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

Daniel Mejia[†]

Pascual Restrepo[‡]

Abstract

We model the war on drugs in source countries as a conflict over scarce inputs of successive levels of the production and trafficking chain. We explicitly model the vertical structure of the drug trade as being composed of several stages, and study how different policies aimed at different stages affect the supply, prices and input markets. 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 illegal armed groups' control of the routes used to transport drugs outside of the country - two of the main inputs of the production and trafficking chain. The model fits many of the patterns found in the data and sheds light on certain puzzling findings. For a reasonable set of parameters that match well the data on the war on drugs under Plan Colombia, our model predicts that the marginal cost to the U.S. of reducing the amount of cocaine transacted in retail markets by one kilogram is \$1'631.900 if resources are allocated to eradication efforts; and \$267.450 per kilogram if resources are allocated to interdiction efforts.

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

JEL Classification Numbers: D74, K42.

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La economía de la guerra contra la producción y tráfico de drogas*

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Pascual Restrepo[‡]

Abstract

En este artículo proponemos un modelo de la guerra contra las drogas, en donde existe un conflicto por factores intermedios escasos de eslabones sucesivos de la cadena de producción y tráfico de drogas ilegales. Para esto, modelamos de manera explícita la estructura vertical del tráfico de drogas, la cual esta compuesta por varios eslabones, y estudiamos como políticas enfocadas en diferentes eslabones de la cadena afectan la oferta, los precios y los mercados de insumos intermedios para la producción de drogas. Luego, usamos el modelo para estudiar el Plan Colombia, una intervención de gran escala enfocada en reducir la oferta de drogas mediante el combate a los cultivos ilícitos y el control de las rutas de narcotráfico que utilizan organizaciones ilegales para traficar drogas. El modelo se ajusta a muchos de los patrones observados en los datos y explica algunos resultados extraños, observados luego de la puesta en marcha del Plan Colombia. Para un conjunto razonable de parámetros que se ajustan bien a los datos observados de la guerra contra las drogas bajo el Plan Colombia, nuestro modelo predice que el costo marginal para Estados Unidos de reducir en 1 kg adicional la cantidad de cocaína transada en mercados minoristas en este país es de \$1'631.900 dólares, si los subsidios se asignan a esfuerzos de erradicación de cultivos ilícitos, y de \$267.450 por kg si los subsidios son asignados a labores de interdicción en Colombia.

Palabras clave: Drogas duras, Conflicto, Guerra contra las drogas, Plan Colombia.

Códigos JEL: D74, K42.

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1 Introduction

Ever since Richard Nixon formally declared a war on drugs in 1971, different anti-drug policies have been implemented in producer, transit and consumer countries. Throughout this war, source and transit countries such as Colombia (where about 70% of the cocaine consumed worldwide is produced), Afghanistan and Mexico have continuously tried to curb the supply of drugs by designing and implementing different anti-drug strategies such as the eradication of illicit crops, the detection and destruction of processing labs used to produce hard drugs, and the interdiction of drug shipments en route to final consumer countries.

In September 1999, the Colombian government announced the launch of 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; the Colombian government spent about \$7.3 billion on this program during the same period. Joint expenditures per year on the military component of Plan Colombia have been, on average, \$1.3 billion per year, which corresponds to about 1.2% of Colombia's average yearly GDP during the period in question. Despite the large amount of resources invested in the war on drugs in Colombia since 2000, 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 17% (from 689,000 kg per year from 1998 to 2000, to 573,000 kg per year on average from 2005 to 2008). This apparently paradoxical outcome can be explained by what has been a significant increase in yields per hectare, from roughly 4.3 kg of cocaine per hectare per year prior to 2000, to about 6.7 kg of cocaine per hectare per year from 2005 to 2008.¹ Furthermore, consistent with the observed patterns of potential cocaine production, the wholesale price of cocaine in Colombia remained relatively stable during this period.²

¹These increases in productivity have taken many different forms, among others, the development of stronger and bigger coca plants, higher densities of coca plants per hectare, better planting techniques, and the use of more efficient chemical precursors in processing coca leaves into cocaine.

²See Mejía and Posada (2008) for a thorough description of the main stylized facts related to cocaine markets, both in producer and consumer countries. Despite the recent intensification of the war on cocaine, market prices at the wholesale and retail levels have remained relatively stable during the last seven years, while consumption trends have not shown any decreasing tendency. See also the evidence cited in Caulkins and Hao (2008), as well as

In this paper, we construct a model of the war on drugs in producer countries in order to study the effects of source country interventions aimed at curbing the supply of illegal drugs. The construction of our model is inspired by Plan Colombia, but its insights are more broadly applicable to any country where drugs are produced and shipped from to consumer markets, such as Mexico or Afghanistan. We model the drug trade as a market composed of several vertical stages, starting with production in the source country and followed by trafficking to transit countries. Drugs are then transported to consumer countries via downstream markets. Source country interventions take place on two fronts. First is the eradication front, where policies are aimed at reducing the cultivation of the illicit crops (coca or opium poppy) required to produce hard drugs (cocaine or heroin, respectively). Second is the interdiction front, where policies are aimed at reducing the use of the routes required to transport the drugs from the source country to transit markets. Our model allows us to study the impact of these policies on equilibrium prices and quantities in source countries and downstream markets, inclusive of their impact on retail prices and quantities.

Our model incorporates several economic forces usually absent in a more reduced form analysis of the supply of drugs, likewise in most policy discussions about the costs and effectiveness of supply-side interventions. First, we allow producers to combine land and complementary factors in producing cocaine, which creates the potential for substitution following increased eradication. This endogenously predicts an increase in land productivity as a result of eradication campaigns, thus rendering policies aimed at eradication less effective at curbing drug production. We also allow traffickers to combine routes and cocaine into a trafficking technology, which also affects the way that eradication and interdiction efforts affect the price of Colombian cocaine in transit countries. Our model also incorporates two relevant features of downstream markets. More specifically, it allows for the possibility that international drug traffickers can buy cocaine from other source countries when the price of Colombian cocaine increases; and it lets international drug traffickers invest in other factors so as to increase the amount of cocaine delivered to final consumers. Such factors include the labor used in distribution networks, bribing government officials to avoid interdiction, etc. Both of these features affect the manner in which increases in the price of Colombian cocaine translate into changes in consumer prices and affect the regional allocation of production. As we will see, the possibility of substituting for cocaine from other source countries coupled with a highly elastic supply in those countries makes supply reduction efforts in one source country less cost effective, because of the possibility of reallocating crops from one country to another. Likewise, the presence of other factors that can increase the amount of cocaine delivered to consumers renders source country interventions less cost effective.

Following Grossman and Mejía (2008), we model eradication and interdiction as conflicts over the control of arable land and routes, respectively. The conflictive nature of enforcement implies

the yearly reports of the United Nations Office for Drug and Crime (UNODC).

that the cost of making important advances on each front is proportional to the economic value of the respective inputs being target in each case, as this increases the willingness of producers and traffickers to avoid government efforts. We also explicitly model the fact that most source country interventions are implemented locally, with partial funding from consumer countries hoping to reduce the availability of drugs and increase their price. 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. Both innovations imply a richer framework for understanding the costs of making important advances in the war on drugs in both producer and transit countries. The possibility that targeting less valuable inputs would be less costly— due to way in which we model enforcement in illegal drug markets— changes previous conclusions that suggested that policies aimed at disrupting these inputs were less desirable because they only had a limited effect on prices. Our framework suggest that this has to be weighed against the fact that such interventions would actually be less costly to implement *vis-à-vis* interventions aimed at other parts of the distribution chain.

We study Plan Colombia and some of the aggregate data under the optic of our model. Our model helps us to understand several stylized facts of the war on drugs under Plan Colombia. For example, our model predicts an increase in land productivity following an intensification of eradication campaigns, as observed in the data on Colombia. Our model also suggests that despite large increases in eradication and interdiction efforts, there are only limited effects on retail quantities and prices. This is because the respected inputs only correspond to a small share of the whole drug trade, and because producers, traffickers and downstream markets will substitute in the direction of cheaper inputs. Consistent with this prediction, the wholesale and retail price of cocaine remained relatively stable during these years.³ Our model also predicts a large substitution of cocaine from other source countries. For example, following the implementation of Plan Colombia, Peru and Bolivia - the other two producers of cocaine in the Andean region - increased their production significantly.

In a more ambitious exercise, we use the observed data and patterns to back up reasonable values for our model's parameters. Using these parameters, we estimate different measures of the costs and efficiency of the anti-drug policies implemented in Colombia between 2000 and 2008, and explore their main determinants and some quantitative implications. According to our results, the marginal cost to the U.S. of reducing the quantity of Colombian cocaine transacted in retail markets in consumer countries by one kilogram is about \$1,631,900, if American assistance is used to subsidize eradication efforts in Colombia (e.g., it is used against drug producers over the control of arable land). By contrast, the marginal cost is approximately \$267,450 if the assistance is used

³See Mejía and Posada (2008) for a thorough description of the main stylized facts related to cocaine markets, both in producer and consumer countries.

to subsidize interdiction efforts (e.g., it is used against drug traffickers over the control of the routes used to transport illicit drug shipments). Both of these numbers are quite large. 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. This implies marginal costs of reducing consumption by 1kg using treatment of \$8,250 versus prevention between \$12,500 and \$68,750, respectively. Correspondingly, source country interventions, such as Plan Colombia, are very costly strategies for curbing the supply of drugs in consumer countries relative to other available strategies such as prevention and treatment.

1.1 Related Literature

Little is known regarding the effects, costs and efficiency of anti-drug policies implemented in producer and transit countries. There is a small but growing empirical literature on Plan Colombia. Dube and Naidu (2009) explore some of the unintended consequences of the initiative. In particular, they examine the impact of U.S. military assistance on the intensity of the conflict in Colombia, and find that it has led to an increase in the number of paramilitary attacks, while having no effect on the number of guerrilla attacks. Mejia, Restrepo and Rozo (2013) use a regression discontinuity design that exploits Colombia's diplomatic compromise of not carrying out more aerial spraying campaigns after 2008 in a 10 km strip in the border with Ecuador in order to assess the impact of this anti-drug strategy on coca cultivation. They find that spraying campaigns have a statistically significant but small effect on coca cultivation, consistent with the large marginal cost estimated in our paper following a different methodology. Finally, Rozo (2013) uses an IV strategy that exploits the location of natural and indigenous reserves, where spraying campaigns cannot be used, in order to estimate their effects on the productivity of coca cultivation and other outcomes, finding negative and significant effects of on different productivity measures. For other countries, Dell (2013) uses a regression discontinuity approach in the election of Mexican mayors and documents strong ballooning effects. This is also a central theme in our model. More specifically, the author shows that following the election of a PAN mayor (i.e., a mayor from the same party as president Calderon), drug routes reallocated to neighboring municipalities. For the U.S., Kuziemko and Levitt (2004) examine a panel of states to show that the imprisonment of drug offenders tends to increase drug prices, consistent with an inward shift in supply. However, further empirical assessments of the cost effectiveness of supply reduction policies are hard to produce given the partial equilibrium nature of these exercises, the potential for spillovers, the lack of good data, and the lack of exogenous sources of variation in the intensive or extensive margins of different anti-drug strategies. Under such a scenario our approach of building a model becomes a valuable alternative.

Most of the available literature on the effects of anti-drug policies has focused on partial equilibrium analysis. Caulkins, Feichtinger and Tragler (2001) and Rydell, Caulkins and Everingham (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. 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).

However, the market for illegal drugs hides complex interactions that should be addressed using models that can account for feedback effects between policies, prices and the consequent strategic reactions of the actors involved in the drug trade and the war on drugs, especially when evaluating large-scale policy interventions such as Plan Colombia. Important papers incorporating these effects are Becker, Murphy and Grossman (2006), Naranjo (2007), Chumacero (2008), Costa Storti and De Grauwe (2009), and Mejía and Restrepo (2011). These papers explicitly model illegal drug markets when analyzing the effects of anti-drug policies. Becker et al. (2006) show how the social costs of fighting against drugs crucially depends on the price elasticity of the demand for drugs. More specifically, they show that if the demand for drugs is inelastic, policies aimed at reducing the supply of drugs by punishing dealers are socially optimal only when the negative externalities associated with drug consumption are sufficiently high. Naranjo (2007) develops a model in which insurgent groups provide security for drug producers in exchange for a fraction of the drug output. He finds that supply side interventions may have a counter-productive effect on the drug industry and may escalate conflict. Costa Storti and De Grauwe (2009), and Mejía and Restrepo (2011) focus on the interrelationship between anti-drug policies aimed at reducing the demand for drugs (such as treatment and prevention policies in consumer countries) and those aimed at reducing the supply of drugs (by means of interdiction and increased enforcement). Finally, Jeff Miron analyses the costs of drug prohibition (Miron and Zwiebel (1995)) and the budgetary consequences of drug legalization in the U.S. (Miron (2010)). None of these contributions focuses on evaluating the costs, effectiveness and future prospects of the war on illegal drugs in producer countries, nor are they aimed at evaluating actual anti-drug policies. This paper does both.

2 The Model

We model drug production in a source country as the first stage of successive levels in a vertical competitive market where all agents involved are price takers.⁴ Although the model is general

⁴In our view, this is a better approximation of reality 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 ter-

enough, the motivation for constructing it is based on the case of Colombia and the cocaine trade. Thus, we refer to cocaine as the illegal drug being produced and traded 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 North America. In both Mexico and Afghanistan, the respective governments design and implement policies aimed at reducing the supply of drugs with partial funding from other (i.e., consumer) countries.

Figure 1 presents a diagram of the actors, markets and technologies involved in our model. The following subsection describes the diagram and the market structure in detail. It is useful for readers to keep the diagram in mind as they proceed through the next section.

Figure 1: Diagram of the actors, markets and technologies involved in our model.

2.1 Description of the markets

The first stage in the production of cocaine is the cultivation of coca crops. Once harvested, coca leaves are combined with large amounts of chemical precursors such as gasoline, cement, sodium permanganate and sulfuric acid in order to process it into cocaine.⁵ The cultivation

ritorial and market control over specific areas, they still face competition from other drug producing and trafficking organizations located in other areas or even other countries.

⁵For a thorough description of the different stages of production and trafficking of cocaine in Colombia, see Mejía and Rico (2010).

and processing of coca crops into cocaine is carried out by illegal armed groups, which have the capacity to confront the state over the control of the arable land necessary to cultivate coca crops. Illegal armed groups such as the Fuerzas Armadas Revolucionarias de Colombia - FARC - and paramilitary groups have been actively involved during the last 15 years in the initial stages of coca cultivation and cocaine production in Colombia.⁶ The final product of this initial stage of production is cocaine at the farm gate (e.g., at processing facilities in the Colombian countryside). Following this stage, cocaine producers sell the final product to a trafficker, who takes charge of transporting it to transit countries. We refer to this market, where the drug producer and the trafficker meet, as the *farm gate market*; all variables related to it are indexed with the subscript fg .

