{1-h} + \frac{1}{\varepsilon^d_r} + \frac{\Lambda_h}{\Lambda_q}\frac{d\ln P_r}{d\ln q}}{\frac{\omega}{(1-\omega)(1-q)} + 2\frac{q}{1-q} + \frac{1}{\varepsilon^d_l} + \frac{\Lambda_q}{\Lambda_h}\frac{d\ln P_l}{d\ln h}}. \tag{18}$$

If $\frac{TC^{\omega}_{US}}{TC^{\Omega}_{US}} > \overline{m}$, too much resources are being assigned to eradication; while the opposite happens if the inequality is reversed.

The above proposition is useful because it gives us an easy heuristic rule to determine how inefficient is the U.S. allocation of subsidies from a supply-reduction perspective. We provide a proof of the derivation of $\overline{m}$ in the Appendix.

The proposition suggests that, for a given set of U.S. expenditures, the U.S. is likely to be over-investing in eradication whenever $\frac{\Lambda_q}{\Lambda_h}$ is small. Thus, lower shares s_{fg} and s_l make it more likely that the marginal cost of eradication is higher. This does not contradict our discussion in Proposition 4 because here we are holding expenditures constant. This proposition is simply saying that expenditures should, in principle, be proportional to factor shares in an efficient allocation.

Likewise, all factors that reduce $\frac{\Lambda_q}{\Lambda_h}$ discussed in Proposition 1 reduce $\overline{m}$. Namely, a larger elasticity of substitution in production, σ_{fg}, and a lower elasticity of substitution in trafficking, σ_c. Efficiency requires total expenditures to reflect the different effectiveness of policies, captured by a lower $\overline{m}$.

The empirical observation that the share of land is small, and the adjustment patterns— captured by a large σ_{fg} and small σ_c— favor interdiction, requires expenditures in eradication to be lower relative to expenditures in interdiction. However, during Plan Colombia, expenditures in eradication were significantly larger than expenditures in interdiction, a pattern that is indicative of too many resources being allocated to eradication.

Finally, the above proposition also clarifies the role of the agency problem. If the U.S. is interested in reducing supply, it should anticipate that subsidies will lead to expenditures in both fronts depending on c_1 and c_2, as shown in equations 8 and 12. Suppose $c_1 > c_2$, so that the Colombian government has a political interest in reducing land cultivated with coca. To achieve efficiency, the U.S. must undo this distortion by assigning less subsidies to eradication, as to maintain its relative expenditures on both fronts equal to $\overline{m}$. In practice, the local government may not like this assignment and prefer higher subsidies for this front, creating an interesting divergence of interests when coordinating and financing source-country interventions.

6 Using the model to understand the cocaine market response to Plan Colombia

In this section we present the main empirical patterns observed during the implementation of Plan Colombia, and use our model to make sense of them. We focus on data from 2000 to 2008, when Plan Colombia received the highest levels of funding, though we also mention some recent developments in the cocaine market.

We think of Plan Colombia as an increase in both $1-\omega$ and $1-\Omega$. We confirm this view using data from the U.S. General Accountability Office GAO (2008). According to this report, the U.S. disbursed roughly \$593 million per year to Plan Colombia from 2000 to 2008, out of which \$408 million were used to subsidize programs related to eradication, and the remaining \$185 million subsidized programs related to interdiction efforts.[18]

Though we do not directly observe the fraction of land effectively controlled by producers, nor the fraction of routes effectively controlled by traffickers, we have two intuitive proxies for both. We use the fraction of land used for coca cultivation as our proxy for q.[19]. For the fraction of routes controlled by traffickers, we use as a proxy the fraction of cocaine not seized by Colombian authorities.[20] This proxy is arguably less straightforward than the one for q, but we still think it gives us a reasonable idea concerning the dynamics of the control over routes. For instance, one would expect seizures to be frequent on routes not controlled by traffickers, and infrequent or zero on routes under their effective control. Likewise, one could interpret seizures as an iceberg cost of exporting more cocaine through fewer routes.

Figure 2 shows that q increased until 1998, as coca cultivation shifted from Peru to Colombia. However, following the implementation of Plan Colombia it decreased sharply, from 0.32 to 0.17.

[18]See the working paper version of this paper Mejía and Restrepo (2008) for the details of how we constructed these numbers and more information regarding the U.S. expenditure figures.

[19]Grossman and Mejía (2008) estimate that the potential arable land contested for coca cultivation (L in the model) is around 500,000 hectares. We thus construct our proxy for q using the UNODC data for coca cultivation in Colombia, divided by 500,000 hectares. One alternative is to use total cultivation divided by cultivation plus the land where crops were eradicated. The pattern is similar, but this measure leaves out the gains in the control of land that was never cultivated in the first place.

[20]Cocaine seizures and potential cocaine production were both obtained from UNODC yearly reports (See UNODC, 2013).

Likewise, the figure reveals a simultaneous decline in h from 0.91 to 0.78. Importantly, this is not simply driven by a fall in production, but the level of seizures also increased significantly during this period, specially in 2008. To summarize, it is reasonable to assume that, in terms of supply reduction, the main achievement of Plan Colombia was the reduction in q and h of 63% and 16%, respectively, from 2000 to 2008.

The decline in q and h is consistent with a large increase in subsidies for eradication and interdiction from 0— before Plan Colombia— to $1 - \omega = 0.57$ and $1 - \Omega = 0.65$ afterwards (see equations 8 and 12). We take the values $\omega = 0.43$ and $\Omega = 0.35$ as a natural benchmark for our quantitative predictions. These imply that Colombia spent roughly \$314 million in eradication efforts and \$100 million in interdiction efforts per year during Plan Colombia. Unfortunately, we do not have good data on Colombian expenditures by component to verify this, but it certainly matches the view that the government emphasized primarily eradication efforts from 2000 to 2008.

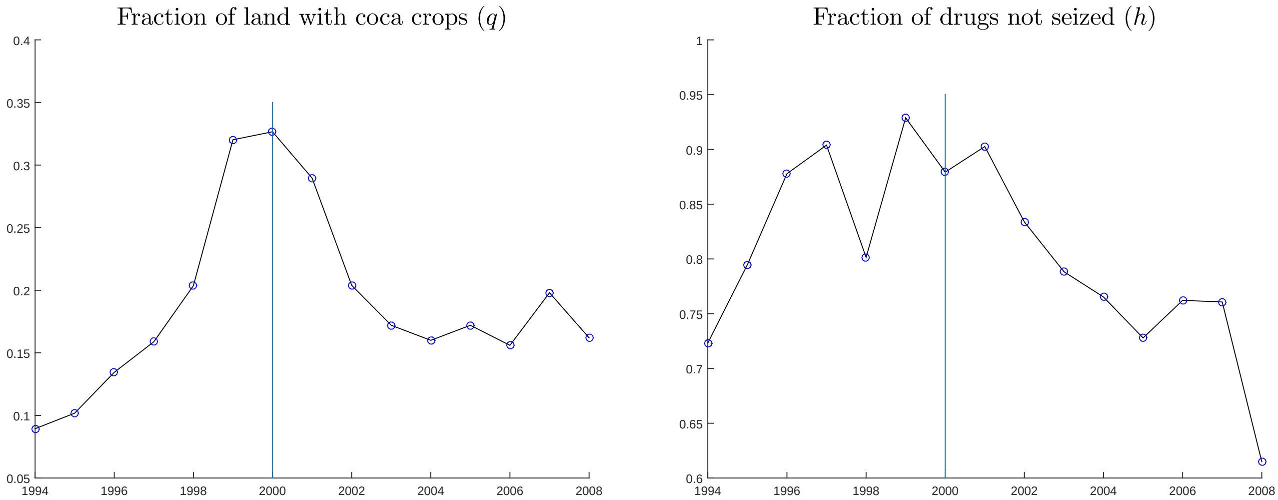

Figure 2: Increase in eradication and interdiction efforts during Plan Colombia.

Nevertheless, and despite the large drop in land and routes controlled by producers and traffickers, there was no similar effect on quantities. The left panel in Figure 3 plots data for potential cocaine production in Colombia (dotted line) and the estimated amount of drugs successfully trafficked from Colombia to transit countries. As it is apparent from the figure, potential cocaine production fell only by 24%, while the amount of Colombian cocaine transacted in transit countries, Q_c, decreased by about 32%, from 600 metric tons (MT) prior to Plan Colombia, to about 400 MT afterwards.

