Research methods

A system dynamics approach to the study of Colombian coca cultivation and the counter-intuitive consequence of law enforcement

Sebastian Jaén\textsuperscript{a,}\textsuperscript{*}, Isaac Dyner\textsuperscript{b}

\textsuperscript{a} Departamento de Ingeniería Industrial, Universidad de Antioquia, Colombia, Calle 67 \# 53-108, Office 21-407, Medellín, Colombia

\textsuperscript{b} Universidad Jorge Tadeo Lozano and Universidad Nacional de Colombia, AA 1027 Medellín, Colombia

A R T I C L E  I N F O

Article history:
Received 24 August 2012
Received in revised form 23 December 2013
Accepted 15 January 2014

Keywords:
System dynamics
Coca crop
Illegal monopolies
Counter-intuitive behavior in illegal markets
Law enforcement

A B S T R A C T

A large-scale expansion of the Colombian coca cultivation is one of the most revealing signs of a structural change in the illegal cocaine market in the Andean region. From being a modest and domestic production, in the space of five years Colombian coca cultivation supplied a competitive market, capable of substituting almost completely the foreign sources of supply. The purpose of this work is to explore the role and potential of system dynamics (SD) as a modeling methodology to better understand the consequences of drug policy. As a case study, this work tests the hypothesis that the outbreak of Colombian coca cultivations is a consequence of the take down of large cartels, leading to the surge of small drug-trafficking firms called “cartelitos.” Using an SD model, and elements from the economic theory of the criminal firm, our work shows how the formation of these small firms might significantly contribute to the configuring of a more competitive domestic coca industry (and hence to a more efficient crime industry).

We conclude that SD seems an appropriate dynamic modeling-based approach to address policy issues regarding drug markets. The methodology takes into account the dynamic nature of drug markets and their multi-dimensional responses to policy interventions.

© 2014 Elsevier B.V. All rights reserved.

Introduction

Illegal drug markets appear to be different than legal markets on a number of dimensions related to their complexity, dynamics, and response to policy interventions (Reuter, 2001). This suggests the need for methodologies that take into account these markets’ characteristics and provide new opportunities for policy analysis and design. This work explores the role and potential of system dynamics (SD) (Forrester, 1994) as an approach for addressing and understanding the behavior of illegal markets. As an example, the work introduces a case study that analyses the outbreak of Colombian coca cultivations. The paper tests the suitability of the approach for addressing the causes of the problem, and suggests its future use when considering the consequences of law enforcement.

The case study

By the mid-1980s, cocaine was prevalent in most cities in the United States (US), where the Colombian drug dealers were the main suppliers (Chepesiuk, 2005). Although Colombian cartels were the main producers of cocaine, they were not the main farmers of coca (Thoumi, 2009). They also had to smuggle coca paste, obtained from Peruvian and Bolivian middlemen, conducting logistical operations that included clandestine runways and overnight flights (Chepesiuk, 2005; Krauthausen, 1998). In fact, by the middle of the 1980s Colombian coca crops were only 9% of the Andean cultivation, while the Peruvian and Bolivian cultivations amounted to 61% and 30% respectively (US State Department, 2011, 2010). A different scenario was seen fifteen years later, when the Colombian coca production peaked at 76% of total Andean cultivation (Fig. 1), while Peru and Bolivia were by then supplying only the remainder (UNODC, 2010, 2011).

This work tests the SD methodology for exploring the hypothesis that the expansion of coca cultivations in Colombia, in 1995, is related more to the take-down of the main Colombian drug cartels (Medellín and Cali), than to the traditional explanations for such expansions. Although this paper does not discard traditional explanations, it does challenge the effectiveness of the Peruvian Air Bridge Denial Program (ABDP).
Background

The history of law enforcement operations against the main Colombian cartels begins after their expansion during the 1980s and 1990s (Levitt & Rubio, 2000). The Government reacted by getting support from the US, focusing its efforts mainly on the Medellin cartel (Thoumi, 2001). This American cooperation was a preamble to “Plan Colombia” (1999–2005), which consisted of a comprehensive strategy whose main component was to strengthen the Colombian armed forces and national police (DNF, 2006). After all the coordinated efforts against the Medellín cartel, the Cali cartel became the largest single player in the cocaine industry, attracting the attention of Colombian law enforcement (Chepesiuk, 2005). Its defeat left a hole in the Colombian drug scene, where a multitude of trafficking organizations were in the contest to become primary suppliers (Mallory, 2007). This led to the formation of an estimated 160–360 of the so-called “cartelitos” or baby cartels (Garzon, 2008; Grossman, 2006; ICG, 2005; Mallory, 2007). These small firms were harder to penetrate, became more elusive, and collectively were just as successful in exporting cocaine as the large cartels had been (Corcoran, 2007; ICG, 2005).