This market is depicted in Figure 1 in the left most stage. 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 fixed and not affected by drug markets. Land is held by the drug producer, but it is useful to introduce its shadow price, P_l , which measures the shadow value of holding an extra unit of land. We assume that only a fraction, $q \in [0, 1]$, of the available arable land, L , is effectively controlled by the drug producer. We endogenize this fraction when introducing anti-drug policies, but for now we might think of it as a fixed factor of production. The drug production technology is given by the following constant returns to scale function:

$$Q_{fg} = F_{fg}(a, qL). \quad (1)$$

Let σ_{fg} be the elasticity of substitution between both inputs in this production technology; s_l the share of land; and $s_a = 1 - s_l$ the share of the factors complementary to land in the cocaine production technology.⁷

When determining his demand for complementary factors, and the shadow demand for land, the producer is effectively choosing the following cost minimization problem:

$$\min_{l, a} P_l l + a \quad \text{s.t.} \quad F_{fg}(a, l) = Q_{fg}, \quad (2)$$

wherein the condition $l = qL$ determines the shadow price of land. The workings of anti-drug policies become clearer if we focus explicitly on this shadow market. The drug producer sells the total amount of farm gate production, Q_{fg} , to a Colombian trafficker at price P_{fg} . An assumption of perfect competition and constant returns to scale implies that the farm gate price of cocaine is

$$P_{fg} = \min_{l', a'} P_l l' + a' \quad \text{s.t.} \quad F_{fg}(l', a') = 1, \quad (3)$$

⁶In the case of Afghanistan, the Taliban has been the group most in charge of the cultivation of opium poppy.

⁷The constant returns to scale technology in equation 1 implies that, at the aggregate level, it does not make any difference whether there is just one or many drug producers.

where l' and a' are the amounts of land and complementary factors per unit of farm gate cocaine produced, respectively.

In the next stage, the Colombian trafficker transports the drugs bought at the farm gate to the transit country (for instance, Mexico), where he sells the drugs that survive government interdiction efforts. In order to do this, the trafficker must guarantee the control of the routes necessary for transporting the drugs out of the producer country. We refer to the market where the trafficker sells the drugs in transit countries as the *trafficking market*; all variables related to it are indexed with the subscript c . This market is depicted in Figure 1 in the subsequent panel to the one already noted.

We assume that the Colombian trafficker combines routes, r , with domestic drugs bought at the farm gate market, Q_{fg} , to “produce” Colombian cocaine in transit countries, Q_c . Thus, the trafficker is modeled here as an intermediary who transports drugs from Colombia to transit countries. Farm gate cocaine is purchased from the producer at price P_{fg} , given by equation 3. Routes are held by the trafficker, but it is useful to introduce their shadow price, P_r , which measures the shadow value of holding one extra route. 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 other words, fraction h of the routes is effectively controlled by the Colombian drug trafficker. We endogenize this fraction when we introduce the workings of anti-drug policies. Formally, the drug trafficking technology is given by the following constant returns to scale function:

$$Q_c = F_c(Q_{fg}, hR). \quad (4)$$

Let σ_c denote the elasticity of substitution between both inputs in the trafficking technology; s_r the share of routes; and $s_{fg} = 1 - s_r$ the share of farm gate cocaine in the trafficking technology in equation 4.

When choosing the demand for farm gate cocaine, and the shadow demand for routes, the trafficker solves the following cost minimization problem:

$$\min_{Q_{fg}, r} P_{fg}Q_{fg} + P_r r \quad \text{s.t.} \quad F_c(Q_{fg}, r) = Q_c, \quad (5)$$

where the condition $r = hR$ pins down the shadow price of routes.

The drug trafficker sells the total amount of Colombian cocaine in the transit country, Q_c , at price P_c . This cocaine is then transported to final consumer markets (i.e., downstream markets). Perfect competition and constant returns to scale imply that the price of Colombian cocaine in the trafficking market (e.g., the price of cocaine in transit countries) is:

$$P_c = \min_{Q'_{fg}, r'} P_{fg}Q'_{fg} + P_r r' \quad \text{s.t.} \quad F_c(Q'_{fg}, r') = 1, \quad (6)$$

where Q'_{fg} and r' are the amounts of farm gate cocaine and drug routes used per unit of cocaine shipped to transit countries, respectively.

It is at this point that we obtain the Colombian supply of cocaine in transit markets, $Q_c(P_c)$. 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) price. Therefore, if these shadow markets and the farm gate market are in equilibrium, they will induce an upward slopping supply of Colombian cocaine in transit markets.

The supply curve, $Q_c(P_c)$, is the only thing that is affected by supply reduction policies in Colombia. However, from a policy perspective, we are not interested in studying the effects of anti-drug policies implemented in Colombia on quantities transacted in transit countries, since these are only related in a complicated way to retail quantities and prices, which is what we are really interested in. In order to understand how drug policies implemented in source countries affect retail markets in consumer countries, we incorporate downstream markets in the simplest way possible. We model 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) in transit countries, smuggles the drugs into the consumer country and distributes them to the final consumers in retail markets. For the sake of simplicity, we refer to this organization as “downstream markets.” Its real vertical structure does not matter as long as there is perfect competition, so we can think of downstream markets as a vertically integrated “agent” without any loss of generality. Downstream markets are depicted in Figure 1, in the two far right panels. These abstract markets are located in transit and consumer countries, and are affected by supply reduction policies in source countries via changes in the price of Colombian cocaine, P_c . For our application, we think of the consumer country as being the U.S. - the place where these markets are located.

Formally, downstream markets buy cocaine from Colombia, Q_c , and other source countries, Q_o , and aggregate them into cocaine to be transported to consumer countries, Q_t . Colombian cocaine is purchased from the drug trafficker at price P_c , while cocaine derived from other sources is supplied by a competitive market at price P_o , with a supply elasticity of ε_o^s . The aggregation technology is given by:

$$Q_t = F_t(Q_c, Q_o), \quad (7)$$

where F_t is a constant returns to scale technology with an elasticity of substitution of σ_t . This elasticity captures the extent to which cocaine from other source countries can be substituted for Colombian cocaine in a sufficiently general way.⁸ Let s_c be the share of Colombian cocaine and $s_o = 1 - s_c$ the share of drugs from other source countries in technology F_t .

⁸Technology F_t is flexible enough so as to capture different forms for aggregating Q_c and Q_o into Q_t - for instance, such that $Q_t = w_c Q_c + w_o Q_o$, wherein drugs from both sources are perfect substitutes for one another, and are weighted by quality. However, the fact that we are studying illegal markets makes it difficult to argue that cocaine from different source countries are perfect substitutes for one another, as there might be horizontal

Downstream markets then attempt to smuggle the aggregate drugs, Q_t , into consumer countries. At a conceptual level, it is useful to define the shadow price of cocaine in downstream markets as P_t . Perfect competition, profit maximization and constant returns to scale imply that this shadow price is given by

$$P_t = \min_{Q'_c, Q'_o} P_c Q'_c + P_o Q'_o \text{ s.t. } F_t(Q'_c, Q'_o) = 1, \quad (8)$$

where Q'_c and Q'_o are the respective quantities of drugs from Colombia and other source countries per unit of drugs in transit. The shadow price, P_t , measures the marginal cost of obtaining one extra unit of cocaine in transit countries, Q_t , as perceived in downstream markets. Prices in Mexico or other transit countries are a reasonable empirical counterpart to P_t .

In order to transport and distribute drugs bought in transit countries, Q_t , downstream markets combine them with complementary factors, b , so as to “produce” drugs at the retail level in consumer countries, Q_f . Formally, this distribution technology is given by:

$$Q_f = F_f(Q_t, b), \quad (9)$$

where F_f is once again a CRS technology. The complementary factors, b , can be thought of as the distribution networks, means of transportation, and wage bill of drug dealers in U.S. retail markets, all of which are necessary inputs in the distribution technology. Without any loss of generality, we assume that these complementary factors are supplied inelastically at price P_b (normalized to 1). This assumption implies that we do not think that these prices (wages and so forth) are affected by the drug trade. We denote the 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 $s_b = 1 - s_t$. In equation 9, we abstract from the effects of crackdowns in transit and consumer countries and assume that they are already incorporated into the distribution technology.

At this point we obtain the supply of drugs at the retail level and the corresponding price. Perfect competition, profit maximization and constant returns to scale in downstream markets imply that the price faced by final consumers is equal to

$$P_f = \min_{Q'_t, b'} P_t Q'_t + b' \text{ s.t. } F_f(Q'_t, b') = 1, \quad (10)$$

where Q'_t and b' are the inputs per unit of the final product. Here, the shadow price is taken as given and equates to the marginal cost of obtaining drugs in transit with the marginal benefit of smuggling them, as any integrated structure or competitive downstream market would do. 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 ε_f^d .

differentiation between different suppliers in terms of quality and location, likewise the non-negligible costs of establishing new commercial relationships with different drug traffickers.

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 substitution for 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 . This is also corresponds to the fact that the share of Colombian cocaine in the drug trade is just a small fraction of the overall trade; we have to take into account the remaining factors involved in distribution and trafficking in order to understand how changes in the Colombian price of cocaine affect retail prices in consumer countries. In addition, this way of modeling downstream markets also allows us to capture the effects of anti-drug policies implemented in Colombia on other source countries.

2.2 The war on drugs

We model the war on drugs in Colombia as consisting of two main fronts: the eradication front and the interdiction front. First, on the eradication front, interventions are aimed at disrupting the production of cocaine. More precisely, we assume that farm gate production is disrupted by *eradication efforts*, whereby the Colombian government fights with drug producers over the effective 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.

Second, 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 with drug traffickers over the effective control of the routes necessary for transporting drugs from the producer to transit countries. These efforts often take the form of such interventions as crackdowns, surveillance flights and the installation of radars, all aimed at detecting trafficking routes and/or the transportation means used by drug traffickers to ship drugs out of the source country. Formally, these efforts are aimed at reducing h , the fraction of routes under the effective control of the trafficker in our model.

The fractions of land or routes under the effective control of the producer or trafficker, q and h , do not depend only on government efforts, but also on the strategic responses of the producer and trafficker seeking to counteract these policies. Drug producers try to offset eradication efforts through various means, for instance, land mines and other explosive devices aimed at preventing manual eradication teams from entering coca fields, or the shooting of the airplanes used in aerial

spraying campaigns. In other cases, they engage into direct confrontations against government forces in order to increase their territorial control of coca crops. 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 aircrafts, etc. - in order to prevent radars from detecting illegal drug shipments.

To account for the first front, we model q , the fraction of land that survives government eradication efforts, as the outcome of a conflict between the government and the drug producer over the effective control of the land necessary to cultivate coca crops. Formally, q is endogenously determined by a standard context success function (CSF) of the following form:⁹

$$q(x, z) = \frac{\phi x}{\phi x + z}, \quad (11)$$

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.

Similarly, in accounting for the second front, we model h , the fraction of routes that survives government interdiction efforts as the outcome of the conflict between the government and the drug trafficker over the effective control of the drug routes used for shipping drugs out of the producer country. Formally, h is endogenously determined by a standard context success function (CSF) of the following form:

$$h(t, s) = \frac{\gamma t}{\gamma t + s}, \quad (12)$$

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, 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, x , can be easily characterized using the shadow price of land, since this measures the marginal value of holding an additional unit of land. When choosing counter-eradication efforts, the producer takes the shadow price of land, P_l , as given and solves

⁹A 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)). See Skaperdas (1996) and Hirshleifer (2001) for a detailed explanation of the different functional forms of CSFs.

the following problem:

$$\max_x P_l q(x, z) L - x \rightarrow P_l \frac{\phi z}{(\phi x + z)^2} = 1. \quad (13)$$

Given that land for cultivating coca is not transacted in markets, but it is obtained via conflict with the government, the producer makes profits from securing control of a given fraction of land. This is because the conflict technology, $q(x, z)$, introduces a source of decreasing returns to scale, and hence allows the producer to profit from the cultivation of coca crops.

Likewise, the optimal choice by the trafficker, t , can be characterized using the shadow price of routes, since this measures the marginal value of holding an additional route. When choosing counter-interdiction efforts, the trafficker takes the shadow price of routes, P_l , as given and solves the following problem:

$$\max_t P_r h(t, s) R - t \rightarrow P_r \frac{\gamma s}{(\gamma s + t)^2} = 1. \quad (14)$$

Given that the routes for transporting cocaine are not transacted in markets, but are obtained via conflict with the government, the trafficker makes profits from securing control of a given fraction of routes. In other words, profits in this model arise on the basis of the ability of the drug trafficker to fight the government for the control of routes (an inelastic resource).

In order to characterize the optimal choice for eradication and interdiction efforts, we must specify the government's objective and its funding. Here, we are explicitly accounting for the fact that most supply reduction programs financed by the U.S. government in source and transit countries are actually implemented by the governments of the latter group of countries. This generates special tensions and the potential for agency problems. 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, and that the U.S. is able to provide incentives to strengthen these efforts by subsidizing them on either of the two fronts. There is thus a partial alignment of interests. This is a simple way of microfunding the way in which U.S. assistance and resources actually translate into eradication and interdiction efforts, such as takes into account the incentives of source countries and the main tools available by which the U.S. is able to induce greater effort. Alternatively, one could abstract from this and simply assume that the U.S. directly invests in eradication and interdiction efforts, but we believe this omits important and very real constraints related to the implementation of these programs.

Formally, we assume that the government wants to minimize the social cost imposed on society by drug producers and traffickers. 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 , and a net cost per unit of income net of payments obtained by the local trafficker, c_2 . This modeling assumption is motivated by the fact that in many source and transit countries - inclusive of 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 reduce the amount of drugs being produced and exported, but rather to reduce the collateral costs imposed by illegal armed groups involved in drug production and trafficking activities.

We model the U.S. funding of the two fronts of the war on drugs in the producer country as a multiplicative subsidy per dollar spent on each front by the source country's government. More specifically, we assume that the U.S. pays for fraction $1 - \omega$ of eradication efforts and fraction $1 - \Omega$ of interdiction efforts. These are the only tools available for encouraging the Colombian government efforts; by increasing the subsidies (decreasing ω or Ω) the U.S. government is able to intensify supply reduction efforts abroad. This modeling strategy is consistent with a framework wherein the expenditures of the two governments (Colombia's and the U.S.'s) are complements. 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, aircrafts, herbicides for aerial spraying campaigns, military intelligence, the use of satellites for detecting illegal drug shipments, etc. These types of contributions decrease the marginal costs of the eradication and interdiction efforts implemented by the Colombian government and, as such, can be modeled as multiplicative subsidies.