This is somewhat paradoxical, since a naive model would predict that a fall in land of this magnitude should have led to a similar contraction in production. In fact, Plan Colombia was supposed to halve cocaine production by reducing cultivation by 50% by 2006.[21] Our framework and

[21] One of the main objectives of Plan Colombia, as stated in the original documents when the *Plan* was launched in 1999, was to reduce cocaine production by 50% within a period of 6 years (that is, *circa* 2006).

the adjustment margins described in Proposition 1, suggest that the possibility of substituting for other inputs – and the fact that land and routes represent only a fraction of the price of Colombian cocaine – implies that the drop in q and h will only affect quantities with some elasticities smaller than one, contrary to what a naive model would suggest.

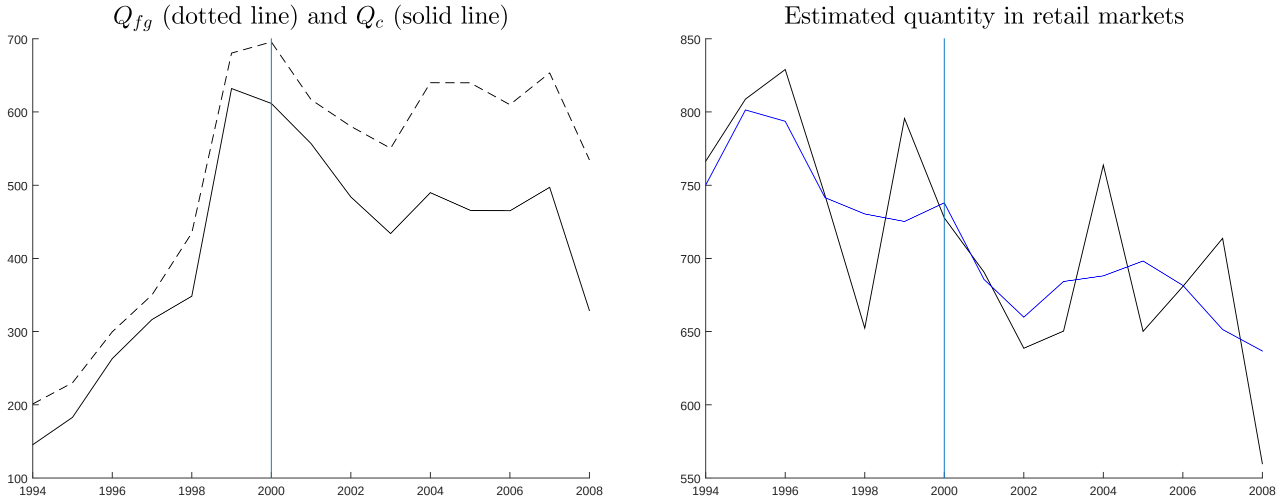

Figure 3: Farm gate production, cocaine trafficked from Colombia (left panel) and estimated cocaine at the retail level (right panel).

As stated in Proposition 1, the main reason why reductions in q — or eradication policies— have a limited effects on the supply of cocaine, is because markets adjust by increasing land productivity. This is exactly what the data in Figure 4 shows. Since 2001, the 24% price increase in farm gate prices from $1,571 to about $2,000 dollars per kg coincided with a significant increase (of about 40%) in yields per hectare, from about 4.4 kg of cocaine/hectare/year before 2000 to about 6.6 kg of cocaine/hectare/year during the period 2005 - 2008. Using the formula in equation 13, we see that the increase in productivity reflects the high elasticity of substitution between land and complementary factors in the production of cocaine. Our model thus explains the puzzling increase in yields and ties it to the unobserved elasticity of substitution σ_{fg}.

Figure 3 plots retail quantities and their three-year moving average. It shows that, leaving the declining trend aside, there was no large drop in retail quantities despite the intensification of supply-reduction policies in Colombia, and the reduction in Colombian supply. This is specially the case for the early years of our sample, when efforts were aimed specially at eradication, but were not reflected in changes in downstream markets in the U.S.. Though these comparisons may be clouded by several confounding factors (trends, policies in other countries, changes in consumption, and so on), we see them as consistent with the intuitions developed in Proposition 2. In particular, the value of Colombian cocaine outside the country represents only about 6-7% of the total value added of the trade, suggesting that the observed reductions in the Colombian supply will tend to have small downstream effects unless they significantly increase the price of

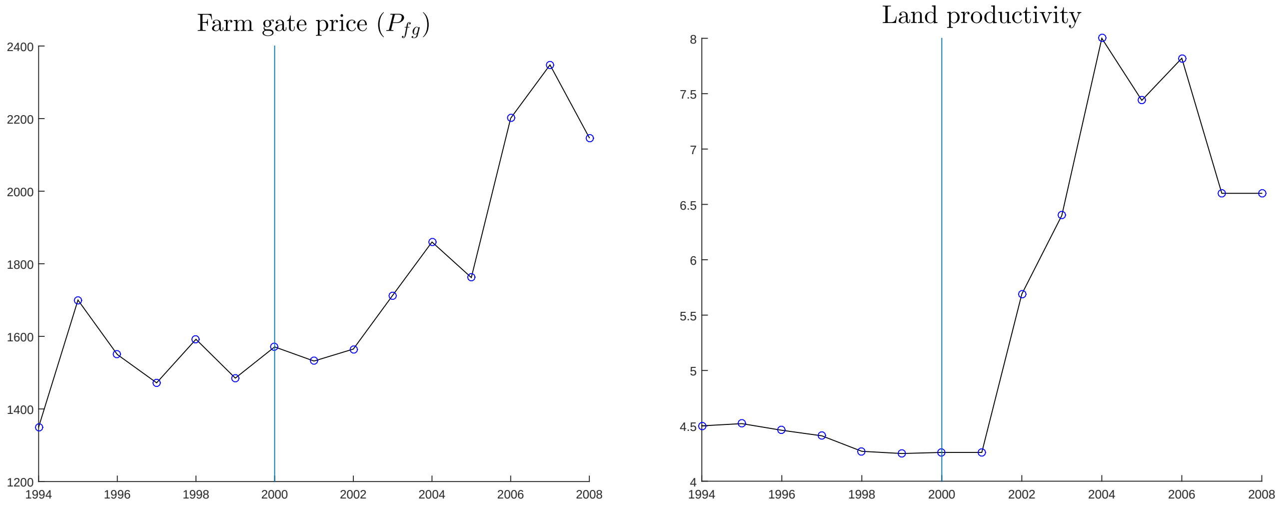

Figure 4: Increase in farm gate prices and land productivity.

Colombian cocaine.[22]

Since 2008 these patterns have changed significantly, as interdiction efforts increased while eradication efforts were scaled-down. Consistent with Proposition 1, interdiction had a strong scale effect on the farm-gate market, reducing prices and land productivity— as observed since 2008. Moreover, there is some evidence that the shift towards interdiction may have had larger effects on cocaine markets (see for instance Figure 3). Presumably, the emphasis in interdiction led to a further increase in route prices (which we cannot observe) and small changes in farm-gate prices, with larger effects in downstream markets. We see these patterns as highly consistent with the intuitions developed in Proposition 1.

Our model also suggests that displacement effects are another factor rendering retail quantities and prices less reactive to interventions in Colombia. We find strong empirical support for this idea. Figure 5 shows that the increase in farm gate prices in Colombia brought about by Plan Colombia led markets to substitute Colombian cocaine for the relatively cheaper cocaine from Peru or Bolivia. Following Plan Colombia, the 32% decline in Colombian cocaine transacted in transit markets was partially compensated by an increase in the supply from Peru and Bolivia. As a consequence, and despite the intensification of the war on drugs in Colombia, the estimated amount of cocaine transacted in transit countries fell only by 6%. Remarkably, the opposite phenomenon occurred between 1994 and 2000, when production shifted from Peru to Colombia,

[22] More specifically, about 800 metric tons of cocaine reach transit markets and about 650 metric tons are actually sold in retail markets, with 54% of the cocaine coming from Colombia. Therefore $s_c = 54\%$, and $s_o = 46\%$. Moreover, according to different accounts, cocaine in transit countries is transacted at around \$10,000 per kg, while the retail price is around \$150,000 per kg, which implies that $s_t \approx 8\%$. The only case in which the effects in retail markets will be large is if σ_f is sufficiently low, so that the demand for Colombian cocaine becomes inelastic, and the price of Colombian cocaine rises sharply.

when Peru intensified its interdiction policies.

Figure 5: Regional production patterns among different source countries.