The Peruvian eradication policies

Parallel to events in Colombia, Peruvian coca cultivation decreased by 27% between 1996 and 1997. Like Peru, Bolivia also registered substantial declines in coca cultivation during the late 1990s (Bagley, 2011). Peruvian Government documents suggest that much of the success of the US-backed coca eradication and alternative-development programs in Peru and Bolivia in the late 1990s is attributable to the disruption of the “air bridge,” which allowed the transport of coca paste from these two Andean countries into Colombia (Bagley, 2011; Thoumi, 2003). The reduced availability of Peruvian and Bolivian coca paste explains a rapid expansion of coca cultivation into Colombia (Bagley, 2011). This theory has become one of the most accepted explanations for the migration of coca production. Several authors (Fukumi, 2008; Huskisson, 2005) had repeated what the early reports by Crane, Rivolo, and Comfort (1997) and Crane (1999) had found.

However, as Navarrete-Frias and Thoumi (2005) point out, this explanation has its problems because even though the ABDP that started during 1990 was intensified over four years, showing results in terms of the number of neutralized airplanes, coca prices in the Upper Huallaga (Peru) remained high and relatively stable and did not fall until late 1995. Although the decline in Peruvian and Bolivian cultivations during 1996–2000 coincided with a few airplane neutralizations, which provides some evidence for us to assume that these captures represented a mere fraction of the coca paste trade between Peru and Colombia that was transported by plane. The estimated number of clandestine flights between those countries had been 20 per month. The effectiveness in terms of plane captures thus represents little more than 10% effectiveness during the best year (Thoumi, 2003).

Ronken, Ledebur, and Kruse (1999) came close to estimates by Thoumi (2003), indicating that the ABDP had only 12% success—capturing one in eight of suspicious airplanes. Success of the program was claimed on the basis that there was a 47% reduction in the number of clandestine flights, assumed to be the result of a deterrence effect (Soberón, 1997). The authors also remark that there is no consensus about the number of intercepted airplanes. In 1995, the DEA (2003) confirmed the interception of 20 airplanes, while the National Narcotics Intelligence Consumers Committee (NNICC) declared a total of 39 (NNICC, 1996), but Peruvian authorities reported captures of as many as 70 airplanes in 1992, 67 in 1993, 36 in 1994, and, up to August of 1995, 21 planes (Soberón, 1997). Likewise, Rumrill (1998) remarks that even though the ABDP affected a percentage of the transit of coca paste from Peru to Colombia, fluvial and terrestrial routes should not be underestimated. They suggest that the market rapidly adapted by incorporating new fluvial and terrestrial corridors that proved to be useful during the 1980–1983 period. The shift toward fluvial routes had begun in 1993, the most successful year in terms

---

**Fig. 1.** Evolution of coca cultivations in the Andean region.

*Source: United Nations (UNODC, 2010) and Rocha (1997).*
of airplane captures, and by 1995–1996 they were fully operational. By 1998, the Peruvian and American authorities acknowledged that the terrestrial and fluvial routes had become the preferred smuggling routes (Ronken et al., 1999). In 2005, a report to congressional requesters acknowledged that the ABDP in Colombia had implemented new safeguards, but its effect on drug trafficking was not clear (GAO, 2005).