Formally, we assume that the government chooses eradication efforts, z , in order to minimize the social costs of drug production activities and the war against drug producers. Formally, the government's problem at this stage is

$$\min_z C_P = c_1(P_{fg}Q_{fg} - a) + \omega z = c_1 P_l q(x, z)L + \omega z \rightarrow c_1 P_l \frac{\phi x}{(\phi x + z)^2} = \omega. \quad (15)$$

The government's problem assumes that the government faces a net cost, $c_1 > 0$, per unit of income received by the producer net of its expenditures on complementary factors. Again, this assumption implies that the drug producer can finance socially costly activities (e.g., violence, insurgent activities, etc.) from the income received net of payments for complementary factors. The term ωz captures the budgetary cost of eradication efforts. Recall that fraction $1 - \omega$ of these expenditures is paid for by the U.S. government.

Likewise, the government chooses interdiction efforts, s , in order to minimize the social costs of drug trafficking activities and the war against drug traffickers. Formally, the government's problem at this stage is

$$\min_s C_T = c_2(P_c Q_c - P_{fg} Q_{fg}) + \Omega s = c_2 P_r h(t, s)R + \Omega s \rightarrow P_r \frac{\gamma t}{(\gamma t + s)^2} = \Omega. \quad (16)$$

In this case, the government's problem assumes that the government faces a net cost, $c_2 > 0$, per unit of income made by the drug trafficker net of payments for farm gate cocaine. What

this assumption implies is that drug traffickers can finance their socially costly activities (e.g., violence, corruption, etc.) from the income received net of payments for the intermediate input. The term Ωs captures the budgetary cost of interdiction efforts. Recall that a fraction $1 - \Omega$ of these expenditures is paid for by the U.S. government.

The equilibrium level of $q^*(\omega, \Omega)$ is determined by the Nash equilibrium (z^*, x^*) derived from the simultaneous solution of problems 13 and 15. This equilibrium is described by the following equations:

$$x^* = (1 - q^*)s_l P_{fg} Q_{fg}, \quad z^* = \frac{c_1}{\omega} (1 - q^*)s_l P_{fg} Q_{fg}, \quad q^* = \frac{\phi\omega}{c_1 + \phi\omega}. \quad (17)$$

The equilibrium level of $h^*(\omega, \Omega)$ is determined by the Nash equilibrium (s^*, t^*) derived from the simultaneous solution of problems in equations 14 and 16. This equilibrium is described by the following equations:

$$t^* = (1 - h^*)s_r P_c Q_c, \quad s^* = \frac{c_2}{\Omega} (1 - h^*)s_r P_c Q_c, \quad h^* = \frac{\gamma\Omega}{c_2 + \gamma\Omega}. \quad (18)$$

Note that the drug producer and trafficker respective equilibrium levels of expenditures in counteracting government eradication and interdiction efforts are each a fraction of the respective total market values of land and routes. This suggests that the cost of making important advances in each of the two fronts depends on the producer and trafficker valuation of the input being contested (i.e., land and routes, respectively). The new insight provided by modeling supply reduction as a conflict over inputs, is that inputs with a large value added in the chain of production and trafficking are more costly to target. Costs are no longer solely a technological factor, but depend on the reaction of market participants. Finally, note that $q^*(\omega, \Omega)$ increases with ω , so q^* is lower when U.S. subsidies constitute a higher share of eradication efforts, as expected. Likewise, $h^*(\omega, \Omega)$ increases with Ω , such that h^* is lower when the U.S. subsidizes a higher share of interdiction efforts, as expected. In fact, the values of q^* and h^* only depend on the subsidies allocated to their respective front.¹⁰

2.3 Market equilibrium

The previous section fully specifies the technologies, markets and optimizing behavior of all agents involved in our model. We can now define our model equilibrium in terms of the subsidies, which

¹⁰One 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 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.

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:

- The final retail market, trafficking market, farm gate market, and all input markets clear. In the case of routes and arable land, the market clearing conditions imply that $r^* = hR$ and $l^* = qL$, respectively.
- All prices are set at marginal costs, and the choice of inputs solves the minimization problems in equations 3, 6, 8 and 10.
- t^* and s^* are the Nash equilibrium strategies for the conflict between the government and the drug trafficker over the control of routes, and x^* and z^* are the Nash equilibrium strategies for the conflict between the government and the drug producer over the control of arable land. h^* and q^* are the equilibrium outcomes of these two games, respectively, as given in equations 17 and 18.

3 The effects of supply reduction policies

We now turn our analysis to the effects of anti-drug policies implemented in the producer country. In particular, we focus on how changes in Ω (or equivalently in h^*) and in ω (or equivalently in q^*) affect the equilibrium quantities and prices of drugs transacted at the farm gate, trafficking and retail markets, and the amounts of drugs produced in other source countries. The formulas we obtain in terms of shares and elasticities are exact for small changes. For larger policy changes, the elasticities and shares may vary, such that these formulas become approximations that are useful but not exact. The basic tools used in this analysis are the two lemmas in the appendix, which are versions of Marshall rules.

3.1 The effects of eradication efforts in markets in Colombian markets

Consider the effects of an increase in the U.S. subsidy for this front of the war on drugs (e.g., a lower ω). Equation 17 implies that q^* falls, as the government of the drug producing country now experiences a lower cost of investing resources in eradication efforts. Let the fall in q^* be denoted by $d \ln q$. For the sake of notational simplicity, we do not index equilibrium variables with an $*$. Nonetheless, the reader should keep in mind that all the following results are obtained at equilibrium.

3.1.1 Effects in the farm gate market

The first effect is an increase in the shadow price of land, P_l , as the supply of land available to drug producers contracts by $d \ln q$. The increase in P_l is given by:

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

The elasticity of demand for land, ε_l^d , can be computed recursively, as discussed in the appendix, and is given by:

$$\varepsilon_l^d = s_l \varepsilon_{fg}^d + (1 - s_l) \sigma_{fg}. \quad (19)$$

The elasticity of demand for land allows us to understand how a reduction in the fraction of land held by the drug producer, q , translates into a higher shadow price for land. Notably, it increases with 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; hence, it makes eradication less cost effective.

An increase in P_l leads the producer to substitute land for complementary factor a . We can use lemma 1 in the Appendix to find the overall effect on land productivity. The corollary of this lemma implies that, with productive complementarities, land productivity increases by

$$(1 - s_l) \sigma_{fg} d \ln P_l. \quad (20)$$

Thus, our model endogenously predicts an increase in the productivity of land as a result of an increase in eradication efforts in Colombia. One key aspect of our model is that this increase in productivity is a general equilibrium phenomenon brought about by higher national farm gate prices. This means that it cannot be detected in cross sectional comparisons of municipalities facing different eradication rates. 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 cost effective.

An increase in P_l causes an increase in the price of farm gate cocaine, as the producer now faces a larger marginal cost. The increase in P_{fg} is given by

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

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 - that is, only a small increase in farm gate prices is required to cover the extra costs of production induced by increased eradication efforts. This equation accounts for the fact that complementary factors, a , are supplied at a constant price (e.g., a price not affected by the intensity of the drug trade).

3.1.2 Effects on the trafficking market

The drug trafficker reacts to an increase in P_{fg} by adapting his input demands. More specifically, the quantity of farm gate cocaine that is transacted falls by

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

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

$$\varepsilon_{fg}^d = \frac{\sigma_c \varepsilon_c^d}{s_{fg} \sigma_c + (1 - s_{fg}) \varepsilon_c^d}. \quad (21)$$

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. This formula already accounts for the fact that the supply of routes is inelastic. Again, this elasticity is increasing in σ_c and ε_c^d .

The effect on the trafficker's demand for routes is ambiguous. An increase in the price of farm gate cocaine has two effects. 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. This effect leads the trafficker to demand fewer routes. 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

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

The analysis above shows that when $\sigma_c > \varepsilon_c^d$, the shadow price of routes increases, as does its market value. This increase in the market value of routes makes interdiction efforts more costly, as the value of the resource over which the government and trafficker are fighting increases (see equation 18). In this case, a negative feedback exists between different anti-drug policies, as more eradication efforts increase the cost of implementing interdiction efforts. When $\sigma_c < \varepsilon_c^d$, the opposite happens, and there is a positive feedback between the two policies.

An increase in P_{fg} causes an increase in P_c , given by:

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

This equation captures two features. First, 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} . Second, the increase in prices also reflects the change in the price of routes.

Our analysis shows that a higher σ_c makes eradication more effective. The intuition is that there are two opposite effects: On the one hand, a higher σ_c implies a more elastic demand for farm gate cocaine, which implies that an increase in eradication efforts does not significantly increase land and farm gate prices. However, this comes at the expense of greater substitution towards the use of more routes, which sharply increases the price of routes since their supply is inelastic. This second effect is the dominant one, such that a higher elasticity of substitution, σ_c , makes eradication more effective.

3.2 The effects of interdiction efforts on Colombian markets

Consider the effects of an increase in U.S. subsidies for this front of the war on drugs (e.g., a lower Ω). Equation 18 implies that h^* falls, as the Colombian government now enjoys a lower cost of investing resources in interdiction efforts. Let the fall in h^* be denoted by $d \ln h$.

3.2.1 Effects on the trafficking market

The first effect is an increase in the shadow price of routes, P_r , as the supply of this input contracts by $d \ln h$. The increase in P_r is given by

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

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:

$$\varepsilon_r^d = \frac{s_r(\sigma_c + \varepsilon_{fg}^s)\varepsilon_c^d + (1 - s_r)(\varepsilon_{fg}^s + \varepsilon_c^d)\sigma_c}{s_r(\sigma_c + \varepsilon_{fg}^s) + (1 - s_r)(\varepsilon_{fg}^s + \varepsilon_c^d)}. \quad (22)$$

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 begins to rely less on routes and 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:

$$\varepsilon_{fg}^s = \frac{s_a}{s_l} \sigma_{fg}, \quad (23)$$

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. The first is a substitution effect, whereby the drug trafficker now demands more farm gate cocaine in order to compensate for the decline in the routes under his control. The second is a scale effect, whereby the increase in P_r raises the trafficker's marginal cost, leading him to

contract his operations. This effect gives rise to a fall in demand for farm gate cocaine. When $\sigma_c > \varepsilon_c^d$, 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

$$d \ln P_{fg} = \frac{s_r(\sigma_c - \varepsilon_c^d)}{s_r(\sigma_c + \varepsilon_{fg}^s) + (1 - s_r)(\varepsilon_{fg}^s + \varepsilon_c^d)} d \ln P_r$$

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

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

This equation captures two features. The first reflects 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 second reflects the fact that prices must also cover the change in farm gate prices.

Combining this with our formula for the elasticity of demand for routes, we see that a greater elasticity of substitution, σ_c , makes interdiction less efficient when σ_{fg} is sufficiently large. In this case, farm gate cocaine is supplied elastically and the possibility of substitution does not increase its price to any considerable extent. However, the possibility of substitution for farm gate cocaine prevents the price of routes from sharply increasing, and hence makes interdiction less effective in terms of increasing the price of cocaine in transit markets.

3.2.2 Effects on the farm gate market

The drug producer reacts to changes in farm gate prices by adjusting his supply of farm gate cocaine by

$$d \ln Q_{fg} = \varepsilon_{fg}^s d \ln P_{fg}.$$

Change in farm gate prices also lead the producer to re-scale his operations by adjusting his demand for land and complementary factors. The corresponding change in the shadow price of land is given by

$$d \ln P_l = \frac{1}{s_l} d \ln P_{fg}.$$

The supply of land, qL , does not change, as the equilibrium level of q does not depend on U.S. subsidies for interdiction efforts, nor on drug prices. The price of complementary factors to land, a , does not increase, but the producer increases his demand for them, thus leading to an increase in the productivity of land.

If $\sigma_c > \varepsilon_c^d$, the increase in interdiction efforts raises the shadow price of land, and hence its market value, as the increase in demand for farm gate cocaine raises the producer's demand for land. The increase in the market value of land makes eradication efforts more costly, as the value of the resource over which the government and producer are fighting increases (see equation 17). In this case, we again have a negative feedback between different anti-drug policies, as more interdiction efforts increase the costs of implementing eradication policies. When $\sigma_c < \varepsilon_c^d$, the opposite happens, and there is a positive feedback between the two types of policies.

3.3 Effects on downstream markets

The effects of greater interdiction in Colombia on downstream markets are the same as the effects of greater eradication, since the channels of transmission in both cases occurs through an increase in P_c . We thus analyze them together here. In particular, we study the effect of an increase in P_c on downstream markets.

The international dealer responds to an increase in P_c by adapting his demand for inputs. More specifically, the quantity of Colombian cocaine transacted in transit countries falls by

$$d \ln Q_c = -\varepsilon_c^d d \ln P_c.$$

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

$$\varepsilon_c^d = \frac{s_c(\sigma_t + \varepsilon_o^s)\varepsilon_t^d + (1 - s_c)(\varepsilon_o^s + \varepsilon_t^d)\sigma_t}{s_c(\sigma_t + \varepsilon_o^s) + (1 - s_c)(\varepsilon_o^s + \varepsilon_t^d)}. \quad (24)$$

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 .

An increase in the price of Colombian cocaine has two effects. The first is a substitution effect, which leads the international dealer to substitute Colombian cocaine with cocaine from other source countries in order to satisfy his input requirements. This effect tends to increase the demand for drugs from other source countries. The second is a scale effect, that induces the international dealer to contract the size of operations, given that he is now operating with a greater marginal cost. This effect leads the international drug dealer to decrease the demand for cocaine from other source countries. Which of the two effects dominates depends on the relative size of the elasticity of substitution and the price elasticity of demand. More precisely, the effect on the quantity of cocaine from other source countries is given by

$$d \ln Q_o = \frac{s_c(\sigma_t - \varepsilon_t^d)\varepsilon_o^s}{s_c(\sigma_t + \varepsilon_o^s) + (1 - s_c)(\varepsilon_o^s + \varepsilon_t^d)} d \ln P_c, \quad (25)$$

while the corresponding increase in price is given by

$$d \ln P_o = \frac{s_c(\sigma_t - \varepsilon_t^d)}{s_c(\sigma_t + \varepsilon_o^s) + (1 - s_c)(\varepsilon_o^s + \varepsilon_t^d)} d \ln P_c. \quad (26)$$

If $\sigma_t > \varepsilon_t^d$, the substitution effect dominates, and the quantity of cocaine demanded from other source countries increases, leading to the so-called ballooning effect, whereby greater eradication efforts in Colombia increase the production of cocaine in other source countries. Moreover, the ballooning effect is stronger when the supply from other source countries is more elastic.

The price of cocaine in transit markets increases by

$$d \ln P_t = \frac{s_c(\sigma_t + \varepsilon_o^s)}{s_c(\sigma_t + \varepsilon_o^s) + (1 - s_c)(\varepsilon_o^s + \varepsilon_t^d)} d \ln P_c = s_c d \ln P_c + (1 - s_c) d \ln P_o. \quad (27)$$

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 . The second reflects the fact that the increase in prices must also cover the change in the price of cocaine from other source countries.