7 Calibration and model predictions

To get a rough idea of the size of the adjustment margins in our model, we calibrate the key elasticities of substitution to match as closely as possible the observed changes in aggregate variables following the implementation of Plan Colombia. In particular, we compute the values for $\sigma_{fg}, \sigma_c, \sigma_t, \sigma_f$ and ε_o^s in order to match the observed changes in land productivity, Q_{fg}, P_{fg}, Q_t and Q_o described in the previous section, following the observed decline in q and h.[23] We make three adjustments. First, we remove trends from production in Peru and Bolivia, which appear to be under a secular increase (potentially) unrelated to Plan Colombia. By doing so, we obtain the targets listed in Table 1.[24] Second, we impose an elasticity of consumers' demand of 0.5, which we use as our benchmark value.[25] Finally, we use observed factor shares obtained from UNODC reports, and described in Mejía and Rico (2010).

The targets we match have the advantage that they are clearly related to the parameters capturing how the cocaine market adjusts following changes in interdiction and eradication. For instance, the change in productivity is informative about the extent of substitution σ_{fg}; while σ_c

[23]In a previous version of this paper, we included the change in Q_c as an additional moment. However, this is mechanically collinear with the change in h and Q_{fg}, providing no information.

[24]Removing these trends gives us a conservative estimate of the extent of displacement effects, captured by σ_t and ε_{st}. With larger values, we obtain larger marginal costs for both fronts of the war on drugs.

[25]This is widely believed to be the case for drugs, especially for cocaine. Becker et al. (2006) summarize the evidence of an elasticity of less than 1 for most drugs, with a central tendency towards 1/2. See also (Bachman et al., 1990), (DiNardo, 1993) and (Saffer and Chaloupka, 1999).

determines the demand elasticity for farm-gate cocaine and how the adjustment splits between prices and quantities. Likewise, the increase in production in other countries is informative about σ_t and ε_o^s. Finally, σ_f determines the elasticity of demand for Q_t, and therefore it is related to the fall in Q_t. However, we recognize that other changes different from Plan Colombia may be driving some of the matched observations, and that the data is not of ideal quality. Moreover, we do not have non-targeted moments to verify the out-of sample predictive power of our model. These limitations must be kept in mind when interpreting our findings, and we prefer to think of this exercise as an informed calibration suggestive of the quantitative implications of our model.

Table 1 summarizes the targeted changes, the imposed parameters and shares, the resulting estimates and the predicted fit of the model. As demonstrated, the model does a good job matching the observed changes (not surprising given that we are matching these moments with the same number of parameters). The parameters are also in line with our knowledge of the drug market and the stylized facts presented in the previous section. We find that $\sigma_{fg} = 1.09$, suggesting that farm-gate cocaine is approximately a Cobb-Douglas in land and complementary factors, and allowing producers to significantly increase land productivity by investing on complementary factors, a. Instead, we find $\sigma_c = 0.51$, suggesting that farm-gate cocaine and routes are gross-complements, as one would intuitively expect. We also obtain $\sigma_t = 2.38$ and $\varepsilon_o^s = 2.62$, which reflect extensive possibilities to substitute Colombian cocaine for cocaine from other sources. Finally, we obtain $\sigma_f = 0.86$, suggesting some reasonable possibilities of substitution in downstream markets.

Using these parameters, we are able to calculate the predicted changes in unobservable prices and quantities. The model predicts a sharp increase in the shadow price of land, which is probably caused by the observed emphasis on eradication campaigns during Plan Colombia. Instead, the price of routes, which could be more easily increased via interdiction and has a larger impact on retail prices, only increased modestly during Plan Colombia. Interestingly, our model suggests this occurs because interdiction efforts were not as strong, for most of the years analyzed, and because the reduction in land creates a scale effect in the Colombian market leading to a lower demand for routes.

The predicted effect of Plan Colombia on prices diminishes as we move downstream: While we observe an increase of about 24% in farm-gate prices, the model predicts an increase of 13% for Colombian prices in transit, 8% for cocaine in transit and only 0.7% for consumer prices. These diminishing effects reflect the possibilities to substitute for more elastic factors of production as we move downstream. More importantly, the predicted reduction in retail quantities attributed to Plan Colombia is about 0.33%, suggesting a negligible effect in retail markets in consumer markets.[26]

[26]Our model predicts a lower decrease in Q_c than the one observed. This has to do with the way in which we compute h, which certainly understates the scope of interdiction efforts by not taking into account shipments that were never sent because of the lack of routes or drugs that are lost while being transported and not reported. If

Table 1: Calibration of elasticities of substitution and supply.

	Panel A: Targeted changes.				
	Productivity	$d\ln Q_{fg}$	$d\ln P_{fg}$	$d\ln Q_t$	$d\ln Q_o$
Observed in data:	40.55%	-24.88%	24.14%	-6.38%	6.41%
Predicted by the model:	39.49%	-23.76%	24.14%	-6.77%	6.59%
	Panel B: Estimated parameters.				
	σ_{fg}	σ_c	σ_t	ε_o^s	σ_f
Calibrated value	1.09	0.51	2.38	2.62	0.86
	Panel C: Imposed parameters.				
	ε_d^f	s_l	s_{fg}	s_c	s_t
Imposed value	0.50	0.40	0.31	0.54	0.08
	Panel D: Model predictions				
	$d\ln P_l$	$d\ln P_r$	$d\ln P_c$	$d\ln P_t$	$d\ln P_f$
Change in prices	60.36%	7.77%	12.86%	8.13%	0.66%
	$d\ln a$	$d\ln b$	$d\ln Q_c$	$d\ln Q_f$	
Change in quantities	2.57%	0.24%	-18.01%	-0.33%	
	ε_t^d	ε_c^d	ε_{fg}^d	ε_{fg}^s	ε_c^s
Elasticities	0.83	1.40	0.64	1.64	0.16

Notes: Panel A summarizes the observed changes in the aggregate data used to match the model, and the ones predicted using the calibrated set of parameters. Panel B presents the obtained parameters. Panel C summarizes the imposed parameters we already observed in the data. Panel D shows the model predicted price changes and other unobservable quantity changes attributable to Plan Colombia. It also presents the implied elasticities of demand and supply at each stage.

Our model also predicts that Plan Colombia increased investments in complementary factors, a, and, b, by 2.57% and 0.24%. Thus, reductions in land and routes are strongly compensated by changes in these complementary factors, which keep supply in downstream markets from falling. The reason why a and b increase is because $\sigma_{fg} > \varepsilon_{fg}^d$ and $\sigma_f > \varepsilon_f^d$, implying that as land and routes became scarce with Plan Colombia, the substitution effect at these stages dominated and led to these countervailing investments.

We believe both effects are quite plausible and we emphasize this here since these margins of adjustment play key roles in keeping retail prices down. Indeed, as explained in the introduction and targeted in the calibration, we observe a sharp increase in land productivity. The observed increase in productivity has taken many different forms; among others, the use of stronger and bigger coca plants, a higher density of coca plants per hectare, better planting techniques, and the

we adjust h to match the decrease in Q_c, we would require it to fall by about 35%. Using this change for h yields similar results and does not change our conclusions.

use of more efficient chemical precursors in the processing of coca leaf into cocaine. As an example, cocaine producers developed what they call the "continuous process," whereby they are able to produce cocaine hydrochloride starting from cocaine paste without stopping in obtaining solid cocaine base. By using this new method, they have been able to increase production efficiency in terms of the use of chemical precursors[27], saving time and minimizing losses (SIMCI, 2015). The use of more efficient methods can be broadly classified as greater use of the complementary factors embodied in a. Likewise, the anecdotal evidence suggests that trafficking and distribution networks abroad became more productive during this period— that is, reduced their cost per unit delivered to consumers. For instance, cartels in Mexico and *transportistas* in the Caribbean have introduced sophisticated ways of smuggling cocaine to the U.S., including submarines, tunnels across the border, and better distribution networks connecting transit countries with retail markets in consumer countries. Likewise, distribution networks tapped into online anonymous markets. Though we do not think all these changes were a response to upstream changes brought about by Plan Colombia, we believe they illustrate the extensive margins of adjustment available to traffickers and distributors in downstream markets, modeled here as embodied in b.

The bottom panel also reports the implied elasticities of demand and supply at the relevant stages of the drug market (see the Appendix for details on how we computed them). Two features are noteworthy: First, despite the inelastic consumers' demand, the demand for Colombian cocaine is elastic. This is a consequence of the possibilities to substitute for other sources. This results rationalizes why countries like Colombia find it worthwhile to fight producers and traffickers on their own; by doing so, they are able to shift production to other source countries and reduce the size of the domestic drug market with all of its associated costs. Interestingly, and as discussed in Proposition 5, if all source countries think alike, they would end up increasing the drug market size regionally because $\varepsilon_t^d < 1$. Second, $\varepsilon_c^d > \sigma_c$— which coincides with the case discussed in the propositions. This means that scale effects dominate substitution effects in the Colombian market. The consequences are that eradication leads to a decline in the price of routes, becoming less effective at raising prices; while interdiction also reduces the demand for farm-gate cocaine, land productivity and to a lesser extent land prices. We believe this scenario is plausible, and may explain why the current emphasis in interdiction policies adopted by the Colombian government since 2008 has led to lower land productivity and somewhat lower farm-gate prices, as discussed above.