The UNODC (2011) shows the number of coca bush hectares eradicated during 1995 were 25,402 in Colombia, 5493 in Bolivia, and 7512 in Peru. Those efforts did indeed achieve an increase in eradication with respect to previous years. However, those values let us conclude that, even when the increase in eradication was high, there was only a 10% decrease in total production in Bolivia, and a 6% decrease in Peru (UNODC, 2011)—just enough to fuel a resistance against those policies by coca farmers from indigenous communities in Peru and Bolivia (Navarrete-Frias & Thoumi, 2005; ICG, 2005). Meanwhile in Colombia, eradications destroyed 33% of its production. What made the Peruvian increase in eradication so visible was the fact that from 240 hectares eradicated in 1994, they reached 7512 hectares in 1995 (UNODC, 2011). The area of eradicated cultivations in Peru was not more than eighteen thousand hectares in any one year during the whole 1994–2004 decade. The Peruvian authorities could explain the drop in cultivations if the destroyed hectares per year were, on average, larger than 10,000, but the efforts per year did not seem to surpass an average of 6700 hectares (UNODC, 2011). This revision suggests the most important factor in the decrease in Peruvian coca cultivation after 1995 was that Colombian traffickers no longer sought coca paste from Peru. The reason for this was the destruction of the big cartels and the emergence of a large number of small groups of traffickers for whom it was not attractive to buy large quantities of drugs in Peru (Navarrete-Frias & Thoumi, 2005).

### The Colombian law enforcement role

In Colombia, in almost every variable related to the ‘war’, there is evidence of constant increases during the last two decades. The law enforcement budget grew on average 7.6% per year during 1990–2000 (Villamizar & Espejo, 2004), while the armed forces and manpower grew 5% per year during 1990–2003 (BICC, 2010). The eradicated coca bush hectares increased on average 104% per year from 1990 until 2000, while the cumulative number of destroyed clandestine laboratories increased by 23% over the whole period. As a result of all combined efforts, the number of drug dealers captured and shot down increased by 41% per year (DNE, 2004) (Table 1). Even though the eradication policy was aggressive, its efforts could not counterbalance the expansion of coca farming. In fact, the initial efforts of law enforcement just led to a greater increase in the number and sizes of coca-bush crops spread across the Colombian landscape, until eventually the cumulative experience and efforts of eradication started to pay off. Table 1 shows a comparison of the law enforcement performance and budget during the period concerned. The ABDP seems to have accelerated an already existing migration phenomenon but does not entirely account for the migration of coca crops to Colombia (Ronken et al., 1999).

### Method

This paper uses a system dynamics model in order to verify the feasibility of the hypothesis described above. Both the modeling technique and the causal relationships that support the theoretical framework of this research came from a careful review of the literature to be discussed below. The model simulates the scenario where Colombian law enforcement focuses its action on cocaine production and the trade of large firms (big cartels), within a concentrated criminal industry. In this context, the model is capable of explaining how the market reacted by decreasing both firm size and demand for foreign coca, as well as increasing competition among illegal firms. Simulation reproduces the observed data, suggesting that the proposed dynamic hypothesis might be an alternative explanation of the coca outbreak in Colombia, and further research is necessary to verify such possibility. Moreover, these findings provide a basis for questioning the role of law enforcement efforts when intervening in an illegal system, and what the appropriate kinds of tools are for supporting such decisions.

SD is a computer-aided approach to policy analysis and design that might be applied to problems arising in complex social, managerial, economic, or ecological systems, at the strategic level. The approach is appropriate for a dynamic system that is characterized by interdependence, mutual interaction, information feedback, and circular causality (Randers, 1980). In this way, the input of parameters and data is directed in a different way than econometrics, as relatively few variables are represented exogenously (Randers, 1980). The method enables concentration on the required level of interest without being overwhelmed by lower-level details (Sterman, 2000). It focuses on the essential determinants of the system’s behavior; transparency and structural validity are more valued than the precise and quantitative representation of empirical observations. As a methodology for system modeling, system dynamics also faces some drawbacks that should be considered. Given the context of interdisciplinary societal problems, it is not always possible to determine exactly when a conceptual or empirical model contains enough aspects captured in such a way that the model can be used as an adequate representation of reality. Even when the construction of a model of a societal problem is carried out with as much knowledge, methodological support, and human effort as is available, such models will still contain a large amount of uncertainty (Randers, 1980). However, system dynamics is also described as a tool for overcoming the limitations of mental models, and for structuring relationships among variables. It is a methodology for problem analysis and alternative solutions in a systematic manner (Sterman, 2000).