If ε_o^s is large enough, a higher elasticity of substitution does not imply a sharp increase in the price of cocaine from other source countries; hence, source country interventions become less effective, inasmuch as the demand for Colombian cocaine becomes more elastic. However, if ε_o^s is small, a higher elasticity of substitution implies a greater price increase in other source countries; this makes source country interventions more effective at raising retail prices. Likewise, the elasticity of supply from other source countries plays an ambiguous role. If $\sigma_t > \varepsilon_t^d$, supply reduction policies in Colombia increase the demand for cocaine from other source countries; hence, a higher elasticity of demand implies a smaller increase in prices. In this case, the presence of a more elastic supply from other source countries renders supply reduction efforts in Colombia less effective. However, if the opposite inequality holds, the situation is reversed.

As a result of an increase in transit prices, the quantity of drugs demanded in transit countries by downstream markets falls by

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

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

$$\varepsilon_t^d = s_t \varepsilon_f^d + (1 - s_t) \sigma_f. \quad (28)$$

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. Here there is no ambiguous effect because downstream markets substitute for factors supplied at constant prices, P_b .

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

$$d \ln P_f = s_t d \ln P_t. \quad (29)$$

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. In this case, complementary factors are supplied at a constant price, so in this equation, there is no need to consider the effect of a change in their price.

It is worth noting that 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, $s_t s_c$. Equation 29 shows that the transmission of price changes between source countries and retail markets occurs with an elasticity that is strictly less than s_t - the share of the value of cocaine in transit countries in retail markets. It is also worth noting from equation 29, that when the price elasticity of the supply of cocaine from other source countries, ε_o^s , is sufficiently large, the elasticity of the price of cocaine in retail markets to the price of cocaine in Colombia is approximately $s_t s_c$. These observations show that if the share of source country markets in the drug trade is small, supply reduction policies in these countries will have a limited effect on consumer prices.

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 being exogenous, makes supply reduction policies less effective in reducing quantities.

4 The determinants of the cost-effectiveness of supply reduction policies

In order to understand how the benefits weigh against the costs of eradication and interdiction, we calculate the marginal cost of reducing the amount of cocaine transacted in retail markets by subsidizing the Colombian government on each front of the war on drugs. Although the U.S. may have objectives other than supply reduction, we focus only on the anti-narcotic dimension of these policies. We maintain this focus for two reasons: The first is for the sake of comparability, so that the respective marginal costs can be compared to the cost of alternative policies, such as treatment and prevention policies, in reducing the demand for drugs in consumer markets. The second is because these costs are informative of the technological and economic constraints facing the U.S. in the war on drugs, and these constraints are operative even if the U.S. has other objectives. 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. We make this choice because we are mostly interested in establishing the cost effectiveness of source country interventions from the U.S. perspective, as it is the U.S. that has been promoting these policies in an effort to curb domestic consumption.

In order to calculate the marginal costs, we need to characterize the benefits (i.e., the effect on retail quantities) and the cost (i.e., the increased cost faced by the U.S.) of changing the subsidies allocated to Plan Colombia. The recursive structure of all the effects described above implies that we can decompose the change in retail quantities into the change in the fraction of land controlled by the drug producer and the change in the fraction of routes controlled by the drug trafficker, as follows

$$d \ln Q_f = \Lambda_q d \ln q + \Lambda_h d \ln h,$$

where Λ_q and Λ_h depend only on price elasticities, substitution elasticities and shares that can be estimated. These two numbers capture the effectiveness of anti-drug policies implemented in Colombia at reducing the amount of cocaine transacted in retail markets, as they correspond to the elasticities of retail quantities with respect to changes in q and h , respectively.

These elasticities are given by

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

and

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

The manner in which we have formulated these expressions makes it clear that a drop in q or h operates by increasing the price of Colombian cocaine, P_c . This leads to an increase in the retail price so as to cover the extra cost of production, while at the same time allowing for the possibility of substituting scarce Colombian cocaine for cocaine from other source countries, as well as adjustments in complementary factors, b . However, since the cost of Colombian cocaine is only a fraction of the total cost, retail prices increase with an elasticity of $\frac{d \ln P_f}{d \ln P_c}$ (see equation 29), which is less than 1 and, in fact, less than s_t . Finally, the price increase translates into lower consumption depending on the elasticity of demand. In the appendix, we analyze the main determinants of these elasticities.

Despite the sharp characterization of these elasticities, a comparison between Λ_q and Λ_h cannot tell us if anti-drug efforts in source countries should focus on interdiction or eradication, as we need to take into account the costs of these two policies as well. Let $TC_{US} = (1 - \omega)z + (1 - \Omega)s$ be the total cost to the U.S. at equilibrium. Recall from equations 18 and 17, that the two subsidies are increasing functions of q and h , respectively. We can thus calculate the marginal cost of reducing

q by increasing subsidy $1 - \omega$ as

$$C_q = -\frac{\partial TC_{US}}{\partial q} = c_1 P_l L + 2(1 - \omega)\phi(1 - q)P_l L + (1 - \omega)\phi(1 - q)^2 P_l L \frac{1}{q \varepsilon_l^d} + (1 - \Omega)\gamma(1 - h)^2 P_r R \frac{1}{q} \frac{d \ln P_r}{d \ln q}. \quad (30)$$

Likewise, the marginal cost of reducing h by increasing subsidy $1 - \Omega$ can be calculated as

$$C_h = -\frac{\partial TC_{US}}{\partial h} = c_2 P_r R + 2(1 - \Omega)\gamma(1 - h)P_r R + (1 - \Omega)\gamma(1 - h)^2 P_r R \frac{1}{h \varepsilon_r^d} + (1 - \omega)\phi(1 - q)^2 P_l L \frac{1}{h} \frac{d \ln P_l}{d \ln h}. \quad (31)$$

These costs capture an interesting feature, namely that they are proportional to the market value of the total amount of the input being targeted ($P_l L$ and $P_r R$). This is a direct consequence of modeling eradication and interdiction as conflicts over factors of production. The intuition is that the producer and the trafficker are willing to invest a fraction of the value of these inputs in order to maintain effective control; therefore, the government must outbid them if it wants to reduce q or h . The above equation also shows that costs are higher when the producer or the trafficker are more efficient at counteracting government efforts (captured by ϕ and γ). Also, these costs already incorporate all potential inefficiencies arising from the agency problem between the U.S. and the source country implementing the policy.¹¹

The marginal cost of reducing the amount of cocaine transacted in retail markets by 1 unit by *only* increasing subsidies for eradication is given by¹²

$$MC_\omega = -\frac{\frac{\partial TC_{US}}{\partial q}}{\Lambda_q \frac{Q_f}{q}} = P_f \frac{s_l s_f g s_c s_t}{\Lambda_q} \left(c_1 + 2(1 - \omega)\phi(1 - q) + (1 - \omega)\phi \frac{(1 - q)^2}{q} \frac{1}{\varepsilon_l^d} \right) + P_f \frac{s_r s_c s_t}{\Lambda_q} (1 - \Omega)\gamma \frac{(1 - h)^2}{h} \frac{d \ln P_r}{d \ln q}. \quad (32)$$

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

$$MC_\Omega = -\frac{\frac{\partial TC_{US}}{\partial h}}{\Lambda_h \frac{Q_f}{h}} = P_f \frac{s_r s_c s_t}{\Lambda_h} \left(c_2 + 2(1 - \Omega)\gamma(1 - h) + (1 - \Omega)\gamma \frac{(1 - h)^2}{h} \frac{1}{\varepsilon_r^d} \right) + P_f \frac{s_l s_f g s_c s_t}{\Lambda_h} (1 - \omega)\phi \frac{(1 - q)^2}{q} \frac{d \ln P_l}{d \ln h}. \quad (33)$$

¹¹These costs are the only measure that rely on the specific functional form of our contest success function. Yet, the main insight- that these costs are proportional to the market value of inputs- is more general, and the analysis remain similar so long as the conflict technologies are homogeneous of degree 0.

¹²The marginal cost is calculated on the assumption that Ω and h remain constant, such that the expenditure in the other front must necessarily change depending on the cost of the routes being used. This can be relaxed, and we could also calculate the marginal cost if holding constant the level of expenditure on the other front. The results would remain mostly unchanged.

The marginal costs are simply the ratio of the change in costs over the induced change in retail quantities. The first term in the parentheses in equations 32 and 33 captures the fact that the U.S. is now paying for a greater fraction of expenditures for each front. The second term reflects the extra expenditure incurred by the U.S. 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 initial policy. The last term outside the parentheses 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 before, when $\sigma_c > \varepsilon_c^d$, eradication increases the cost of routes and interdiction, the costs of land, meaning that the policies have negative spillovers. The opposite occurs when the inequality is reversed.

We now discuss the main determinants of these costs in the following propositions. All the proofs follow through differentiation of the above formulas, and are available upon request.

Proposition 1: The role of the elasticities σ_{fg} and σ_c . *The marginal cost of reducing retail quantities by 1 unit by subsidizing eradication efforts, MC_ω , and interdiction efforts, MC_Ω , have the following properties:*

- *The elasticity of substitution between land and complementary factors, σ_{fg} , increases MC_ω . However its effect on MC_Ω is ambiguous. In particular, when $\sigma_c < \varepsilon_c^d$, a higher elasticity of substitution, σ_{fg} , decreases the first three terms and increases the last one in the expression for MC_Ω . If current expenditures for eradication are large relative to expenditures for interdiction, the latter effect dominates.*
- *The elasticity of substitution between routes and farm gate cocaine, σ_c , increases MC_Ω so long as ε_{fg}^s is large, while it always decreases MC_ω . In particular, σ_c increases the marginal cost of interdiction so long as σ_{fg} is above some threshold $\underline{\sigma}$.*

The first result shows that σ_{fg} makes eradication less effective, as it creates the possibility of substituting for complementary factors, a , which are supplied at a constant price. Here it is fundamental to note that, since the complementary factors are supplied at a constant price, a larger elasticity of substitution does not increase their price. This is the intuitive result of allowing for substitution at different stages of the drug production process. Agents can adapt to the increase in the cost of inputs by substituting alternative inputs for them. If these substitutes are supplied with a high elasticity- so that their price does not increase significantly- this possibility makes supply reduction programs in upstream markets less effective and increases their marginal cost.

To gain intuition for the result regarding interdiction, we should first study the effects on the first three terms in the equation for MC_Ω . These are proportional to the inverse of effectiveness,

Λ_h . The elasticity of substitution, σ_{fg} , makes the farm gate supply more elastic. Let us assume that $\sigma_c < \varepsilon_c^d$, which we think is an empirically plausible scenario, given that it seems difficult to substitute farm gate cocaine for routes. In this case, an increase in interdiction efforts reduces the demand for farm gate cocaine and pushes its price down. A more elastic supply of farm gate cocaine implies that domestic prices only drop by a little, and hence, does not cause significant savings for consumers. This makes interdiction more effective at reducing supply, and increases the first three terms in MC_Ω . However, there is an additional effect. Since $\sigma_c < \varepsilon_c^d$, interdiction reduces the current costs of eradication by lowering the price of land. If σ_{fg} is high, the reduction in the price of land is smaller (because supply of land is very elastic); hence, the savings in eradication costs are less. If current expenditures for eradication are greater relative to the expenditures for interdiction, the savings generated by general equilibrium spillovers on eradication are more significant and the latter effect dominates, meaning that MC_Ω increases with σ_{fg} .

The second result has to do with the effect of the elasticity of substitution in the trafficking technology. First, it shows that the possibility of substituting routes for farm gate cocaine makes interdiction less effective so long as farm gate prices do not increase considerably. This occurs precisely when σ_{fg} is large enough such that drugs in farm gate markets are supplied with a high elasticity. To see why this is the case, note that a higher σ_c has two effects. First, it makes the demand for routes more elastic, which implies that interdiction will have a smaller effect on prices. This tends to increase MC_Ω . However, it also has an additional effect. By increasing the demand for complementary factors, Q_{fg} , and hence their price, P_{fg} , a large elasticity of substitution also causes an additional increase in consumer prices. When farm gate cocaine is supplied with a high elasticity, the former effect dominates, since the increase in farm gate prices is modest, and σ_c increases the marginal cost of interdiction. This logic is present in all of our analyses of the role of elasticities of substitution.

The situation for eradication is reversed. In this case, a larger elasticity of substitution, σ_c , makes the demand for land more elastic. However, eradication brings a sharp increase in the shadow price of routes - as the trafficker substitutes for the now more expensive farm gate cocaine - and thus generates an extra increase in retail prices. The latter effect dominates in this case, because routes are supplied inelastically.

Proposition 2: The role of ballooning effects and downstream markets. *The marginal cost of reducing retail quantities by 1 extra unit by subsidizing eradication efforts, MC_ω , and interdiction efforts, MC_Ω , have the following properties:*

- *Both increase when σ_t and ε_o^s are large, though only so long as these parameters are above certain thresholds. In particular, ε_o^s increases both marginal costs when $\sigma_t > \varepsilon_t^d$, and σ_t increases both marginal costs when $\varepsilon_o^s > \underline{v}$. The combined effect of these parameters is to ease the extent of substitution for cocaine from other source countries without significantly*

increasing its price, thus rendering supply reduction programs in source countries less effective.

- *Both marginal costs are always increasing in σ_f . The effect of this parameter is to ease the extent of substitution for complementary inputs, the price of which is unaffected by the drug trade, thus rendering supply reduction programs in source countries less effective.*

The role of the elasticity of substitution in downstream markets is intuitive. When the international drug trafficker is more able 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), he 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 complementary factors, b , in order to satisfy demand. This makes the demand for land and routes more elastic relative to retail demand; hence, a drop in q and h only has a limited effect on retail prices and quantities.

In the particular case of substitution for cocaine from other source countries, the mechanism is amplified when the supply from these countries is very elastic (i.e., when ε_o^s is large). In this case, the international dealer can substitute for cocaine from these countries without significantly increasing the cost of buying cocaine, thus preventing retail prices from going up. If, on the contrary, this supply is very inelastic, an increase in other sources' price would also increase retail prices, thus potentially having the opposite effect. This is why the condition $\varepsilon_o^s > \underline{v}$ is required. Since complementary factors are supplied at a constant price, the effect of σ_f is to always increase the marginal cost of source country interventions, as this additional effect on prices is not present.

A by-product of the possibility of substitution for cocaine from other source countries is the so-called ballooning or displacement effect. These effects arise when pressure is brought to bear in one country or region against illegal drug production or trafficking simply pushes the problem to other countries or regions without reducing aggregate trade. In our model, displacement effects occur when the demand for cocaine from sources with more enforcement and higher relative prices is shifted to sources with less enforcement and lower relative prices. The framework developed here suggests that these ballooning effects are in fact a key determinant of the cost effectiveness of source country interventions. In particular, if we observe large shifts in production following changes in enforcement in different source countries, this is indicative of the presence of significant ballooning effects and will imply that related policies in any of these countries will not be very cost effective. Ballooning effects also have implications that go beyond our model. For instance, source country interventions in Peru or Bolivia will shift the demand of the international dealer towards Colombia, thus increasing the marginal cost of interdiction and eradication in Colombia, as land and routes there become more valuable. The negative feedback between policies in different source countries implies that a failure to coordinate respective policies could lead to more drug enforcement in any given country than what is optimal from a regional perspective.