[27]The continuous process requires less potassium permanganate, as it is not necessary to carry out the re-oxidation of cocaine base.

7.1 The marginal costs of reducing cocaine supply

Our formula for the marginal costs also requires estimates for P_f, c_1, c_2, ϕ— the effectiveness of the producer in the conflict for land— and γ— the effectiveness of the trafficker in the conflict for routes. We set $c_1 = 0.71$ and $c_2 = 0.15$ in order to match the Colombian yearly expenditure level for each front ($314 million in eradication subsidies and $100 million in interdiction efforts). The fact that $c_1 > c_2$ is consistent with our view that the government emphasized eradication for most of the years of Plan Colombia (presumably because it perceived targeting large armed groups involved in the production stage as a political or security priority).[28] We also set $\phi = 0.33$ and $\gamma = 1.55$ in order to match the observed levels of q and h. Finally, we set $P_f = 150,000$ following UNODC (2013).

Our parameters imply that $MC_\omega = \$940,900$ and $MC_\Omega = \$175,273$. As our calculation in the introduction suggests, these are large numbers when compared to other policies, such as treatment and prevention, which have a marginal cost below $\$60,000$. To understand the role of the key parameters determining both the size and difference in these costs and explore the sensitivity of our findings, we examine how these marginal costs change as we impose different values of our parameters.

Table 2 analyzes the role of the adjustment mechanisms in the Colombian cocaine market, emphasized in Proposition 1. In particular, the table shows how the implied marginal costs change as we vary the elasticities of substitution σ_c and σ_{fg}. Consistent with our theoretical results, the marginal cost of reducing retail quantities by subsidizing eradication sharply increases with σ_{fg} and decreases with σ_c. The marginal cost of reducing retail quantities by subsidizing interdiction increases mildly with σ_{fg}. This is because expenditures on eradication are high relative to interdiction, and the effect brought about by the savings in eradication costs dominates. This point is exemplified by the top left corner marginal cost, which is actually negative, indicating large savings in eradication costs for this particular configuration of parameters. Finally, σ_c increases the marginal cost MC_ω. Importantly, the obtained marginal costs are all larger than those of alternative policies, especially whenever $\sigma_{fg} > 1$.

Summarizing, the low value of σ_c together with the large value of σ_{fg}, which are both intuitive and apparent from the data, imply a large marginal cost for eradication and a lower (though still large) marginal cost for interdiction. As explained in Proposition 4, this occurs because eradication does not increases the price of land as much— as it is easy to substitute it— and actually decreases the price of routes, leading to a small increase in Colombian cocaine prices. On the other hand,

[28] Ideally, we would prefer to estimate these costs from expenditures reported by the Colombian government, but these are not available. In any case, we do not want to push the interpretation of these costs too far, as they are only a modeling tool for capturing the Colombian government's incentives rather than a true measure of the social costs of cocaine production and trafficking in Colombia.

interdiction is more effective at increasing the price of routes, which are harder to substitute, while it does not affect as much the price of land, so long as σ_{fg} is large. Since the price of land represents only a small fraction of the Colombian price, while the price of routes represents a larger fraction, interdiction is more effective at increasing the price of Colombian cocaine and affecting downstream markets. Importantly, the table shows that for eradication to be as cost-effective as interdiction, we would need implausibly high levels of σ_c and low levels of σ_{fg}, which are at odds with the data.

Table 2: Marginal costs and the role of substitution in the Colombian market.

	Marginal cost subsidizing eradication MC_ω					
	$\sigma_{fg} = 0.1$	$\sigma_{fg} = 0.5$	$\sigma_{fg} = 1$	$\sigma_{fg} = 1.5$	$\sigma_{fg} = 2$	$\sigma_{fg} = 5$
$\sigma_c = 0.1$	\$2117.071	\$2745.502	\$3531.039	\$4316.577	\$5102.114	\$9815.339
$\sigma_c = 0.5$	\$602.863	\$744.241	\$920.964	\$1097.687	\$1274.409	\$2334.745
$\sigma_c = 1$	\$413.587	\$494.084	\$594.705	\$695.325	\$795.946	\$1399.671
$\sigma_c = 2$	\$318.949	\$369.005	\$431.575	\$494.145	\$556.715	\$932.134
$\sigma_c = 5$	\$262.166	\$293.958	\$333.697	\$373.436	\$413.176	\$651.612
	Marginal cost subsidizing interdiction MC_Ω					
	$\sigma_{fg} = 0.1$	$\sigma_{fg} = 0.5$	$\sigma_{fg} = 1$	$\sigma_{fg} = 1.5$	$\sigma_{fg} = 2$	$\sigma_{fg} = 5$
$\sigma_c = 0.1$	\$-97.959	\$90.436	\$127.232	\$140.541	\$147.410	\$160.154
$\sigma_c = 0.5$	\$143.379	\$164.806	\$173.511	\$177.467	\$179.728	\$184.391
$\sigma_c = 1$	\$208.960	\$209.959	\$210.534	\$210.843	\$211.036	\$211.480
$\sigma_c = 2$	\$248.614	\$251.008	\$252.846	\$254.035	\$254.868	\$257.102
$\sigma_c = 5$	\$275.178	\$288.487	\$301.668	\$312.121	\$320.615	\$350.173

Notes: The table presents the estimated marginal costs obtained by imposing different values of the elasticities of substitution σ_{fg} and σ_c.

Table 3 examines the role of displacement effects explained in Proposition 5. In particular, the table shows how the implied marginal costs change as we vary the elasticities σ_t and ε^s_o — capturing the extent of displacement. Our parameters imply that $\sigma_t > \varepsilon^d_t$, so that reductions in the Colombian supply will be compensated by increasing the quantities supplied by other countries; that is, the substitution effect dominates in this case. Moreover, the high estimated elasticity of supply, ε^s_o, implies displacement will occur without raising consumer prices. The table shows that, indeed, displacement effects— captured by larger values of σ_t and ε^s_o— play a major role in increasing the marginal costs of source country interventions. However, the table also shows that a higher elasticity of substitution increases marginal costs so long as other sources' supply is sufficiently elastic (an elasticity slightly above 0.5 is enough in our case). Otherwise, the resulting price increases in other sources will also be passed to consumers. Likewise, a more elastic supply ε_o^s makes source country interventions less effective only when $\sigma_t > \varepsilon_t^d$, and the substitution effect dominates. These observations combined imply that the large values obtained in the calibration for both σ_t and ε_o^s, and reflecting the sharp increase in production in other source countries following the implementation of Plan Colombia, make both marginal costs large.

Table 3: Marginal costs and the role of displacement effects.

	Marginal cost subsidizing eradication MC_ω					
	$\sigma_t = 0.5$	$\sigma_t = 1$	$\sigma_t = 1.5$	$\sigma_t = 2$	$\sigma_t = 5$	$\sigma_t = 10$
$\varepsilon_o^s = 0$	\$754.896	\$699.238	\$680.685	\$671.409	\$654.712	\$649.146
$\varepsilon_o^s = 0.5$	\$681.171	\$720.225	\$739.753	\$751.469	\$777.033	\$787.177
$\varepsilon_o^s = 1$	\$656.595	\$730.719	\$775.194	\$804.843	\$878.967	\$912.659
$\varepsilon_o^s = 1.5$	\$644.308	\$737.015	\$798.821	\$842.967	\$965.219	\$1027.231
$\varepsilon_o^s = 2$	\$636.935	\$741.213	\$815.697	\$871.560	\$1039.149	\$1132.254
$\varepsilon_o^s = 5$	\$620.850	\$751.707	\$862.432	\$957.339	\$1327.477	\$1615.362
	Marginal cost subsidizing eradication MC_Ω					
	$\sigma_t = 0.5$	$\sigma_t = 1$	$\sigma_t = 1.5$	$\sigma_t = 2$	$\sigma_t = 5$	$\sigma_t = 10$
$\varepsilon_o^s = 0$	\$160.953	\$139.720	\$132.643	\$129.104	\$122.734	\$120.611
$\varepsilon_o^s = 0.5$	\$144.422	\$143.840	\$143.549	\$143.375	\$142.994	\$142.843
$\varepsilon_o^s = 1$	\$138.912	\$145.900	\$150.093	\$152.888	\$159.877	\$163.053
$\varepsilon_o^s = 1.5$	\$136.156	\$147.136	\$154.456	\$159.684	\$174.162	\$181.507
$\varepsilon_o^s = 2$	\$134.503	\$147.960	\$157.572	\$164.781	\$186.407	\$198.422
$\varepsilon_o^s = 5$	\$130.896	\$150.020	\$166.201	\$180.071	\$234.162	\$276.234

Notes: The table presents the estimated marginal costs obtained by imposing different values of the elasticities of substitution σ_t and supply from other sources ε_o^s.