### Literature about dynamic modeling

As a response to the heroin epidemic in the US, several quantitative models have appeared since the 1970s, and they became more common after the spread of cocaine during the 1980s (Caulkins, 2002). Those models were mainly focussed on the perspective of a consumer country, and from an economic approach (Behrens, Caulkins, Tragler, Haunschmied, & Feichtinger, 1999; Gardiner & Shreckengost, 1987; Homer, 1993; Liccardo Pacula et al., 2009; Rydell, Caulkins, & Everingham, 1996; Yalcın, 2004). They acknowledge the need for dynamic modeling to understand better the illegal drug market behavior (Boyum & Reuter, 2005; Reuter, 2001), and perhaps most importantly, the likely occurrence of unintended consequences of drug policies (Reuter, 2009; Caulkins & Reuter, 2006; Caulkins & Tragler, 2004; Kleiman, 1993; Kleiman & Reuter, 1986). Indeed, the manifest complexity of illegal drug markets, their unexpected changes, and the unintended evolution, have encouraged some scholars to migrate from static assumptions to dealing with nonlinearities, feedbacks, and the concept of systems (Caulkins,

---

**Table 1**

<table>
<thead>
<tr>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Colombian growth rates per year</td>
</tr>
<tr>
<td>Law enforcement budget</td>
</tr>
<tr>
<td>Soldiers and policemen</td>
</tr>
<tr>
<td>Eradicated coca hectares</td>
</tr>
<tr>
<td>Destroyed laboratories</td>
</tr>
<tr>
<td>Captured drug dealers</td>
</tr>
</tbody>
</table>

---

acted; offered; (2001; Grass, Caulkins, Feichtinger, Tragler, & Behrens, 2008). However, as a methodology, the system dynamics literature had already offered its contributions (Gardiner & Shreckengost, 1987; Homer, 1993; Levin, Roberts, & Hirsch, 1975); though not focusing on a cost-effectiveness analysis (Behrens & Tragler, 2001), all of them acted under the assumption that the conceived policies might be useful as a result of their understanding of the systems involved (Schlenger, 1973).

The contribution of dynamic modeling and of the system concept was made even more visible by its value in explaining counter-intuitive effects of some law enforcement policies within illegal drug markets. For instance, Lee (1993) provides a theoretical model that shows how the decriminalization of marijuana consumption might be followed by an unexpected decrease in demand. Scott and Jensen (2001) show how, under certain conditions, a law enforcement policy can enhance the criminals’ “marketing”, increasing the number of addicts and consumption. Also, the US President’s Commission on Organized Crime (1986) describes the rise of Mexican and Burmese heroin trafficking as a consequence of a disruption of the French connection. There are more examples that emerge from the theoretical analyses and dig into this particular issue of unintended consequences of law enforcement interventions, using a cost-effectiveness perspective (Garoupa, 2007; Poret, 2002; Poret & Téjedo, 2006). What they have in common is the description of how system structure is misunderstood, triggering unintended causalities whose negative impact on the system only can become apparent when the policy has already been implemented. The review of this literature helped us to understand why the Colombian case might be analyzed from a systems perspective, given the fact that illegal drug markets are systems that respond in either an intuitive or counter-intuitive way to the effect of policies. In other words, with the support of the literature review, this paper identifies SD as a methodology well suited to testing the hypothesis that the expansion of the Colombian coca crops might be an unintended consequence of an intervention in the illegal system.

**System dynamics model**

The model relies on two basic assumptions: in the illegal drug industry there are large, medium, and small firms who attend to

![Fig. 2. Basic dynamics of illegal firms.](image)