Proposition 3: The (new) role of shares. *The marginal costs of reducing retail quantities by 1 extra unit by subsidizing eradication efforts, MC_ω , and interdiction efforts, MC_Ω , have the following properties:*

- *Both increase when s_t is smaller so long as $\sigma_f > \varepsilon_f^d$. More importantly, this only occurs through the effect of the share in the demand elasticity for cocaine in transit countries. This demand elasticity increases as s_t drops when $\sigma_f > \varepsilon_f^d$. More to the point, if $\sigma_f = \varepsilon_f^d$, the transit country's share has no effect on marginal costs.*
- *Both increase when s_c is smaller so long as $\sigma_t > \varepsilon_t^d$, and $\varepsilon_o^s > \underline{v}$, for some threshold $\underline{v} > 0$. More specifically, if $\sigma_t = \varepsilon_t^d$ or $\varepsilon_o^s = \underline{v}$, the Colombian cocaine share in transit countries has no effect on marginal costs. If $\varepsilon_o^s < \underline{v}$, the effect works in the other direction.*
- *When $\sigma_c < \varepsilon_c^d$, MC_ω and MC_Ω decrease with s_{fg} . The situation is the reverse when the opposite inequality holds. A low share of farm gate cocaine thus implies higher marginal costs on both fronts.*
- *An increase in s_l makes the supply of farm gate cocaine more inelastic. This makes interdiction less effective (i.e., it decreases the first three terms in the expression for MC_Ω) so long as $\varepsilon_c^d > \sigma_c$. However, a higher s_l also implies a large reduction in land prices following an increase in eradication, which means savings in the cost of eradication, which in turn could cause a reduction in MC_Ω . On the other hand, s_l makes the demand for land more inelastic so long as $\sigma_{fg} > \varepsilon_{fg}^d$. This implies that s_l reduces MC_ω .*

The key new insight in this proposition is that shares have ambiguous effects. We want to emphasize these findings, because previous analyses have concluded that it was more cost effective to target inputs with a large share or value added. Previous analysis posited a linear technology using several inputs in constant proportions. Targeting inputs with a large share generated the biggest impact on consumer prices, and so it was argued that these interventions were more cost effective. For instance, targeting relatively unimportant crops with eradication was doomed to failure because of the small share they represent in the drug trade. A similar force is present in our model, as can be seen in the equations for Λ_q and Λ_h . These equations show that the share of inputs, as well as the share of Colombian cocaine in the market, make supply reduction policies in Colombia more effective. The logic is the same as above - namely that a modest increase in retail prices is needed to cover the extra costs of an input with a small share. However, our formula also adjusts for changes in the prices of other inputs.

However, in our framework the cost of reducing an input also depends on its value, which in turn depends on its share. These effects have to be weighed against each other, which creates the ambiguous effects described in proposition 3. Our model suggests that once one takes into account

the willingness of producers and traffickers to avoid supply reduction efforts, previous conclusions are no longer valid. Targeting 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. The general message from this analysis is that we also have to consider the cost side of interventions; in particular, the possibility that these costs are shaped by the incentives confronting producers and traffickers to avoid eradication and interdiction efforts.

One case is particularly instructive. Focusing for a moment on interdiction, let us imagine that all inputs (other than routes) are supplied at a constant price. This means that $\Lambda_h = \frac{\varepsilon_f^d}{\varepsilon_r^d} s_r s_c s_t$, since an increase of 1% in the price of routes can be covered by an increase of $s_r s_c s_t$ in the final price. This is a direct consequence of the envelope theorem applied to the cost minimization problem of all agents. The general formula for Λ_h adjusts for the fact that a change in the price of routes also leads to a change in other input prices, making the effect on final prices different from the original one.

Ignoring the last term, which captures the spillovers between policies, we find that the scale of the marginal cost is given by

$$P_f \frac{s_r s_c s_t}{\Lambda_h} = P_f \frac{\varepsilon_r^d}{\varepsilon_f^d}. \quad (34)$$

The fact that the shares cancel out shows that the effect of shares on costs, likewise the direct effect of shares on effectiveness, cancel each other out exactly. Only the effect of shares through demand elasticities remains. Thus, contrary to previous results, our framework emphasizes a different channel through which shares have an impact on marginal costs.

The main point is that shares have complicated and ambiguous effects as specified in the last proposition. To gain some intuition for the proposition, in the appendix, we discuss why the ambiguous effects take the particular form described in the proposition.

Proposition 4: The role of consumers' demand. *The marginal cost of reducing retail quantities by 1 extra unit by subsidizing eradication efforts, MC_ω , and interdiction efforts, MC_Ω , have the following properties:*

- *Both increase when the demand for cocaine at the retail level is more inelastic.*
- *Both increase when the overall demand for cocaine increases (leaving its elasticity fixed).*
- *Moreover, both marginal costs are of the same order of magnitude as retail prices.*

A more inelastic demand for retail cocaine causes price increases to have a smaller effect on quantities, as has already been pointed out by Becker et al. (2006) and others. Interestingly, 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 prices, but

this effect is dominated by the fact that these price increases lead to a smaller reduction in retail quantities. However, this also affects the cost side of making advances via eradication or interdiction. More specifically, 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 is absent unless we model enforcement as a conflict.

An interesting result, noted in Proposition 4, derives from the fact that the two marginal costs are proportional to the retail price. Policies in consumer countries that reduce retail demand (e.g., prevention, treatment or rehabilitation) would thus have the extra benefit of lowering the marginal cost of implementing interventions in source countries. In this brief analysis, we assume that shifts in the retail demand for drugs do not affect its elasticity. The two previous observations indicate that prevention and treatment policies in the U.S. could have the extra benefit of reducing the marginal cost of supply reduction policies implemented abroad, either by making demand more elastic (e.g., by providing legal substitutes to treat addiction) or by shifting it and decreasing its level (e.g., through prevention).

Proposition 5: Diminishing returns in the war on drugs. *Supply reduction policies in source countries face decreasing returns - i.e., as subsidies increase, the marginal costs of reducing retail quantities by 1 extra unit (MC_ω and MC_Ω), become greater.*

The following comments explain the logic of this proposition. Without loss of generality, in this discussion, we ignore the last term in both equations, which captures the feedback between policies via market prices. We focus here on the marginal using eradication, since the argument for interdiction is analogous. As the U.S. allocates more resources to eradication, we see a decrease in ω and a drop in q . This produces two effects: First, the reduction in supply increases retail prices, P_f . This implies that more money will be paid per unit of drugs, and hence that the producer will have extra incentives to contest the government for the control of land, given that a marginal unit is now more valuable. Second, the drops in q and ω cause the term in the parentheses to increase as well. This reflects two main factors: First, that the U.S. is paying for a larger fraction of a now greater level of expenditure; and second, that as the U.S. and Colombia advance in the conflict over the control of land, it becomes harder to achieve additional improvements, because the contest success function is concave (from each groups' perspective). All these factors result in diminishing returns for investments in eradication, likewise for investments in interdiction.

This result is important for three main reasons. First, it shows that the war on drugs cannot be won in the sense that 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 (as long as our formulas remain good approximations). Moreover, our framework shows that arguments in favor of supply side interventions on the basis of the supposed existence of

increasing returns in enforcement do not hold, at least in the simplest possible model incorporating all relevant economic forces. Second, it suggests that while source country interventions may have positive results in the beginning, when few resources have yet been invested, these results cannot be extrapolated to argue in favor of the expansion of these programs, because they are likely to become less cost effective as they expand. Our model suggests then that from a supply reduction perspective, it would be better for the U.S. to allocate resources across several source and transit countries rather than creating a huge program in just one. Third and lastly, this result shows that we can use these marginal costs to create upper bounds on the effects of large policy expansions (just as early results created lower bounds).

Proposition 6: The extent of inefficiencies from a supply reduction perspective.

Given the diminishing returns on each front, the relative efficiency of both policies depends on the relative expenditure level at each front (holding q and h constant). In particular, we find that for $\frac{TC_{US}^\omega}{TC_{US}^\Omega} > \bar{m}$, the marginal cost of eradication is greater than the marginal cost of interdiction, with $\bar{m}$ given by

$$\bar{m} = \frac{\Lambda_q}{\Lambda_h} \frac{\frac{\Omega}{(1-\Omega)(1-h)} + 2\frac{h}{1-h} + \frac{1}{\varepsilon_r^d} + \frac{\Lambda_h}{\Lambda_q} \frac{d \ln P_r}{d \ln q}}{\frac{\omega}{(1-\omega)(1-q)} + 2\frac{q}{1-q} + \frac{1}{\varepsilon_l^d} + \frac{\Lambda_q}{\Lambda_h} \frac{d \ln P_l}{d \ln h}}. \quad (35)$$

In particular, if we observe that $\frac{TC_{US}^\omega}{TC_{US}^\Omega}$ is equal to $\bar{m}$, the U.S. allocation of resources is consistent with the minimization of the quantity of drugs transacted in retail quantities.

From this proposition, it is clear that threshold $\bar{m}$ is such that when $\frac{TC_{US}^\omega}{TC_{US}^\Omega} > \bar{m}$, the marginal cost of eradication is greater than the marginal cost of interdiction (given the current level for q and h). Thus, if we observe q and h , and we know U.S. expenditures on the two fronts, we can tell if the subsidies have been optimally allocated from the point-of-view of supply reduction, since an optimal allocation entails equalizing the two marginal costs. From a theoretical point-of-view, this result may not be appealing, because threshold $\bar{m}$ also depends on expenditures via q and h , which are endogenous objects. However, this result is useful from a practical standpoint, since it only involves parameters and endogenous variables that we can observe or for which we have good proxies. Finally, these results also make it clear that our framework treats eradication and interdiction quite symmetrically, and thus does not make one mechanically better than the other.

Notice that the presence of the term $\frac{\Lambda_q}{\Lambda_h}$ multiplying $\bar{m}$ implies that shares s_{fg} and s_l cause $\bar{m}$ to increase. Thus, maintaining the observed levels of expenditures in each front as fixed, smaller shares s_l and s_{fg} increase the marginal cost of eradication relative to interdiction. This is because the model expects expenditures to be proportional to the market value of the inputs. Since we are maintaining expenditures as constant, we are implicitly telling the model that eradication is being enforced to a greater extent than interdiction; given the diminishing returns in each front, the model concludes that eradication is more costly than interdiction. This is different from postulating that eradication is less cost effective because it targets a less important input, as was already clarified in proposition 3.

In addition to this, all factors that reduce $\frac{\Lambda_q}{\Lambda_h}$ (see Appendix B) make eradication less cost effective relative to interdiction, as measured by a decrease in $\bar{m}$. More specifically, a high elasticity of substitution in farm gate production, σ_{fg} , and a low elasticity of substitution in trafficking, σ_c , make this ratio smaller for most configurations of the parameters being analyzed, which is consistent with the results in proposition 1, as long as σ_{fg} is large enough.

5 Using the model to understand Plan Colombia

Anti-drug policies aimed at curbing the supply of cocaine from Colombia give us a natural place to study the implications of our model and see how well it fits the empirical patterns observed there with the implementation of Plan Colombia. We start by presenting some stylized facts that have emerged during Plan Colombia. Using these patterns, we estimate some of the elasticities and parameters required to fit the data, and use them to provide some counter-factual measures of the prospects of Plan Colombia. Given the data limitations inherent in illegal markets, we do not see these parameters as reflecting the exact structural parameters governing our model, nor this exercise as a structural estimation of our model. Our purpose in this section is to use the empirical patterns emerging from the implementation of Plan Colombia to get a sense of the size of most of the parameters, as we did above, and then use them together with other parameters estimated in the literature to get an idea of the range of quantitative predictions that our model yields. This exercise tries to determine the size of the economic forces in the model from the data (e.g., the extent of substitution, ballooning effects, etc.), and then feed them into the model in order to understand their quantitative implications.

We believe Plan Colombia offers a unique setting for studying the implications of our model. One crucial feature is that our choice, to model the war on drugs as a conflict over the key inputs required for production and trafficking, constitutes a reasonable approximation of the war on drugs under Plan Colombia. Although the degree to which each group is involved in each stage in this process - or equivalently, the extent of vertical integration in the industry- is not entirely clear, one can roughly separate the drug trade in Colombia into two fronts. On the one hand, illegal armed groups contest the Colombian government for control of land suitable for cultivation and production. On the other hand, trafficking organizations contest the government for control of the routes used to ship cocaine out of the country. Additionally, the Colombian government has an incentive to engage both groups in a conflict over the assets from which they derive their rents (land and routes) in order to reduce the social costs these rents help finance (i.e., violence, the corrupting of public officials and institutions, etc.). We see Plan Colombia as a scheme whereby the U.S. strengthens these incentives by subsidizing eradication and interdiction efforts

in order to curb the Colombian supply of cocaine, even if this is not the Colombian government's main concern. Finally, as we explain above, we think that the manner in which we incorporate downstream markets using the international drug trafficker takes into account the most interesting aspects of these markets - namely, the possibility of substituting cocaine from Colombia for cocaine from other source countries (Peru and Bolivia), and the fact that drugs have to be transported to consumer countries. Neither aspects are directly affected by policies implemented under Plan Colombia.

5.1 The model and the data

As noted above, 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 resources for Plan Colombia were disbursed beginning in 2000, when about \$800 million was given to finance different anti-narcotic programs in Colombia.¹³ During the period 2000 - 2008, the U.S. disbursed roughly \$593 million per year to Plan Colombia, of which \$408 million was used to subsidize programs related to eradication, and the remaining \$185 million subsidized programs related to interdiction efforts.¹⁴ Unfortunately, we do not have good data on Colombian expenditures by component, but Colombia's aggregate expenditures on the war on drugs and the fight against organized crime increased by 25% between 1999 and 2006, as expected given the increase in subsidies (see DNP, 2008).

From equations 18 and 17, we see that an increase in subsidies implies drops in q and h . 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 . 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 hectares¹⁵. As shown in Figure 2, q increases until 1998, at which point coca cultivation shifted from Peru to Colombia; following the implementation of Plan Colombia, however, it falls sharply, from 0.32 to 0.17. From equation 17, it follows that the decline in q implies a fall in $1 - \omega$ - i.e., an increase in subsidies for eradication - from 0 prior to Plan Colombia to 0.43 afterwards. We take the value $\omega = 0.43$ as a natural benchmark for our quantitative predictions.

¹³Plan Colombia also had a minor social component that increased over time. It also included a program aimed at protecting oil pipelines, worth \$115 million. We do not take into account these resources in this exercise.

¹⁴For the details, see Mejia and Restrepo (2012).

¹⁵One 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.