Table 4 examines the role of the elasticity of demand in retail markets, which is a key parameter we imposed in our calibration. As noted in Proposition 7, the low value assumed for the elasticity of demand explains to a great extent the high marginal costs for both fronts. Importantly, a higher elasticity of demand not only makes both policies more effective— by raising Λ_q and Λ_h, but also reduces the cost of making important advances on both fronts— by lowering C_q and C_h, as discussed in the proposition. This is because a more elastic demand implies that the respective shadow prices of land and routes do not increase as much with supply reduction policies; keeping the willingness of producers and traffickers to fight back against the Colombian government checked. Importantly, even when we allow an implausibly large demand elasticity of 1.5, source country interventions are still more costly than treatment and prevention policies in consumer countries (though interdiction approaches the upper range of estimates for the costs of these alternative policies).

Table 4: Costs, effectiveness and the role of the elasticity of demand.

	Elasticity of consumers' demand					
	$\varepsilon_f^d = 0.25$	$\varepsilon_f^d = 0.5$	$\varepsilon_f^d = 0.75$	$\varepsilon_f^d = 1$	$\varepsilon_f^d = 1.25$	$\varepsilon_f^d = 1.5$
MC_ω	\$1859.293	\$940.360	\$634.049	\$480.893	\$389.000	\$327.738
C_q	\$57375.097	\$57355.280	\$57335.922	\$57317.008	\$57298.523	\$57280.452
Λ_q	0.001	0.002	0.002	0.003	0.004	0.005
MC_Ω	\$347.074	\$175.273	\$118.005	\$89.372	\$72.192	\$60.738
C_h	\$21784.955	\$21744.646	\$21705.272	\$21666.801	\$21629.201	\$21592.445
Λ_h	0.008	0.015	0.022	0.029	0.036	0.043

Notes: The table presents the estimated marginal costs obtained by imposing different values of the elasticity of demand ε_f^d.

Finally, we discuss the implications of our model for the efficiency of the allocation of subsidies. As shown in the previous tables, we find throughout that $MC_\omega > MC_\Omega$. Indeed, using the calibrated parameters we obtain $\overline{m} = 0.5$. This small value is driven by the low share of land, the low value of σ_c and the large value of σ_{fg}. The fact that we observe expenditures for eradication that are twice as high as those for interdiction, suggests an inefficient allocation of resources from a supply reduction perspective. The inefficiency arises for three reasons: First, given the low share of land, the efficient allocation of resources involves the U.S. spending a proportional share of resources in eradication, given that the cost of making advancements in this front is proportional to the value of land. Spending beyond this proportion corresponds to making too many efforts in this front, and these efforts run into diminishing returns. Second, given the domestic substitution patterns determined by the low σ_c and large σ_{fg}, and their effects emphasized in Table 2, the efficient allocation involves even lower expenditures in eradication. Finally, these forces may be exacerbated by the fact that $c_1 > c_2$. If the U.S. does not anticipate the Colombian government incentives it would also end up subsidizing eradication efforts in excess.

Though more speculative, the finding that the U.S. subsidizes eradication efforts excessively is interesting in its own right and could reflect several possibilities. First, it could be that the U.S. does not know, or ignores, the political objectives of source country leaders, and fails to adjust its subsidies to take into account that Colombia will tend to invest more in eradication because $c_1 > c_2$. Second, it could be that Colombia itself has a say in the allocation of subsidies, pushing the U.S. to grant more subsidies to eradication. Finally, it could be that the U.S. has other simultaneous objectives besides supply reduction, like fighting insurgent movements in the region. Eradication efforts may be preferred because they target directly the stages where left-wing guerrillas and illegal armed groups in Colombia are most involved .

8 Concluding remarks

In this paper, we propose a model of the war on drugs in source countries, inspired by the experience of Colombia under Plan Colombia. Our model incorporates several features that we judge to be relevant to understand the effects of supply-side interventions in drug producing countries. First, we explicitly model all successive levels of the drug trade, from cultivation to distribution. Second, we allow actors to substitute for cheaper inputs in response to price changes created by supply reduction programs in source countries. In particular, we allow producers to substitute land for chemical precursors and other factors of production that are complementary to land in the production of hard drugs, such as cocaine or heroine; traffickers to substitute routes for more cocaine being shipped; and downstream markets to substitute for other sources of drugs or to invest in factors that improve its distribution capabilities. All of these responses shape the way in which source country interventions affect quantities and prices throughout the whole production and distribution chain.

We model anti-narcotic efforts as a conflict over scarce inputs at successive levels of the production and trafficking chain. We also incorporate the fact that source countries implement policies with partial funding from an interested outsider (e.g., the government of a consumer country interested in reducing supply), so there is potentially an agency problem. The U.S., or other consumer countries, wishing to curb supply in their domestic markets have to rely on subsidies to strengthen the resolve of producer and transit countries in their war against producer and traffickers.

We use the model to study Plan Colombia, a large-scale intervention in Colombia aimed at reducing the supply of cocaine by targeting illicit crops and the illegal armed groups' control of routes for transporting drugs outside the country, two of the main inputs in the production and trafficking of cocaine. The model fits many of the patterns observed in the data and help us interpret some puzzling findings. For instance, the model explains why, despite the large increase in eradication and interdiction in Colombia, retail and wholesale markets in the U.S. remained essentially unaffected. The model also explains the large increase in land productivity observed following the implementation of Plan Colombia, and the recent shift in production towards Peru and Bolivia.

For a reasonable set of parameters, our model predicts that the marginal cost to the U.S. of reducing by one kilogram the amount of cocaine transacted in retail markets is about \$940,360 if resources are allocated to subsidizing eradication efforts; and about \$175,273 if resorces are allocated to subsidizing interdiction efforts in Colombia. Both numbers are large. MacCoun and Reuter (2001) estimate that it would cost the U.S. about \$8,250 and between \$12,500 and \$68,750 per year to reduce consumption by the same amount (one kg) using treatment and prevention policies, respectively. Source country interventions such as Plan Colombia, therefore, are very costly strategies for curbing the supply of drugs in consumer countries relative to these alternatives.

Source-country interventions are also socially costly strategies. To justify subsidies for interdiction (the most cost-effective program), one would need to argue that 1kg of cocaine supplied in retail markets has a social cost of about $325,000 (the marginal cost of enforcement plus the private valuation by consumers – e.g., the price). We do not know of estimates for these social costs, but we find the number to be too large to be accepted without further evidence. Our numerical exercise suggests that interventions such as Plan Colombia are inefficient and socially costly ways of reducing drug consumption. More so if one takes into account the share of expenditures paid by Colombia, as well as the violence and externalities created by the war on drugs in source, transit and consumer countries.

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Appendix, not for publication

A1 Hicks and Marshall's rules

LEMMA 1 (Marshall Rules): A producer in a perfectly competitive environment combines two inputs, x_1, x_2. to produce a unique good, y, using a constant returns to scale technology $F : \mathbb{R}^2 \to \mathbb{R}$, which is quasi-concave and continuously differentiable. The elasticity of substitution between inputs is σ, while their current shares are s and $1-s$ for x_1 and x_2, respectively. Let ε_s^i, be the elasticity of supply of input i, and let ε_d be the elasticity of demand for output. Following a small increase in p_1 of $d\ln p_1$, we find that in the optimum, all prices and quantities change by:

$$
\begin{aligned}
d\ln p_1 &= d\ln p_1, && \text{(A1)}\\
d\ln p_2 &= \frac{s(\sigma-\varepsilon_d)}{s(\sigma+\varepsilon_s^2)+(1-s)(\varepsilon_s^2+\varepsilon_d)} d\ln p_1, && \text{(A2)}\\
d\ln x_1 &= -\frac{s(\sigma+\varepsilon_s^2)\varepsilon_d+(1-s)(\varepsilon_s^2+\varepsilon_d)\sigma}{s(\sigma+\varepsilon_s^2)+(1-s)(\varepsilon_s^2+\varepsilon_d)} d\ln p_1, && \text{(A3)}\\
d\ln x_2 &= \frac{s(\sigma-\varepsilon_d)\varepsilon_s^2}{s(\sigma+\varepsilon_s^2)+(1-s)(\varepsilon_s^2+\varepsilon_d)} d\ln p_1, && \text{(A4)}\\
d\ln p &= \frac{s(\sigma+\varepsilon_s^2)}{s(\sigma+\varepsilon_s^2)+(1-s)(\varepsilon_s^2+\varepsilon_d)} d\ln p_1, && \text{(A5)}\\
d\ln y &= -\frac{s(\sigma+\varepsilon_s^2)\varepsilon_d}{s(\sigma+\varepsilon_s^2)+(1-s)(\varepsilon_s^2+\varepsilon_d)} d\ln p_1. && \text{(A6)}
\end{aligned}
$$