![Fig. 3. Illegal firms’ dynamics and law enforcement response.](image)
demand, and the Andean coca hectares' production is considered a closed system, which means no coca cultivation is imported from other countries. The size of a firm depends on its production capacity for attending to its demand, and its competition for a market share with other producers (Rubin, 1973). In the long run, one possible scenario could be that in a given market, large and small firms co-exist (Papadonogas & Droucopoulos, 2004). Our model begins with the description of the illegal-firm dynamics in a broad perspective. Illegal firms are constrained to three basic interactions that determine their success, or failure. Cycle I (industry) represents how, as in any industry, competition among firms in illegal markets is ruled by the scheme of supply and demand (Fig. 2). Cycle C (criminal competition) shows their second interaction, with violent rival competition, causing firms to exit from the industry (Gambetta, 1993; De León-Beltrán & Salcedo-Albarán, 2007). Finally, the effect of their size is indicated by how much larger their market share is, making them visible to law enforcement (cycle LE), increasing their probability of being captured and constituting a third cause for exiting from the industry. This basic representation argues that an increase in the probability of being captured will decrease the number of firms in the industry. However, this assessment would be true if all the firms were homogeneous in terms of size. Experience tells that they vary greatly in size, which is why law enforcement drives its offensive in the way it considers efficient, by dismantling large firms rather than the small ones (Fiorentini, 1999). For this reason, we need to present a more detailed cause-effect diagram.
for taking into account all of the differences among firm sizes and the discretionary law-enforcement strategy toward large firms.

Cycle R1 in Fig. 3 depicts how the market is composed of a number of small firms that are competing for market share. The increase in revenues and the low barriers to entry allow for the emergence of many small firms into the market (Fiorentini, 1999). Therefore, some small firms make progress by becoming large because of their accumulated drug processing and trafficking experience (De León-Beltrán & Salcedo-Albarán, 2007). This diagram can also explain the relationship between firm sizes and coca paste demand. Initially, small firms were importing the coca paste from Peru and Bolivia in very meager quantities (Thoumi, 2001), but with the emergence of large firms, the Colombian traffickers could afford massive imports of coca paste from those countries as their capacity for buying and transporting was expanding (López-Restrepo & Camacho-Guiizado, 2003). The initially precarious smuggling process became an industrialized and almost safe procedure that resulted in the possibility of scaling the cocaine deliveries from grams to kilos, and eventually tons (Chepesiuk, 2005).

The small firms’ market share is squeezed during the expansion of the large firms’ market share. It causes them to become less profitable and then having to address the highly risky—and therefore unaddressed—gaps in the market (Krauthausen, 1998). This continued until the small firms could find a way to survive, either by subsuming themselves within the large firms as outsourcers, by becoming highly specialized suppliers, or by paying ‘rent’ for the right to operate under the cartel’s ‘protection’ (Fiorentini & Peltzman, 1995). The role of law enforcement is related to the firm’s market share (Poret, 2002; Poret & Téjedo, 2006). Large market share leads to large numbers of illegal transactions. Their growth increases the firm’s visibility, increasing their probability of being captured (Poret, 2002; Poret & Téjedo, 2006).

Although the reasoning is valid for large and small firms alike, firms with a large market share (Cycle R2) are the primary objective of law enforcement (Fiorentini, 1999; Fiorentini & Peltzman, 1995). By focusing on organizations involved in large-scale trading of illegal goods, law enforcement expects to eliminate organizations that are rather difficult to replace in the short run (Fiorentini, 1999; Fiorentini & Peltzman, 1995). However, by following the strategy of focusing on large organizations, law enforcement provided relief for those affected by the large firms’ concentration process and created positive externalities for the small market-participants and newcomers. Finally, by tackling larger organizations, law enforcement was promoting a process of replacement that is natural to the criminal career (Blumstein & Cohen, 1987; Venkatesh & Levitt, 2000). At least in Colombia, there is evidence that because of the Cali cartel’s demise, there was a sort of criminal career path or heritage of positions among the former members (Vice-President of Colombia, 2006), Buchanan (1973) asserts the “convenience” of criminal monopolies, precisely because of their output restriction, lack of competition, and high prices. Conscious of the critics and endorsements to Buchanan’s statement (Backhaus, 1979; Martens, 1986; Sisks, 1982), the use of the methodology explores the consequences of taking down a concentrated market. It is important to clarify that large firms were also supplied by local providers, and possibly even some of the small firms imported coca paste, as well. However, as is agreed in the literature, most of the large cartels were supplied by Peruvian traffickers (Duncan, 2006; López-Restrepo & Camacho-Guiizado, 2003; Thoumi, 2003; Vargas, 2004). And small firms, given their nature, were mainly supplying the domestic market. Therefore, the model treats as insignificant the domestic demand for coca and the import of coca paste by small firms.