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

For the fraction of routes controlled by traffickers, we use as a proxy the fraction of cocaine not seized by Colombian authorities. Cocaine seizures and potential cocaine production were both obtained from UNODC yearly reports (see UNODC, 2008). 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 that they do control. Again, Figure 2 shows a sharp decline in h from 0.91 to 0.78 following the implementation of Plan Colombia. From equation 18, it follows that a decline in h implies a drop in $1 - \Omega$ – i.e., an increase in subsidies for interdiction – from 0 prior to Plan Colombia to 0.35 afterwards. We take the value $\Omega = 0.35$ as a natural benchmark for our quantitative predictions.

To summarize, and consistent with our view that Plan Colombia can be thought of as an increase in subsidies, q and h decreased by 63% and 16%, respectively. 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 by only 13%, 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.¹⁶ This is somewhat paradoxical, since a naive model would predict that a fall in land of this magnitude would lead to a similar contraction in production. In fact, one of the original goals of Plan Colombia was to reduce cocaine production by 50% by reducing cultivation by the same amount. However, the framework developed here suggests that the possibility of substituting for other inputs – and the

¹⁶The productivity figures for the last few years have not been revised, and may be higher than reported. Correspondingly, this constitutes an upper bound for the drop in quantities.

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. This implies that the increase in the shadow price of land that eradication must have caused only had a small impact on the total cost of production and trafficking, and hence on the price of Colombian cocaine transacted in transit countries (likewise on its retail price).

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

Another reason why drops in q and h have only limited effects on the supply of cocaine from Colombia, Q_c , is the possibility of substituting among for inputs. For instance, the model predicts that producers will react to a drop in q by substituting for complementary factors, a ; as a result, land productivity will increase (as demonstrated when we described the effects of eradication on the farm gate market). In fact, this is exactly what the data in Figure 4 shows. After 2000, the increase in farm gate prices from \$1,538 to \$2,232 dollars per kg coincided with a significant increase in yields per hectare, from about 4.3 kg of cocaine/hectare/year before 2000 to about 6.66 kg of cocaine/hectare/year during the period 2005 - 2008. These increases in productivity have 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 use of more efficient chemical precursors in the processing of coca leaf into cocaine – all can be broadly classified as greater use of the complementary factors embodied in a . Using the formula in the corollary to lemma 1 and in equation 20, 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 per area of land following the implementation of Plan Colombia. More importantly for the purposes of quantifying the costs and benefits of source country interventions, the model and the data imply that the great extent to which producers

can substitute land for other inputs renders eradication fairly ineffective at curbing the supply of cocaine, even if producers hold less land, they are able to produce more cocaine per unit of land.¹⁷

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

Figure 3 plots retail quantities and the three-year moving average. It shows that there was no large drop in retail quantities despite the decreasing trend. Moreover, most of the decline can be explained by seizures in transit countries or the U.S., neither of which is a direct consequence of policies implemented under Plan Colombia. Notably, and consistent with the observed patterns for quantities, the wholesale and retail price of cocaine remained relatively stable during these years. We recognize that this comparison is clouded by the fact that other changes could have occurred in downstream markets during this period, and we do not have the right counter-factual, still, it is interesting to note that the 17% decrease in the Colombian supply of cocaine, Q_c , did not lead to significant changes in retail quantities and prices. Our model provides a good explanation for this. As shown in the above sections, a decrease in the Colombian supply of cocaine –which theoretically is what must have happened, even if we cannot observe it– will only have a limited effect on retail prices and quantities, because its share of the cocaine trade is quite small. More specifically, about 800 metric tons of cocaine reach transit markets and about 650 metric tons are actually sold at retail markets, with 54% of the cocaine coming from Colombia. Therefore $s_c = 0.54$, and $s_o = 0.46$. Moreover, according to different accounts, cocaine in transit countries is transacted at around \$12,000 per kg, while the retail price is around \$150,000 per kg, which implies that $s_t = 0.1$. Supply reduction policies in Colombia thus have only a limited effect on retail prices, because payments to producers and traffickers for the control of land and routes

¹⁷This calculation assumes that the entire increase in productivity was caused by Plan Colombia. This interpretation is supported by the fact that the UNODC data do not show this variable trending up prior to the implementation of Plan Colombia. Interestingly, during the last few years (after 2008), eradication was cut back and productivity again decreased, which is consistent with our interpretation.

represent only a small fraction of the world drug trade; hence, a small increase in retail prices is enough to compensate for the extra cost created by source country interventions.

Our model also suggests that the possibility of substituting for cocaine from other source countries – captured in the model by a higher σ_t – is another factor rendering retail quantities and prices less reactive to interventions in Colombia. Interestingly, we find strong empirical support for this idea – the so called “ballooning effect.” 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. Although we are unable to observe the price for Colombian cocaine in transit markets, P_c , our model predicts that it had to increase relative to the price of cocaine from other source countries, thus leading to this substitution. The right panel shows that, following Plan Colombia, the 32% decline in Colombian cocaine transacted in transit markets was partially compensated by an increase of 45% in the supply from Peru and Bolivia, which increased from 220 to 350 MT over this period. Remarkably, the opposite phenomenon occurred between 1994 and 2000, when production from Peru was substituted by production from Colombia, following an intensification of the war on drugs in Peru. However, once one controls for the apparent trend in the production of cocaine in other source countries (which may entail capturing supply or demand side factors not taken into account by the model), the residual increase in cocaine production in other source countries that can be attributed to Plan Colombia is 6.5%. Consistent with this view, and despite the intensification of the war on drugs in Colombia, the estimated amount of cocaine transacted in transit countries fell by 6% relative to its trend, which is less than the decrease in the Colombian supply.

Figure 5: Increase in prices in Colombia leads to substitution towards Peruvian or Bolivian cocaine after 2000. The opposite happens between 1994 and 2000.

5.2 Calibrating the elasticities of substitution

To get a rough idea of the size of the unobserved elasticities of substitution, we calibrate them 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 $\sigma_{fg}, \sigma_c, \sigma_t, \sigma_f, \varepsilon_o^s$ that minimize the distance between the predicted changes in land productivity, $Q_{fg}, P_{fg}, Q_c, Q_t, Q_o$ noted in the above section. The predicted changes are obtained using the elasticities predicted by the model between all endogenous variables and q and h , and then multiplying them by the actual changes in these variables. The literature estimates an elasticity of demand at the retail level of around 0.5, which we use as our benchmark value. Additionally, we use the shares noted above and obtained from UNODC reports, and Mejía and Rico (2010). Table 1 summarizes the targeted changes and the closest fit provided by the model.

Table 1: Model aggregate predictions.

	Targeted changes					
	Productivity	$d \ln Q_{fg}$	$d \ln P_{fg}$	$d \ln Q_c$	$d \ln Q_t$	$d \ln Q_o$
Observed	48.22%	-13.75%	23.07%	-32.71%	-6.38%	6.41%
Predicted	47.95%	-15.30%	23.67%	-19.20%	-7.65%	6.08%
	Untargeted changes					
	$d \ln P_l$	$d \ln P_r$	$d \ln P_c$	$d \ln P_t$	$d \ln Q_f$	$d \ln P_f$
Unobserved	59.18%	0.18%	6.27%	3.96%	-0.19%	0.39%

Notes: The table summarizes the observed changes in the aggregate data used to match the model, and the ones predicted by the most plausible configuration of parameters. The bottom panel shows the predicted effects on some of the variables that are not observed empirically but which our model helps to recover. The source of the data is described in the text.

As demonstrated, the model does a good job matching the observed changes of which we are most certain. The only change that cannot be matched closely is that in Colombian quantities, Q_c . Using the obtained parameters, we are also able to calculate the predicted changes in unobservable variables. The model predicts a sharp increase in the shadow price of land, which is probably caused by the large increase in eradication campaigns. The increase in the price of routes, however, is much smaller, and it only translates to a modest increase in the price of cocaine in transit countries and an even smaller increase in its price at retail markets. The predicted reduction in quantities is below 1%, which is consistent with the evidence suggesting no detectable impact on retail quantities or prices.

Table 2 summarizes the parameters obtained, as well as the ones directly imposed (shares and the elasticity of demand). A technical point worth emphasizing is that we capped all elasticities above 5 (at which point inputs are essentially perfect substitutes) in order to avoid making claims

based on unreasonably large elasticities. As can be seen, the elasticity of supply from other source countries and the elasticity of substitution obtained are set at this higher boundary, implying considerable ballooning effects, as hinted in Figure 5. Essentially, the model requires large ballooning effects in order to match the data. We obtain a relatively high level for σ_{fg} so as to match the sharp increase in land productivity. Costs c_1 and c_2 are computed to match the U.S. expenditure level for each front, while ϕ and γ are computed to match the levels of q and h , though they are not reported. The large value of c_1 reflects the large expenditures on eradication relative to interdiction as observed in the data, and matches anecdotal evidence about the focus on eradication during the period 2000-2007. 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.

Table 2: Parameters and elasticities used in the quantitative exercise.

Shares			
$s_a = 1 - s_l$	$s_{fg} = 1 - s_r$	$s_c = 1 - s_o$	$s_t = 1 - s_b$
0.6	0.3	0.5	0.1
Elasticities of substitution			
σ_{fg}	σ_c	σ_t	σ_f
0.9	0.6	5.0	2.1
Other		Current q and h	
ε_f^d	ε_o^s	q	h
0.5	5.0	0.17	0.78
Costs to Colombia		Current subsidies	
c_1	c_2	ω	Ω
0.71	0.12	0.44	0.35

Notes: The table shows the estimated and imposed parameters that we feed to our model in our baseline exercise. The shares are computed from UNODC data.

5.3 Quantitative implications for Plan Colombia

The parameters estimated above, together with the UNODC price and quantities data, imply that $MC_\omega = \$1'631.900$ and $MC_\Omega = \$267,450$. As our calculation in the introduction suggests, these are large numbers when compared to other policies, such as treatment and prevention, which have marginal costs below \$60,000. To understand the role of key parameters in determining both the size and difference in these costs, we examine the effect of changing the baseline levels for these marginal costs.

Table 3 analyzes the role of the elasticities of substitution in production and trafficking, as explained in Proposition 1. As demonstrated, the marginal cost of reducing retail quantities by subsidizing eradication sharply increases with σ_{fg} . Since this parameter was initially given a high value to match the increase in productivities, we obtain a large value for MC_ω . Equivalently, the observation that productivity increased sharply following the introduction of Plan Colombia implies that σ_{fg} is not small, and hence that MC_ω is large, as stated in Proposition 3. The marginal cost of reducing retail quantities by subsidizing interdiction is also decreasing. This is because expenditures on eradication are high relative to interdiction, such that the effect brought about by the savings in eradication costs dominates and Proposition 3 implies a decreasing relationship. 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.

The elasticity of substitution for trafficking always decreases MC_ω , as was proved in Proposition 3. The effect on MC_Ω is the opposite; this always increases with σ_c for the range of parameters being considered (meaning $\sigma_{fg} > \underline{\sigma}$ for this range). Thus, the low value of σ_c , which is both intuitive and comes out of the data, implies a large marginal cost for eradication and a low marginal cost for interdiction.

Table 3: Marginal costs and the role of substitution.

Marginal cost subsidizing eradication MC_ω						
	$\sigma_{fg} = 0.1$	$\sigma_{fg} = 0.5$	$\sigma_{fg} = 1$	$\sigma_{fg} = 1.5$	$\sigma_{fg} = 2$	$\sigma_{fg} = 5$
$\sigma_c = 0.1$	\$4924.097	\$6373.526	\$8185.313	\$9997.099	\$11808.885	\$22679.602
$\sigma_c = 0.5$	\$1294.153	\$1597.132	\$1975.857	\$2354.581	\$2733.305	\$5005.649
$\sigma_c = 1$	\$840.410	\$1000.083	\$1199.674	\$1399.266	\$1598.857	\$2796.405
$\sigma_c = 2$	\$613.538	\$701.558	\$811.583	\$921.608	\$1031.633	\$1691.783
$\sigma_c = 5$	\$477.415	\$522.444	\$578.729	\$635.014	\$691.299	\$1029.010
Marginal cost subsidizing interdiction MC_Ω						
	$\sigma_{fg} = 0.1$	$\sigma_{fg} = 0.5$	$\sigma_{fg} = 1$	$\sigma_{fg} = 1.5$	$\sigma_{fg} = 2$	$\sigma_{fg} = 5$
$\sigma_c = 0.1$	\$-243.226	\$130.150	\$203.075	\$229.452	\$243.066	\$268.324
$\sigma_c = 0.5$	\$170.743	\$231.858	\$256.686	\$267.971	\$274.420	\$287.720
$\sigma_c = 1$	\$283.235	\$293.609	\$299.574	\$302.786	\$304.794	\$309.399
$\sigma_c = 2$	\$351.253	\$349.747	\$348.590	\$347.841	\$347.317	\$345.911
$\sigma_c = 5$	\$396.819	\$401.003	\$405.146	\$408.432	\$411.102	\$420.394

Notes: The tables show the estimated marginal costs using the data on Table 2 as well as prices and quantities from UNODC mentioned in the text. We show the behavior of these marginal costs as the elasticities of substitution σ_{fg} and σ_c take values other than the baseline ones.

Table 4 examines the role of ballooning effects explained in Proposition 2. In particular, we see that for $\sigma_t > \varepsilon_t^d = 1.93$ (obtained using Marshall's formula in the Appendix), the elasticity of supply in other source countries increases both marginal costs and makes supply reduction policies in one source country less cost-effective. This is exactly the behavior expected based on Proposition 4. Moreover, when ε_o^s is greater than 0.5 (and greater than 1 for the case of interdiction), we see that the marginal costs increase with the elasticity of substitution. Both observations combined imply that the large values obtained in the calibration for both σ_t and ε_o^s make both marginal costs large. These numbers reflect the sharp increase in production in other source countries following the implementation of Plan Colombia; this empirical regularity in turn implies large ballooning effects and large marginal costs for supply reduction policies in Colombia.

Table 4: Marginal costs and the role of ballooning effects.