This implies that the elasticity of demand for the input x_1 is given by

$$
\frac{s(\sigma+\varepsilon_s^2)\varepsilon_d+(1-s)(\varepsilon_s^2+\varepsilon_d)\sigma}{s(\sigma+\varepsilon_s^2)+(1-s)(\varepsilon_s^2+\varepsilon_d)}. \tag{A7}
$$

Proof: The thought experiment underlying this calculation is as follows. Imagine that the price for x_1 increases exogenously. How does the quantity of x_1 used change, taking into account the change in x_2 along its supply curve? Let p_1 and p_2 be the prices for x_1 and x_2, respectively; and p the price of one unit of output. The CRS and competitive markets assumptions imply that

$$
p = \min_{x_1', x_2'} x_1' p_1 + x_2' p_2 \text{ s.t: } F(x_1', x_2') = 1.
$$

Using the envelope theorem, we get (this applies because of the regularity assumptions on F)

$$
d\ln p = s_1 d\ln p_1 + s_2 d\ln p_2, \tag{A8}
$$

and using Euler's theorem, we get

$$
d\ln y = s_1 d\ln x_1 + s_2 d\ln x_2. \tag{A9}
$$

Lastly, by the definition of the elasticity of substitution, we have

$$\sigma(d\ln p_1 - d\ln p_2) = d\ln x_2 - d\ln x_1. \tag{A10}$$

Since we are moving along the (induced) demand curve of x_1, we get

$$d\ln x_1 = -\varepsilon_d^1 d\ln p_1, \tag{A11}$$

where ε_d^1 is the induced elasticity of demand for the input. Also, since we are moving along the supply curve of x_2 we get

$$d\ln x_2 = \varepsilon_s^2 d\ln p_2. \tag{A12}$$

Finally, since we are moving along the demand curve of y, we get

$$d\ln y = \varepsilon_d d\ln p. \tag{A13}$$

Equations A8, A9, A10, A11, A12 and A13 define a system of equations in $d\ln p_2$, $d\ln x_1$, $d\ln x_2$, $d\ln p$, $d\ln y$, ε_1^d in terms of all the parameters and the exogenous change in $d\ln p_1$. Since the system is homogeneous in $d\ln p_1, d\ln p_2, d\ln x_1, d\ln x_2, d\ln p, d\ln y$, then clearly the implied value for ε_1^d is independent of $d\ln p_1$. Solving the system yields

$$\varepsilon_1^d = \frac{s(\sigma+\varepsilon_s^2)\varepsilon_d + (1-s)(\varepsilon_s^2+\varepsilon_d)\sigma}{s(\sigma+\varepsilon_s^2)+(1-s)(\varepsilon_s^2+\varepsilon_d)}. \tag{A14}$$

The expressions for the other variables are also interesting, because they tell us how the endogenous variables react to a shock that changes the supply of x_1, ultimately increasing its price by $d\ln p_1$. These expressions are as given above.

Corollary 1: The effect of an increase in the price of x_1 of $d\ln p_1$ on the productivity of this input (the unit of output per unit of input used) is given by

$$\frac{(1-s)(\varepsilon_s^2+\varepsilon_d)\sigma}{s(\sigma+\varepsilon_s^2)+(1-s)(\varepsilon_s^2+\varepsilon_d)} d\ln p_1 > 0. \tag{A15}$$

Proof: This follows directly from computing $d\ln y - d\ln x_1$ using the above formulas. This ratio increases because of the q-complementarity between inputs.

LEMMA 2: A producer in a perfectly competitive environment combines two inputs, x_1 and x_2, to produce a unique good, y, using a constant returns to scale technology $F : \mathbb{R}^2 \to \mathbb{R}$, which is quasi-concave and continuously differentiable. The elasticity of substitution between inputs is σ, and their current shares are s and $1-s$ for x_1 and x_2, respectively. Let ε_s^i be the elasticity of supply of input i, and let ε_d be the elasticity of demand for the output. The induced elasticity of the supply of y (assuming the input markets are at equilibrium) is

$$\begin{aligned}
d\ln p_1 &= \frac{\sigma+\varepsilon_2^s}{s_1(\sigma+\varepsilon_2^s)+s_2(\sigma+\varepsilon_1^s)}d\ln p, && \text{(A16)}\\
d\ln p_2 &= \frac{\sigma+\varepsilon_1^s}{s_1(\sigma+\varepsilon_2^s)+s_2(\sigma+\varepsilon_1^s)}d\ln p, && \text{(A17)}\\
d\ln x_1 &= \frac{(\sigma+\varepsilon_2^s)\varepsilon_1^s}{s_1(\sigma+\varepsilon_2^s)+s_2(\sigma+\varepsilon_1^s)}d\ln p, && \text{(A18)}\\
d\ln x_2 &= \frac{(\sigma+\varepsilon_1^s)\varepsilon_2^s}{s_1(\sigma+\varepsilon_2^s)+s_2(\sigma+\varepsilon_1^s)}d\ln p, && \text{(A19)}\\
d\ln y &= \left(\frac{(\sigma+\varepsilon_2^s)s_1\varepsilon_1^s}{s_1(\sigma+\varepsilon_2^s)+s_2(\sigma+\varepsilon_1^s)}+\frac{(\sigma+\varepsilon_1^s)s_2\varepsilon_2^s}{s_1(\sigma+\varepsilon_2^s)+s_2(\sigma+\varepsilon_1^s)}\right)d\ln p. && \text{(A20)}
\end{aligned}$$

This implies a price elasticity of supply equal to

$$\frac{(\sigma+\varepsilon_2^s)s_1\varepsilon_1^s}{s_1(\sigma+\varepsilon_2^s)+s_2(\sigma+\varepsilon_1^s)}+\frac{(\sigma+\varepsilon_1^s)s_2\varepsilon_2^s}{s_1(\sigma+\varepsilon_2^s)+s_2(\sigma+\varepsilon_1^s)}. \tag{A21}$$

Proof: First, it is worth clarifying what the proposition says. Standard producer theory suggests that the supply of a firm with a CRS technology is perfectly elastic, or fixed at one price. However, since the inputs themselves are provided with some elasticity, this creates an upward slopping supply for output. The thought experiment thus assumes that input markets are in equilibrium and then asks what happens to the supplied quantity when the output price increases.

As before, we use the envelope theorem, Euler's theorem and the definition of the elasticity of substitution in equations A8, A9 and A10 hold. Moreover, since we are on the supply curve for x_1 and x_2, we get

$$d\ln x_i = \varepsilon_s^i d\ln p_i, \tag{A22}$$

for $i = 1, 2$.

Using these relationships, we get a system of equations in $d\ln p_1, d\ln p_2, d\ln x_1, d\ln x_2, d\ln y$, with $d\ln p$ taken as given (recall the thought experiment). Solving it yields the above results.

A2 Proof of propositions 1 and 2

This section describes the steps required to arrive to Propositions 1 and 2.

We focus on how changes in Ω and ω affect the equilibrium quantities and prices of drugs transacted at the farm gate and trafficking markets. For the sake of notational simplicity, we do not index equilibrium variables with an *. Also, demand elasticities are always given in absolute terms, since all demands are downward slopping in this model.

Suppose the U.S. subsidizes more eradication (e.g., sets a lower ω). We have the following consequences:

- Equation 8 implies that q *falls* by $d\ln q > 0$, as the government of the drug producing country now experiences a lower cost of investing resources in eradication efforts.

- The shadow price of land, P_l, increases by

  $$d\ln P_l = \frac{1}{\varepsilon_l^d} d\ln q > 0.$$

  The elasticity of demand for land, $\varepsilon_l^d > 0$ (in absolute terms), can be computed recursively, as discussed in the appendix, and is given by:

  $$\varepsilon_l^d = s_l \varepsilon_{fg}^d + (1 - s_l)\sigma_{fg}.$$

  The elasticity of demand for land is a weighted average of the elasticity of substitution and elasticity of demand faced by the producer. A higher elasticity of substitution at the farm gate level implies that eradication efforts do not significantly increase land prices; making eradication less effective at raising prices.