Model equations

The model is a stylized representation of the market dynamics and is not intended to describe it in detail. Variables that describe the market (e.g. number of firms in each stage, production capacity, supply, and captures) are estimations of the actual data and in most of the cases convey the average values in the industry. The model of the described system has three main components. The first component establishes the distinction between small and large firms operating in the industry. Given the UN estimations of the demand for cocaine (UNODC, 2011), and the description by Uribe
of the cost and quantities required for processing cocaine, we made an assumption about the firms’ production capacities, which allowed us to distinguish between them. Large firms have the advantage of addressing the whole market, while small firms compete for the demand that is unmet by the large firms, constituting their own niche. The arrival of small firms depends on whether the market is profitable or the probability of being captured is low. Large firms surge in the market as a consequence of the small firms’ criminal careers. However, to do so, they have to overcome the internal competition and incarceration risk. We model competition among firms as a function of the number of firms that can address the demand. If the firms’ supply surpasses demand, lowering prices, some firms are forced to leave the industry as a way of regulating profits (Fiorentini, 1999; Fiorentini & Peltzman, 1995). Law enforcement action depends on the market share and the length of time required for taking them down, which is longer for large firms (Fiorentini, 1999; Fiorentini & Peltzman, 1995). The second component explains the market share co-optation process and the demand for coca paste, given the type of firm. The Peruvian and Bolivian coca cultivations increase as a consequence of the large firms’ cocaine demand; meanwhile, the small firms increase domestic coca paste processing. Eradication rates in both coca markets are exogenous parameters provided by UN reports (UNODC, 2010, 2011). Here we specify some of the basic equations, for a better understanding of the model. Cocaine Demand in tons \( D \) is modeled as a sigmoid, according to Homer (1993), where two parameters are considered: maximum demand \( D^* \) and a constant, \( k \):

\[
\frac{dD}{dt} = (D^* - D)kD^* \tag{1}
\]

Firms’ production capacity in tons \( PC \) is modeled as follows, according to the SD modeling.

\[
\frac{dPC}{dt} = \frac{D - PC}{T} \tag{2}
\]

Average firms’ supply in tons \( FS \), considering seizures \( s \):

\[
FS = F \cdot PC(1 - s) \tag{3}
\]

Probability of being captured, \( p \), depends linearly on their market share \( MS \) and a parameter \( I \) (Poret & Téjedo, 2006):

\[
p = \frac{MS}{I} \tag{4}
\]

The model assumes that competition \( C \), which results in the exit of firms, is the result of a saturated market. That is, when the actual number of firms \( F \) supplying the market surpasses the relation \( D/PC \), the market has at least two firms competing, and eventually one of the firms would defeat the other after an average period of time \( T \).

\[
C = \begin{cases} 
0 & F \leq \frac{D}{PC} \\
\left( \frac{F - (D/PC)}{T} \right) & F > \frac{D}{PC}
\end{cases} \tag{5}
\]

### Data, parameters, and initial conditions

For research on criminal markets the data may not be abundant. As Andreas (2004) and Reuter and Greenfield (2001) point out, the estimations are often ‘guesstimates,’ at best, and are particularly susceptible to distortion and manipulation. This requires a heavy dose of skepticism of official data and a high sensitivity to, and tolerance for, the limitations of quantification (Andreas, 2004). In our model, demand triggers the firms’ production, so demand is modeled as an epidemic process following the approach described by Yalçın (2004) and Homer (1993), with the data provided by United Nations report (UNODC, 2011). We are conscious of the different estimates for the amount of coca crop in Colombia reported by the US Secretary of State as compared with the UN, however both of their trends are similar, and do not disturb our main findings. Data from Maya’s (2000) study was used in the model, to establish the amount of coca paste required for producing cocaine. Prices in Colombia and the US are provided by United Nations report (UNODC, 2011) and by Reuter and Greenfield (2001). The number of small firms in the industry depends on current estimations (Bagley, 2011; Gootenberg, 2011; Mallory, 2007; Vice-President of Colombia, 2006), and the number of formerly existing large firms is provided by Krauthausen (1998).