Marginal cost subsidizing eradication MC_ω						
	$\sigma_t = 0.5$	$\sigma_t = 1$	$\sigma_t = 1.5$	$\sigma_t = 2$	$\sigma_t = 5$	$\sigma_t = 10$
$\varepsilon_o^s = 0$	\$1389.642	\$1288.532	\$1254.829	\$1237.977	\$1207.644	\$1197.533
$\varepsilon_o^s = 0.5$	\$1124.185	\$1189.612	\$1222.326	\$1241.954	\$1284.779	\$1301.773
$\varepsilon_o^s = 1$	\$1035.699	\$1140.152	\$1202.824	\$1244.605	\$1349.058	\$1396.537
$\varepsilon_o^s = 1.5$	\$991.456	\$1110.476	\$1189.822	\$1246.499	\$1403.448	\$1483.060
$\varepsilon_o^s = 2$	\$964.910	\$1090.692	\$1180.536	\$1247.919	\$1450.068	\$1562.373
$\varepsilon_o^s = 5$	\$906.992	\$1041.232	\$1154.819	\$1252.179	\$1631.885	\$1927.212
Marginal cost subsidizing eradication MC_Ω						
	$\sigma_t = 0.5$	$\sigma_t = 1$	$\sigma_t = 1.5$	$\sigma_t = 2$	$\sigma_t = 5$	$\sigma_t = 10$
$\varepsilon_o^s = 0$	\$275.127	\$233.626	\$219.792	\$212.875	\$200.424	\$196.274
$\varepsilon_o^s = 0.5$	\$216.161	\$214.714	\$213.991	\$213.557	\$212.610	\$212.235
$\varepsilon_o^s = 1$	\$196.505	\$205.259	\$210.511	\$214.012	\$222.765	\$226.744
$\varepsilon_o^s = 1.5$	\$186.677	\$199.585	\$208.190	\$214.337	\$231.358	\$239.992
$\varepsilon_o^s = 2$	\$180.781	\$195.803	\$206.533	\$214.580	\$238.723	\$252.136
$\varepsilon_o^s = 5$	\$167.915	\$186.347	\$201.943	\$215.311	\$267.447	\$307.997

Notes: The tables show the estimated marginal costs using the data on Table 2 as well as prices and quantities from UNODC mentioned in the text. We show the behavior of these marginal costs as the elasticities of substitution σ_t and supply ε_o^s take values other than the baseline ones. This illustrates the role of ballooning effects.

Table 5 examines the role of the elasticity of demand. As noted in Proposition 4, the low value assumed for the elasticity of demand explains to a great extent the high marginal costs for both fronts. It is interesting to note that, as per proposition 4, a higher elasticity of demand not only makes both policies more effective, but also reduces the cost of making important advances on both fronts, though this effect is smaller. 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; hence, the willingness of producers and traffickers to fight back against the Colombian government does not increase significantly.

Table 5: Costs, effectiveness and 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	\$1539.859	\$780.387	\$527.230	\$400.651	\$324.704	\$274.072
C_q	\$46.7M	\$46.6M	\$46.6M	\$46.6M	\$46.5M	\$46.5M
Λ_q	0.001	0.003	0.004	0.005	0.006	0.007
MC_Ω	\$531.141	\$268.825	\$181.386	\$137.667	\$111.435	\$93.947
C_h	\$24.4M	\$24.4M	\$24.3M	\$24.3M	\$24.2M	\$24.2M
Λ_h	0.009	0.018	0.026	0.034	0.042	0.050

Notes: The tables show the estimated marginal costs, change in total costs and effectiveness measures using the data on Table 2 as well as prices and quantities from UNODC mentioned in the text. We show the behavior of these marginal costs as the elasticity of demand ε_f^d take values other than the baseline ones.

Finally, in Table 6, we study the determinants of $\bar{m}$. The value obtained for this threshold in our baseline exercise is 0.47. Given that we observe expenditures for eradication that are twice as high as those for interdiction, our model predicts a larger marginal cost for eradication, consistent with Proposition 7. This occurs mainly because the model interprets the high expenditure on eradication as if the U.S. was already making too many efforts on this front. Given the decreasing returns for each front, the model predicts a much higher marginal cost for eradication. The way to interpret $\bar{m}$ is as follows: So long as the U.S. spends on eradication more than 47% of what it spends on interdiction, our model will predict that eradication is more costly at the margin.

One way to also check the robustness of this result – and to explore the determinants of $\bar{m}$ – is to change some of our baseline parameters. Table 6 shows the effect of changing the parameters corresponding to the estimated value for $\bar{m}$. As discussed in Proposition 1, a higher elasticity of substitution σ_{fg} , decreases $\bar{m}$, which is the same as saying that it makes eradication less cost-effective than interdiction. This was already evident from Table 3, which showed a sharp increase in MC_ω for higher elasticities, and only a limited effect on MC_Ω . A higher elasticity of substitution σ_c , increases $\bar{m}$, which is the same as saying that it makes eradication more cost-effective than interdiction. This was already evident from Table 3, which showed the opposite effects for σ_c on both marginal costs. When $\sigma_c = 5$, we still get $\frac{TC_\omega^{US}}{TC_\Omega^{US}} > \bar{m}$, which implies that even in this extreme case, eradication has a larger marginal cost than interdiction.

Finally, the share of land, s_l , and farm gate cocaine in trafficking, s_{fg} , increase $\bar{m}$, meaning that they make eradication more cost-effective relative to interdiction. This was already explained in our discussion of Proposition 7. The important point here is that even when these shares are set at high and unreasonable values, we still get $\frac{TC_\omega^{US}}{TC_\Omega^{US}} > \bar{m}$. Thus, our parameters would have to be

Table 6: The relative cost effectiveness as measured by $\overline{m}$.

Elasticity of substitution σ_{fg}						
	0.1	0.5	1	1.5	2	5
$\overline{m}$	0.69	0.56	0.45	0.38	0.33	0.18
Elasticity of substitution σ_c						
	0.1	0.5	1	1.5	2	5
$\overline{m}$	0.15	0.40	0.65	0.84	1.00	1.54
Share s_l						
	0.2	0.3	0.4	0.5	0.6	0.7
$\overline{m}$	0.23	0.34	0.47	0.59	0.71	0.84
Share s_{fg}						
	0.2	0.3	0.4	0.5	0.6	0.7
$\overline{m}$	0.37	0.53	0.71	0.91	1.14	1.42

Notes: The tables show the estimated threshold $\overline{m}$ using the data on Table 2 as well as prices and quantities from UN-ODC mentioned in the text. We show the behavior of this threshold as the elasticities of substitution σ_{fg} , σ_c , and the shares s_l , s_{fg} take values other than the baseline ones.

far from the estimated ones in order for us to be able to conclude that the observed allocation of expenditures is optimal from the point-of-view of supply reduction. We believe that the fact that eradication has a larger marginal cost than interdiction is a robust finding, that depends on the importance of the calibrated structural parameters, and is not an artifact of our baseline choice of parameters nor a result imposed by our modeling assumptions. In particular, the low shares of land and farm gate cocaine – which is backed up by the data – likewise the high elasticity of substitution in production – deduced from the observed increase in land productivity – are two robust facts that imply a greater marginal cost for eradication than for interdiction efforts.

In the Appendix, we provide different figures illustrating the role of shares, which confirm our discussion in Proposition 3. We do not present them here for lack of space.

6 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 when modelling 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 calculate the marginal cost of reducing the retail quantity of drugs by 1kg using subsidies for eradication or interdiction, and characterize their determinants.

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 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 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 that match the data for the war on drugs under Plan Colombia, our model predicts that the marginal cost for the U.S. of reducing by one kilogram the amount of cocaine transacted in retail markets is about \$1.6 million if resources are allocated to subsidizing eradication efforts in Colombia; and about \$270,000 if allocated to subsidizing interdiction efforts in Colombia. Both numbers are large. 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. This implies marginal costs of reducing consumption by 1kg of about \$8,250 and between \$12,500 and \$68,750 using treatment and prevention, respectively. Source country interventions such as Plan Colombia, therefore, are very costly strategies for curbing the supply of drugs in consumer countries relative to other available strategies such as prevention and treatment. Moreover demand reduction strategies would have positive spillovers; for instance, they would likely reduce the direct and indirect costs of supply-side intervention strategies.

They are also socially costly strategies. To justify subsidies for interdiction (the most cost-effective program), one would have to argue that 1kg of cocaine supplied in retail markets has a social cost of about \$417.000 (the marginal cost of enforcement plus the private valuation by consumers – e.g., the price). This is an optimistic calculation erring on the side of favoring the war on drugs. A global welfare analysis would also have to take into account the share of the expenditures paid by Colombia, as well as the violence and externalities created by the drug trade in source, transit and consumer countries as a consequence of higher prices. Our numerical exercise suggests that Plan Colombia, at least during our period of analysis, was an inefficient and socially costly way of reducing the drug supply.

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Appendix A: the two main lemmas.

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 $F : \mathbb{R}^2 \rightarrow \mathbb{R}$, 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:

$$d \ln p_1 = d \ln p_1, \quad (\text{A1})$$

$$d \ln p_2 = \frac{s(\sigma - \varepsilon_d)}{s(\sigma + \varepsilon_s^2) + (1 - s)(\varepsilon_s^2 + \varepsilon_d)} d \ln p_1, \quad (\text{A2})$$

$$d \ln x_1 = -\frac{s(\sigma + \varepsilon_s^2)\varepsilon_d + (1 - s)(\varepsilon_s^2 + \varepsilon_d)\sigma}{s(\sigma + \varepsilon_s^2) + (1 - s)(\varepsilon_s^2 + \varepsilon_d)} d \ln p_1, \quad (\text{A3})$$

$$d \ln x_2 = \frac{s(\sigma - \varepsilon_d)\varepsilon_s^2}{s(\sigma + \varepsilon_s^2) + (1 - s)(\varepsilon_s^2 + \varepsilon_d)} d \ln p_1, \quad (\text{A4})$$

$$d \ln p = \frac{s(\sigma + \varepsilon_s^2)}{s(\sigma + \varepsilon_s^2) + (1 - s)(\varepsilon_s^2 + \varepsilon_d)} d \ln p_1, \quad (\text{A5})$$

$$d \ln y = -\frac{s(\sigma + \varepsilon_s^2)\varepsilon_d}{s(\sigma + \varepsilon_s^2) + (1 - s)(\varepsilon_s^2 + \varepsilon_d)} d \ln p_1. \quad (\text{A6})$$

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

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

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)

$$d \ln p = s_1 d \ln p_1 + s_2 d \ln p_2, \quad (\text{A8})$$

and using Euler's theorem, we get

$$d \ln q = s_1 d \ln q_1 + s_2 d \ln q_2. \quad (\text{A9})$$

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

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

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

$$d \ln x_1 = -\varepsilon_d^1 d \ln p_1, \quad (\text{A11})$$

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

$$d \ln x_2 = \varepsilon_s^2 d \ln p_2. \quad (\text{A12})$$

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

$$d \ln y = \varepsilon_d d \ln p. \quad (\text{A13})$$

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

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

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

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

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 $F : \mathbb{R}^2 \rightarrow \mathbb{R}$, 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

$$d \ln p_1 = \frac{\sigma + \varepsilon_2^s}{s_1(\sigma + \varepsilon_2^s) + s_2(\sigma + \varepsilon_1^s)} d \ln p, \quad (\text{A16})$$

$$d \ln p_2 = \frac{\sigma + \varepsilon_1^s}{s_1(\sigma + \varepsilon_2^s) + s_2(\sigma + \varepsilon_1^s)} d \ln p, \quad (\text{A17})$$

$$d \ln x_1 = \frac{(\sigma + \varepsilon_2^s)\varepsilon_1^s}{s_1(\sigma + \varepsilon_2^s) + s_2(\sigma + \varepsilon_1^s)} d \ln p, \quad (\text{A18})$$

$$d \ln x_2 = \frac{(\sigma + \varepsilon_1^s)\varepsilon_2^s}{s_1(\sigma + \varepsilon_2^s) + s_2(\sigma + \varepsilon_1^s)} d \ln p, \quad (\text{A19})$$

$$d \ln y = \left(\frac{(\sigma + \varepsilon_2^s)s_1\varepsilon_1^s}{s_1(\sigma + \varepsilon_2^s) + s_2(\sigma + \varepsilon_1^s)} + \frac{(\sigma + \varepsilon_1^s)s_2\varepsilon_2^s}{s_1(\sigma + \varepsilon_2^s) + s_2(\sigma + \varepsilon_1^s)} \right) d \ln p. \quad (\text{A20})$$

This implies a price elasticity of supply equal to

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

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

$$d \ln x_i = \varepsilon_s^i d \ln p_i, \quad (\text{A22})$$

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.

Appendix B: The derivation of Λ_q , Λ_h and their determinants.

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:

$$\varepsilon_l^d = s_l \varepsilon_{fg}^d + (1 - s_l) \sigma_{fg}, \quad \varepsilon_a^d = \frac{\sigma_{fg} \varepsilon_{fg}^d}{s_a \sigma_{fg} + (1 - s_a) \varepsilon_{fg}^d}. \quad (\text{A23})$$

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

$$\varepsilon_{fg}^s = \frac{s_a}{s_l} \sigma_{fg}. \quad (\text{A24})$$

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:

$$\varepsilon_{fg}^d = \frac{\sigma_c \varepsilon_c^d}{s_{fg} \sigma_c + (1 - s_{fg}) \varepsilon_c^d}, \quad \varepsilon_r^d = \frac{s_r (\sigma_c + \varepsilon_{fg}^s) \varepsilon_c^d + (1 - s_r) (\varepsilon_{fg}^s + \varepsilon_c^d) \sigma_c}{s_r (\sigma_c + \varepsilon_{fg}^s) + (1 - s_r) (\varepsilon_{fg}^s + \varepsilon_c^d)}, \quad (\text{A25})$$

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:

$$\varepsilon_c^s = \frac{s_{fg} \sigma_c}{s_{fg} \sigma_c + s_r (\varepsilon_{fg}^s + \sigma_t)} \varepsilon_{fg}^s. \quad (\text{A26})$$

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

$$\varepsilon_c^d = \frac{s_c (\sigma_t + \varepsilon_o^s) \varepsilon_t^d + (1 - s_c) (\varepsilon_o^s + \varepsilon_t^d) \sigma_t}{s_c (\sigma_t + \varepsilon_o^s) + (1 - s_c) (\varepsilon_o^s + \varepsilon_t^d)}, \quad (\text{A27})$$

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

$$\varepsilon_t^d = s_t \varepsilon_f^d + (1 - s_t) \sigma_f. \quad (\text{A28})$$

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

$$\varepsilon_f^s = \frac{1}{s_t} \left(\frac{s_c (\varepsilon_o^s + \sigma_t)}{s_c (\varepsilon_o^s + \sigma_t) + s_o (\varepsilon_c^s + \sigma_t)} \varepsilon_c^s + \frac{s_o (\varepsilon_c^s + \sigma_t)}{s_c (\varepsilon_o^s + \sigma_t) + s_o (\varepsilon_c^s + \sigma_t)} \varepsilon_o^s \right) + \frac{s_b}{s_t} \sigma_f. \quad (\text{A29})$$

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.

The following two propositions show the main determinants of elasticities Λ_q and Λ_h .

Proposition A1: Comparative statics on Λ_q .

- Λ_q is decreasing in the elasticities of substitution σ_f and σ_{fg} . It is only decreasing in the elasticity of substitution σ_t if drugs from other countries are supplied with an elasticity of $\varepsilon_o^s > \underline{\varepsilon}$. However, it is always increasing in the elasticity of substitution σ_c .

- Λ_q is increasing in the shares s_t , s_c , s_{fg} and s_l .
- Λ_q is increasing in the price elasticity of final consumers' demand for cocaine, ε_f^d .
- Λ_q is decreasing in the price elasticity of supply in other source countries, ε_o^s , so long as $\sigma_t > \varepsilon_t^d$.

Proof: This proof follows directly from the expression for Λ_q , presented in the above equations after substituting the elasticities and taking derivatives.