- An increase in P_l driven by a lower supply of land increases the use of the complementary factor a. The corollary of lemma 1 in the appendix implies that, due to $q-$complementarities, land productivity increases by

  $$(1 - s_l)\sigma_{fg} d\ln P_l > 0$$

  Thus, our model endogenously predicts an increase in the productivity of land as a result of an increase in eradication efforts in Colombia. According to this equation, a large observed increase in land productivity implies a large elasticity of substitution, σ_{fg}, and under such a setting one ought to expect that eradication becomes less effective at increasing the price of Colombian cocaine.

- An increase in P_l raises the price of farm gate cocaine by

  $$d\ln P_{fg} = s_l d\ln P_l > 0,$$

  which captures the fact that if land is relatively unimportant (e.g., if it has a low share, s_l), an increase in its price will not translate into a large increase in the farm gate price of cocaine.

- The drug trafficker reacts to an increase in P_{fg} by demanding less farm gate cocaine:

  $$d\ln Q_{fg} = -\varepsilon_{fg}^d d\ln P_{fg} < 0.$$

  The demand elasticity for farm gate cocaine is derived recursively in the appendix and is given by

  $$\varepsilon_{fg}^d = \frac{\sigma_c \varepsilon_c^d}{s_{fg}\sigma_c + (1 - s_{fg})\varepsilon_c^d}.$$

- An increase in the price of farm gate cocaine has two effects on the value of routes. First, it generates a substitution effect that leads the trafficker to substitute farm gate cocaine for a more intensive use of routes, thus increasing his demand for the latter. Second, it generates a scale effect, which brings about a contraction in the size of the trafficker's operations, as he now operates at a larger marginal cost. If $\sigma_c > \varepsilon_c^d$, the substitution effect dominates the scale effect, causing an increase in the demand for routes (otherwise, the opposite happens). Since the supply of routes is fixed at hR, this translates into a change in the shadow price of routes that is given by

$$d\ln P_r = \frac{s_{fg}(\sigma_c - \varepsilon_c^d)}{s_{fg}\sigma_c + (1-s_{fg})\varepsilon_c^d} d\ln P_{fg} \lesseqgtr 0$$

  The analysis above shows that when $\sigma_c > \varepsilon_c^d$, the shadow price of routes increases, as does its market value. In this case, a negative feedback exists between different anti-drug policies, as more eradication efforts increase the cost of implementing interdiction efforts by raising traffickers' valuation of routes. When $\sigma_c < \varepsilon_c^d$, the opposite happens, and there is a positive feedback between the two policies.

- P_c, increases by:

$$d\ln P_c = \frac{s_{fg}\sigma_c}{s_{fg}\sigma_c + (1-s_{fg})\varepsilon_c^d} d\ln P_{fg} = s_{fg} d\ln P_{fg} + (1-s_{fg}) d\ln P_r > 0.$$

  This equation captures the fact that the increase in prices needs to cover the extra cost of purchasing more expensive farm gate cocaine. This is why the increase in P_c is proportional to the share of farm gate drugs, s_{fg}.

Now, suppose the U.S. subsidizes interdiction more (e.g., sets a lower Ω). We have the following consequences:

- Equation 12 implies that h falls by $d\ln h > 0$.

- The shadow price of routes, P_r, increases by

$$d\ln P_r = \frac{1}{\varepsilon_r^d} d\ln h > 0.$$

  The elasticity of the demand for routes, which determines the size of the price increase, is derived recursively in the appendix, and is given by:

$$\varepsilon_r^d = \frac{s_r(\sigma_c + \varepsilon_{fg}^s)\varepsilon_c^d + (1-s_r)(\varepsilon_{fg}^s + \varepsilon_c^d)\sigma_c}{s_r(\sigma_c + \varepsilon_{fg}^s) + (1-s_r)(\varepsilon_{fg}^s + \varepsilon_c^d)}.$$

  This formula already accounts for the fact that the trafficker can partially substitute routes for farm gate cocaine and perceives an elasticity in the demand for his products of ε_c^d. This elasticity increases with σ_c, as the trafficker can substitute for them buying more cocaine at the farm gate in order to achieve the desired level of trafficking operations. This formula also accounts for the fact that farm gate cocaine is supplied with an elasticity given by:

$$\varepsilon^s_{fg} = \frac{s_a}{s_l}\sigma_{fg},$$

which increases with σ_{fg}. Thus, a higher σ_{fg} leads to a more elastic demand for routes, as a substitute can be purchased without significantly affecting its price.

- An increase in P_r gives rise to two opposing effects on the trafficker's demand for farm gate cocaine: a substitution and a scale effect, as explained above. When $\sigma_c > \varepsilon^d_c$, the substitution effect dominates and the increase in P_r causes a net increase in the demand for farm gate cocaine; otherwise, the opposite happens. The corresponding change in the farm gate price of cocaine is given by

$$d\ln P_{fg} = \frac{s_r(\sigma_c - \varepsilon^d_c)}{s_r(\sigma_c + \varepsilon^s_{fg}) + (1 - s_r)(\varepsilon^s_{fg} + \varepsilon^d_c)} d\ln P_r \lesseqgtr 0.$$

$$\varepsilon^s_{fg} = \frac{s_a}{s_l}\sigma_{fg},$$

As above, when $\sigma_c < \varepsilon^d_c$, policies are complementary: increasing interdiction reduces the demand for farm-gate cocaine, reducing land productivity and its value.

- Finally, an increase in P_r, by raising the trafficker's marginal cost, leads to an increase in the price of cocaine in transit markets of

$$d\ln P_c = \frac{s_r(\sigma_c + \varepsilon^s_{fg})}{s_r(\sigma_c + \varepsilon^s_{fg}) + (1 - s_r)(\varepsilon^s_{fg} + \varepsilon^d_c)} d\ln P_r = s_r d\ln P_r + (1 - s_r)d\ln P_{fg} > 0.$$

This equation captures the fact that the increase in prices has to cover the extra cost of purchasing more expensive routes. This is why the increase in P_c is proportional to the share of routes, s_r.

The analysis above suggests that interdiction and eradication affect downstream markets only though the induced increase in P_c; that is, by shifting the supply of Colombian cocaine. However, the above analysis also shows that both policies affect P_c with different elasticities, depending on factor shares and possibilities for substitution in production and trafficking.

We now analyze how these increases in Colombian cocaine prices, $d\ln P_c > 0$, affect downstream markets and other source countries.

- Downstream markets respond to an increase in P_c by demanding less Colombian cocaine:

$$d\ln Q_c = -\varepsilon^d_c d\ln P_c < 0.$$

The elasticity of demand for Colombian cocaine in transit markets faced by the trafficker as derived in the appendix is given by

$$\varepsilon_c^d = \frac{s_c(\sigma_t + \varepsilon_o^s)\varepsilon_t^d + (1 - s_c)(\varepsilon_o^s + \varepsilon_t^d)\sigma_t}{s_c(\sigma_t + \varepsilon_o^s) + (1 - s_c)(\varepsilon_o^s + \varepsilon_t^d)}.$$

This elasticity accounts for the fact that downstream markets can obtain cocaine from other source countries as a substitute, and that this cocaine is supplied with an elasticity ε_o^s.

- The effect on the quantity of cocaine from other source countries is given by

$$d \ln Q_o = \frac{s_c(\sigma_t - \varepsilon_t^d)\varepsilon_o^s}{s_c(\sigma_t + \varepsilon_o^s) + (1 - s_c)(\varepsilon_o^s + \varepsilon_t^d)} d \ln P_c \lesseqgtr,$$

while the corresponding increase in price is given by

$$d \ln P_o = \frac{s_c(\sigma_t - \varepsilon_t^d)}{s_c(\sigma_t + \varepsilon_o^s) + (1 - s_c)(\varepsilon_o^s + \varepsilon_t^d)} d \ln P_c \lesseqgtr .$$

If $\sigma_t > \varepsilon_t^d$, the substitution effect dominates, and the quantity of cocaine demanded from other sources increases, leading to the so-called displacement effect, whereby supply-reduction efforts in Colombia increase the production of cocaine in other source countries. Displacement effects are stronger when σ_t and ε_o^s are large.