### Findings

The model was simulated over the period 1979–2010, with a set of parameter values giving the closest possible overall fit to the historical indicator data. The baseline simulation is validated according to tests suggested by Forrester and Senge (1980) and Barlas (1989) (Fig. 4). These findings allow us to ponder more carefully the role of the law enforcement intervention as an alternative hypothesis for explaining the coca outbreak. The proposed structure of the system shows how the surge of the small firms increased competition, boosting the domestic coca-base demand. Table 2 depicts several forecast error measurements.

The model fits the data relatively well. Our analysis suggests that the model captures the main structure of the market, even though there are some elements of coca hectare productivity and demand that have changed over recent years. Thus, the model is appropriate for simulating alternative scenarios, where our dynamic hypothesis can be tested more carefully. A first scenario explores a situation where law enforcement is not focused on large firms. Fig. 5 shows the results of a counterfactual simulation to test this alternative industry structure (e.g., keeping the market concentrated in one or two cartels). The simulation indicates that under this scenario, coca cultivation would have stayed in Bolivia and Peru as a consequence of their large production capacity.

A second scenario considers a counter-intuitive intervention where law enforcement focuses its initial intervention on small firms (before tackling large cartels) with the purpose of concentrating even further this criminal industry. Fig. 6 depicts how this policy would decrease the large firm’s output and then its demand for domestic and foreign coca paste. Nevertheless, the large firms’ high level of concentration would increase their visibility and probability of being captured, prompting their demise in the long run.

### Table 2

<table>
<thead>
<tr>
<th>Measures of goodness of fit</th>
<th>Colombia Actual vs. simulated</th>
<th>Peru and Bolivia Actual vs. simulated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coefficient of determination, ( R^2 )</td>
<td>0.94</td>
<td>0.95</td>
</tr>
<tr>
<td>Median absolute deviation (MAD)</td>
<td>11,230</td>
<td>11,750</td>
</tr>
<tr>
<td>Mean absolute percentage error (MAPE)</td>
<td>27</td>
<td>13</td>
</tr>
<tr>
<td>Mean absolute percentage deviation</td>
<td>0.17</td>
<td>0.10</td>
</tr>
<tr>
<td>Mean square error (MSE)</td>
<td>216,450,165</td>
<td>206,344,962</td>
</tr>
<tr>
<td>Theil index</td>
<td>0.085</td>
<td>0.059</td>
</tr>
</tbody>
</table>
Conclusions

This work shows how it is possible to explain the Colombian expansion in coca cultivation, given the structure of competition among firms and the role of law enforcement. Use of the SD approach facilitates the combination of elements dispersed across the literature, in order to simulate some of the main market elements. As a result, the findings show how the role of law enforcement might impede the formerly high degree of concentration in the illegal industry, thereby boosting competition among rival firms, and explaining unintended consequences of law enforcement. The paper also explores the potential of the SD approach for addressing complex systems. In providing models capable of reproducing the observed data, the methodology indicates its potential for deeper analysis of the studied problem. It also serves as a computationally based aid for guiding thinking and policy design.

The Colombian case, modeled here, illustrates an example that is insightful for the design of contemporary drug policy together with the support of the SD approach. It shows how law enforcement could determine the level of competition in the industry with all its varied consequences. It calls for greater care in analyzing what the rationale of the discretionary power of law enforcement should be. Regarding the war on drugs in Latin America, these remarks are especially relevant when further direct confrontations with large criminal organizations seem likely in the coming decade (US State Department, 2012). Maybe Buchanan’s theory is a useful point of reference for examining the phenomenon from a different perspective. The consequences of dismantling large organizations might not have the same magnitude and intensity as in Colombia, but they would certainly be undesired by any other country.

Acknowledgments

This work was supported by Colciencias and the Universidad Nacional de Colombia doctoral fellowships. The authors would also like to thank Dr. Nuno Garoupa, Dr. Robert Evan Ellis, Dr. Bethany Karman and Dr. Paul Ellis for their insightful feedback in editing this manuscript. The authors would also like to thank Guillermo Restrepo-Gonzalez for his support.

Conflict of interest

The authors declare no conflict of interest.

References

Chepesiuk, R. (2005). The rise and fall of the Cali cartel, the world’s most powerful criminal organization. Wina Green, Preston: Milo.