Proposition A2: Comparative statics on Λ_h .

- Λ_h is decreasing in the elasticity of substitution σ_f . It is decreasing in the elasticity of substitution σ_c , as long as $\varepsilon_{fg}^s > \underline{\varepsilon}$. It is only decreasing in the elasticity of substitution σ_t if drugs from other countries are supplied with an elasticity $\varepsilon_o^s > \underline{\varepsilon}$.

- Λ_h is increasing in the shares s_t , s_c and s_r .
- Λ_h is increasing in the price elasticity of final consumers' demand for cocaine, ε_f^d .
- Λ_h is decreasing in the price elasticity of supply from other source countries, ε_o^s , so long as $\sigma_t > \varepsilon_t^d$.

Proof: This proof follows directly from the expressions for Λ_h , presented in the above equations after substituting the elasticities and taking derivatives.

Propositions 1 and 2 explicitly account for the key factors determining the effectiveness of anti-drug policies in source countries. In general, there are four driving forces behind the effectiveness of source country interventions. The first is the extent to which the agents involved in production

and distribution networks can substitute for other inputs; intuitively, the possibility substitution creates two opposite forces. On the one hand, it makes the demand for land and routes more elastic, as producers and traffickers are able to compensate for an increase in the cost of land and routes by using other inputs more intensively. This makes reductions in q and h less effective at raising prices. However, greater substitution also implies a higher demand for substitutes, which could lead to an increase the cost of using other inputs. As long as substitutes are supplied with a high enough elasticity, the first effect dominates and the possibility of substitution renders supply reduction policies less effective.

Take for instance σ_t , which captures the extent of substitution for cocaine from other sources. When σ_t increases, we find two effects on Λ_q and Λ_h . On the one hand, the demand for land and routes becomes more elastic, as changes in the prices of these inputs in Colombia raise the price of Colombian cocaine, thus leading to a greater demand for cocaine from other source countries. This, in turn, implies a sharp reduction in the demand for these inputs. This means that eradication and interdiction will both have a weaker effect on Colombian cocaine prices, and therefore on retail prices and quantities. On the other hand, an increase in σ_t also affects the transmission of prices $\frac{d \ln P_f}{d \ln P_c}$, by making this elasticity larger. Intuitively, this occurs because the supply from other sources countries is elastic, and hence greater substitution leads to higher prices, which translates into higher retail prices. More specifically, if the supply from other source countries is fully elastic (i.e., at a constant price), this effect disappears. Conversely, if the supply fro other source countries is completely inelastic (i.e., at a constant quantity), this effect dominates and Λ_q and Λ_h increase with the elasticity of substitution, σ_t .

This logic also explains why σ_c has a counterintuitive positive effect on λ_q . The idea is that, in this case, routes are a substitute for the more expensive farm gate cocaine, and they are supplied inelastically. Eradication increases the demand for routes when σ_c is larger, and this greatly increases their price, which implies a greater increase in the price of Colombian cocaine in transit countries, P_c . Conversely, σ_c has a negative effect on λ_h so long as $\varepsilon_{fg}^s > \varepsilon$. The idea is that, in this case, farm gate cocaine is a substitute for the more expensive routes, and it is supplied elastically. Thus, its price does not increase considerably, and the possibility of substituting for routes and farm gate cocaine makes interdiction efforts less effective.

One final case which serves to clarify this point is the effect of σ_{fg} on Λ_q , or σ_f on Λ_q and Λ_h . In this case, the substitutes are always supplied at a constant price, so the possibility of substitution renders supply reduction policies less effective, since there is no counteracting force via the higher prices of substitutes that leads to higher consumer prices.

The second set of determinants are the shares of the factors targeted in the cocaine trade. The common theme is that policies that target factors with a lower share will be less effective at reducing quantities transacted in retail markets. Thus, eradication and interdiction in Colombia

are less effective if only a small share of the price paid by retail consumers covers the cost of land and routes. In this case, a small increase in retail prices is enough to cover the extra costs generated by these policies. Shares also have an effect through some of the elasticities of demand, whose formulas involve input shares. However, these effects are dominant. This factor explains why the shares of cocaine in transit, s_t , and the share of Colombian cocaine, s_c , increase the effectiveness of both policies; also why the share of farm gate cocaine in trafficking, s_{fg} , increases the effectiveness of eradication and reduces the effectiveness of interdiction.

Third, as already pointed out by Becker et al. (2006), the price elasticity of final consumers' demand is a key determinant of the effectiveness of anti-drug policies. More precisely, when final consumers' demand for drugs is very inelastic, most of the effect of anti-drug policies is adjusted via changes in prices, and final quantities transacted in retail markets do not change much. In this case, we can see the direct effect of having a higher elasticity of demand in the term ε_f^d by multiplying the expressions. However, the elasticity of demand also affects the elasticity of the demand for inputs, though these effects are dominated by the direct effect of having quantities that react less to increases in retail prices.

Finally, a large price elasticity of supply from other source countries implies that a contraction of the supply from Colombia can easily be compensated with cocaine from other sources. In particular, if $\sigma_t > \varepsilon_t^d$, downstream markets will substitute Colombian cocaine in transit cocaine by increasing the demand for cocaine from other source countries in response to an increase in Colombian prices caused by interdiction or eradication. This possibility makes the equilibrium demand for Colombian cocaine more elastic, thus avoiding a large price increase in Colombian cocaine, especially if drugs from other sources are supplied with a high elasticity. Moreover, a high price elasticity of supply, ε_o^s , implies that the price of drugs from other sources does not increase significantly, which is reflected in a smaller increase in final prices. Conversely, if $\varepsilon_t^d > \sigma_t$, downstream markets will scale down their operations and will reduce their demand for cocaine from other sources. In this case, a more inelastic supply implies a large reduction in prices from other sources, which makes supply reduction policies less effective, as these savings are translated into smaller increases in consumer prices.

By combining the analysis of the effects of the elasticity of substitution for cocaine from other sources with that of the elasticity of their supply, we can understand the role of so-called ballooning (or displacement) effects. More precisely, our propositions imply that when ε_t^d and σ_t are large, they generate spatial dynamics that make cross-country interventions less effective. This combination captures the extent to which interventions in a given source country lead to the reallocation of production to other source countries without significantly increasing prices in transit countries. The innovation here is that we account for the fact that the existence and extent of these ballooning or displacement effects makes source country interventions in one country less effective

by shifting production to other sources. This dynamic affects all source country interventions that target just one producer country or one transit country, and not all producer and transit countries simultaneously.

The four factors noted above explain the key determinants of the effectiveness of eradication and interdiction efforts. However, it is also interesting to note that these factors also help explain the relative effectiveness of different interventions. In particular, the ratio $\Lambda_h/\Lambda_q = \frac{d \ln P_c}{d \ln h} / \frac{d \ln P_c}{d \ln q}$ is informative of the factors that make interdiction efforts more effective relative to eradication efforts; the remaining terms, $\frac{d \ln P_f}{d \ln P_c} \varepsilon_f^d$, are common, and capture the role of downstream markets. A direct analysis of this ratio shows that lower values for s_{fg} and s_l increase the relative effectiveness of interdiction efforts (*vis-à-vis* eradication), since the latter would be targeting an input with a lower value as a share of Colombian production. Additionally, the extent to which the drug producer can substitute land for complementary factors (a higher σ_{fg}) renders eradication less effective without significantly affecting the effectiveness of interdiction. Finally, the extent to which the drug trafficker can substitute routes for farm gate cocaine (a higher σ_c , which captures the possibility of using less routes more intensively, for example) makes interdiction less effective relative to eradication.

Appendix C: Discussion of the effect of shares.

We provide here some discussion of Proposition 3. As the proposition suggests, the effect of shares is ambiguous. Let us consider, for instance, a case in wherein $\sigma_f > \varepsilon_f^d$, which we think is relevant empirically, given the low estimated elasticity of demand. In this case, a lower share s_t implies a larger elasticity of demand for cocaine in transit relative to final demand. Thus, supply reduction policies in source countries have only a limited effect on P_t because its demand is more elastic. This channel is entirely different from the one emphasizing the limited effect of these policies on retail prices due to the small share of the costs affected by these policies; this cancels out the lower cost of these policies, and only the effect of s_t via the demand for cocaine in transit matters.

The analysis of s_c is more involved, because drugs from other sources are not supplied at a constant price. The proposition gives the exact conditions under which lower share s_c affects cost effectiveness, but the broad message is similar to the one in the previous item. Shares make policies more effective but also more costly, and these effects typically cancel one another out. Thus s_c only has an ambiguous effect through the elasticities of demand and the cross elasticities of demand for inputs. More specifically, this is the case if $\sigma_t > \varepsilon_t^d$ and ε_o^s is not too small, which we believe is the more plausible configuration of these parameters. The fact that Colombian cocaine represents only a small share of all the Andean drug trade implies larger marginal costs. We think this is plausible, because cocaine from other sources offers a close substitute for Colombian

cocaine; given the increase in production in Bolivia and Peru following the implementation of strong supply reduction policies in Colombia, we have good reasons to believe that we are in the region where $\varepsilon_o^s > \underline{v}$.

This occurs because a smaller share s_c makes the demand for Colombian cocaine more elastic. The reason why we need the condition $\varepsilon_o^s > \underline{v}$ is because a lower s_c makes demand for Colombian cocaine more elastic (i.e., so as long as $\sigma_t > \varepsilon_t^d$), but it also implies a large substitution for cocaine from other source countries. If supply from other source countries is rather inelastic and corresponds to a larger share of cocaine transacted in transit countries, it would bring about a large increase in the price of cocaine following supply reduction policies in Colombia. The condition $\varepsilon_o^s > \underline{v}$ guarantees that this last effect is small and the effect of the share s_c through the elasticity of demand for Colombian cocaine, dominates.

The analysis for s_{fg} is similar. More specifically, let us assume that $\sigma_c < \varepsilon_c^d$, which we think is a relevant and plausible configuration of the parameters, since we do not expect routes and farm gate cocaine to be easy to substitute for. In this case, s_{fg} only has an effect through elasticities of input demands and supply curves. A higher s_{fg} implies a lower s_r and hence a more inelastic demand for routes. This makes interdiction more effective at raising prices, thus reducing its marginal cost. The opposite occurs for the demand for farm gate cocaine, which becomes more elastic. However, despite the small increase in prices brought about by eradication efforts, the substitution by traffickers towards using more routes sharply increases their price and ends up making eradication more effective, thus reducing its marginal cost. This second effect dominates in this case, because routes are supplied inelastically, so their price increases sharply.

Finally, the analysis of s_l is as follows: First, s_l makes the supply of farm gate cocaine more inelastic. As before, let us assume that $\varepsilon_c^d > \sigma_c$. Interdiction will then cause a decrease in the demand for farm gate cocaine. The more inelastic the supply of farm gate cocaine, the greater the decline in farm gate prices – this translates into less effective interdiction. This tends to increase the first three terms in the expression for MC_Ω . However, a larger s_l also implies that interdiction brings about a large reduction in land prices, and hence will lead to more savings in the cost of eradication captured by the last term in the formula for MC_Ω . The last effect dominates whenever expenditure on eradication is large relative to expenditure on interdiction.

This makes interdiction more cost effective (i.e., it decreases MC_Ω) so long as $\varepsilon_c^d > \sigma_c$.

On the other hand, s_l makes the demand for land more inelastic so long as $\sigma_{fg} > \varepsilon_{fg}^d$. Given the large increase in land productivity following Plan Colombia, we think this is a reasonable assumption, as the increase in productivity implies a large elasticity of substitution, σ_{fg} . This implies that s_l reduces MC_ω , because a more inelastic demand for land implies that eradication will have a greater effect on prices.

More interesting than the specific details determining in which direction marginal costs move with changes in the observed shares, is the fact that the usual logic that postulates that policies

aimed at factors with a higher share are more cost effective does not hold under our setting. Rather, shares only have an effect by determining demand elasticities and cross elasticities, so their effects are typically ambiguous and have to be analyzed with care.

Appendix D: Proof of proposition 7.

We outline a proof for Proposition 7, which is the only one that requires anything more than differentiation.

Proof: Define $TC_{US}^\omega = \phi(1 - q)^2 P_l L$ and $TC_{US}^\Omega = \gamma(1 - h)^2 P_r R$ as total U.S. expenditure in subsidizing eradication and interdiction, respectively. We can rewrite the marginal costs in equations 32 and 33 as:

$$MC_\omega = \frac{1}{\Lambda_q} \frac{TC_{US}^\omega}{Q_f} \left(\frac{1}{\omega(1 - \omega)} q^2(1 - q) + 2 \frac{q}{1 - q} + \frac{1}{\varepsilon_l^d} \right) + \frac{1}{\Lambda_q} \frac{TC_{US}^\Omega}{Q_f} \frac{d \ln P_r}{d \ln q}, \quad (\text{A30})$$

and

$$MC_\Omega = \frac{1}{\Lambda_h} \frac{TC_{US}^\Omega}{Q_f} \left(\frac{1}{\Omega(1 - \Omega)} h^2(1 - h) + 2 \frac{h}{1 - h} + \frac{1}{\varepsilon_r^d} \right) + \frac{1}{\Lambda_h} \frac{TC_{US}^\omega}{Q_f} \frac{d \ln P_l}{d \ln h}. \quad (\text{A31})$$

Appendix E: The numerical role of shares.

In Figure A1, we study the role of shares. The left panel plots the marginal costs, the center panel plots the total change in costs, and the right panel plots effectiveness Λ_q and Λ_h . Variables related to eradication are in solid lines and interdiction in dotted lines. Both marginal costs are decreasing in s_l , which is consistent with the fact that in our data, $\varepsilon_c^d > \sigma_c$ and a large portion of the U.S. assistance is used for eradication. All plots reveal effects in the same direction as the one documented in Proposition 3. Thus, the low share of land in farm gate production, farm gate cocaine in trafficking, Colombian cocaine in transit, and cocaine in transit for the whole drug trade, make supply reduction policies in Colombia more costly. However, as mentioned before, the mechanism is different from the typical observation that targeting important factors is more cost effective; these shares only have an effect through input demand elasticities and cross elasticities.

More importantly, the effects on Λ_q and Λ_h - which focus only on the benefits of these policies, reveal a different picture, and push forward our case for also considering the effect of shares on costs. For instance, a higher s_l makes eradication more effective, but also much more costly. The net effect is a modest drop in the marginal cost of eradication, which in principle could move in any direction. The same pattern can be observed in all cases: shares tend to move costs and benefits in the same direction, because the main effect of shares on benefits occurs through the transmission of price increases to final prices. This effect implies that targeting more important

factors is more effective at reducing retail quantities. However, targeting factors with a higher share is also more costly, as agents involved in their production are more willing to fight back against the government. This is why both costs and benefits tend to move in the same way; these effects tend to cancel each other out and the net effect goes in an ambiguous direction.

Figure A1: Effect on marginal costs of the different shares.