- The price of the cocaine aggregate, Q_t, increases by

$$d \ln P_t = \frac{s_c(\sigma_t + \varepsilon_o^s)}{s_c(\sigma_t + \varepsilon_o^s) + (1 - s_c)(\varepsilon_o^s + \varepsilon_t^d)} d \ln P_c = s_c d \ln P_c + (1 - s_c) d \ln P_o > 0.$$

This equation captures two features. The first reflects the fact that the increase in prices needs to cover the extra cost of purchasing more expensive Colombian cocaine. This is why the increase in P_c is proportional to the share of farm gate cocaine, s_c. Second, it shows that displacement effects (captured by a large σ_t and ε_o^s) reduce the increase of prices in downstream markets, by providing an elastic alternative to Colombian cocaine.

- Despite the possibilities to substitute, the cocaine aggregate falls by

$$d \ln Q_t = -\varepsilon_t^d d \ln P_t < 0.$$

The price elasticity of demand for cocaine in transit countries, which determines the size of the adjustment in quantities, is given recursively by

$$\varepsilon_t^d = s_t \varepsilon_f^d + (1 - s_t)\sigma_f.$$

This relates recursively all demand elasticities to the elasticity of consumers' demand (which is exogenous), the market structure and technologies. A higher elasticity of substitution, σ_f, implies that upstream markets face a more elastic demand; hence, supply reduction efforts in source countries become less effective, because downstream markets compensate by investing in better distribution networks , and so on.

- The price of cocaine for final consumers in retail markets increases by

$$d \ln P_f = s_t d \ln P_t. \tag{A23}$$

This simply reflects the fact that the cost of drugs in transit countries is only a share of the total cost; as a result, only a small increase in the consumer price is required to cover the extra cost. Likewise, the effect of an increase in the price of Colombian cocaine on the retail price is proportional to the share of its value in retail markets, $s_t s_c$— though the exact formula is more complicated.

- Finally, the decrease in the quantity of cocaine transacted in retail markets is given by

$$d \ln Q_f = -\varepsilon_f^d d \ln P_f.$$

A smaller elasticity of the demand of final consumers, ε_f^d, which is taken as exogenous, makes supply reduction policies less effective in reducing quantities.

A3 Derivation of the elasticities of demand and supply at different stages

If we apply Lemma 1 to the problem solved by the drug producer, we obtain the price elasticities of the producer's demand for land and complementary factors as follows:

$$\varepsilon_l^d = s_l \varepsilon_{fg}^d + (1 - s_l)\sigma_{fg}, \quad \varepsilon_a^d = \frac{\sigma_{fg}\varepsilon_{fg}^d}{s_a \sigma_{fg} + (1 - s_a)\varepsilon_{fg}^d}. \tag{A24}$$

Also, applying Lemma 2 to the problem in equation 1, we obtain the price elasticity of the producer's supply of cocaine in the farm gate market as follows:

$$\varepsilon_{fg}^s = \frac{s_a}{s_l}\sigma_{fg}. \tag{A25}$$

In the application of both lemmas, we use the fact that chemicals and complementary factors, a, are supplied at a constant price, while land is supplied inelastically, since we have fixed q. The elasticity of the demand for land allows us to understand how a reduction in the fraction of land held by the producer, q, translates into a higher shadow price for land.

If we apply Lemma 1 to the problem solved by the trafficker, we obtain the price elasticities of the trafficker's demand for farm gate cocaine and routes, as follows:

$$\varepsilon_{fg}^d = \frac{\sigma_c \varepsilon_c^d}{s_{fg}\sigma_c + (1 - s_{fg})\varepsilon_c^d}, \quad \varepsilon_r^d = \frac{s_r(\sigma_c + \varepsilon_{fg}^s)\varepsilon_c^d + (1 - s_r)(\varepsilon_{fg}^s + \varepsilon_c^d)\sigma_c}{s_r(\sigma_c + \varepsilon_{fg}^s) + (1 - s_r)(\varepsilon_{fg}^s + \varepsilon_c^d)}, \tag{A26}$$

where ε_{fg}^s is the price elasticity of the supply of farm gate cocaine in Colombia, obtained above. The price elasticity of the demand for farm gate cocaine allows us to understand how shifts in the farm gate supply, caused by a reduction in q, affect farm gate prices and quantities. The price elasticity of the (shadow) demand for routes allows us to understand how a reduction in the fraction of routes held by the trafficker, h, affects their shadow price, and subsequently the price of Colombian cocaine in transit.

Applying Lemma 2 to the trafficker's problem, we obtain the price elasticity of the trafficker's supply of Colombian cocaine in the trafficking market, as follows:

$$\varepsilon_c^s = \frac{s_{fg}\sigma_c}{s_{fg}\sigma_c + s_r(\varepsilon_{fg}^s + \sigma_t)}\varepsilon_{fg}^s. \tag{A27}$$

Again, here we use the fact that routes are supplied inelastically, since we have fixed h.

The elasticities in downstream markets can also be characterized using the lemmas. Marshall's law implies that the induced price elasticity of the demand for Q_c is equal to

$$\varepsilon_c^d = \frac{s_c(\sigma_t + \varepsilon_o^s)\varepsilon_t^d + (1 - s_c)(\varepsilon_o^s + \varepsilon_t^d)\sigma_t}{s_c(\sigma_t + \varepsilon_o^s) + (1 - s_c)(\varepsilon_o^s + \varepsilon_t^d)}, \tag{A28}$$

where, again, the price elasticity of demand for Colombian cocaine by the international drug dealer is a weighted average of his own (shadow) price elasticity of demand for Q_t and the elasticity of substitution between Colombian cocaine and cocaine from other source countries.

Similarly, Marshall's law implies that the induced elasticity of demand for Q_t is equal to

$$\varepsilon_t^d = s_t\varepsilon_f^d + (1 - s_t)\sigma_f. \tag{A29}$$

Finally, applying lemma 2 in the appendix twice, we obtain the price elasticity of the cocaine supply in retail markets as

$$\varepsilon_f^s = \frac{1}{s_t}\left(\frac{s_c(\varepsilon_o^s + \sigma_t)}{s_c(\varepsilon_o^s + \sigma_t) + s_o(\varepsilon_c^s + \sigma_t)}\varepsilon_c^s + \frac{s_o(\varepsilon_c^s + \sigma_t)}{s_c(\varepsilon_o^s + \sigma_t) + s_o(\varepsilon_c^s + \sigma_t)}\varepsilon_o^s\right) + \frac{s_b}{s_t}\sigma_f. \tag{A30}$$

Here, ε_c^s is the price elasticity of cocaine being trafficked from Colombia.

Using the above formulas, we can compute all demand and supply elasticities in terms of the observed shares, the elasticities of substitution and the price elasticity of consumers' demand, ε_f^d, and the price elasticity of the supply from other countries, ε_o^s. These formulas already assume that all remaining markets are in equilibrium, so we can directly use the price elasticities of the demand for land and routes to find the equilibrium effect of a change in q or h on the equilibrium prices of land and routes, respectively. We can then use the rest of lemmas 1 and 2 to understand how price changes affect the whole system. What the reader should bear in mind is that, by recursively using the above formulas, we are able to derive explicit formulas for all of the relevant price elasticities of supply and demand in terms of observed shares, s, the elasticities of substitution, σ, and exogenous elasticities ε_f^d and ε_o^s. The fact that complementary factors a and b are supplied at constant prices is already embedded in the formulas, such that they can be generalized to allow for arbitrary price elasticities in the supply of these inputs.

A4 Derivation of $\overline{m}$.

Let $TC^{\omega}_{US} = \phi(1-q)^2 P_l L$ and $TC^{\Omega}_{US} = \gamma(1-h)^2 P_r R$ be the total U.S. expenditure in subsidizing eradication and interdiction, respectively. We can rewrite the marginal costs in equations 16 and 17 as:

$$MC_{\omega} = \frac{1}{\Lambda_q}\frac{TC^{\omega}_{US}}{Q_f}\left(\frac{1}{\omega(1-\omega)}q^2(1-q) + 2\frac{q}{1-q} + \frac{1}{\varepsilon^d_l}\right) + \frac{1}{\Lambda_q}\frac{TC^{\Omega}_{US}}{Q_f}\frac{d\ln P_r}{d\ln q}, \tag{A31}$$

and

$$MC_{\Omega} = \frac{1}{\Lambda_h}\frac{TC^{\Omega}_{US}}{Q_f}\left(\frac{1}{\Omega(1-\Omega)}h^2(1-h) + 2\frac{h}{1-h} + \frac{1}{\varepsilon^d_r}\right) + \frac{1}{\Lambda_h}\frac{TC^{\omega}_{US}}{Q_f}\frac{d\ln P_l}{d\ln h}. \tag{A32}$$

Equating both marginal costs we obtain the desired expression for $\overline{m}$.