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**The effect of commodity price shocks on  
illicit crop production: An insight in the  
economic incentives of rural producers in  
Colombia**

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**Author:**

S.A. de Vries Robb 

**Committee:**

Prof. Dr. E. M. Bosker

Dr. S. V. Kapoor

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**Abstract**

Policies that target drug supply can be categorized in two main strategies; targeting drug suppliers via law enforcement, and offering rural producers incentives to engage in legal alternatives. In this study I focus on the second strategy, digging into the role of rural producers and how shocks to their income affect their cultivation choices. I examine the effect of a coffee price shock on the production of coca in Colombia by exploiting the inter-municipal variation of coffee suitability and exogenous movements of coffee prices between 1999 and 2016. By using coffee *suitability*, I circumvent any endogenous responses of coffee production to coca production that could be present when using actual production data. I distinguish between arabica and robusta coffee and extend the analysis to five other crops that range among Colombia's top ten agricultural export products; banana, cocoa, oil palm, sugarcane and tobacco. My results show that a coffee price shock leads to differential coca planting *only* in municipalities more suited to grow *robusta* coffee. For the other five crops, the proposed effect is present to a less extent, and mainly driven by the eastern part of Colombia, which consists of large municipalities, very suitable in terms of agro-climatic conditions.



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# 1 Introduction

The recently signed peace agreement<sup>1</sup> between the Colombian Government and the Fuerzas Armadas Revolucionarias de Colombia (FARC) rebellion group is a milestone in the history of Colombia and the world. Given the complexity and the innovative character of the agreement, it poses some serious challenges to a successful implementation of the accord.

One of the main challenges is eradication of coca-production, as guaranteeing peace is inextricably linked to illegal drug production. In recent years coca-production levels boomed. The estimated area used for the cultivation of coca increased from 96,000 ha in 2015 to 146,000 ha in 2016, an increase of 52%, according to the United Nations Office of Drugs and Crime (UNODC). Panel A of figure 1.1 depicts the evolution of coca production between 1991 and 2016. Coca production evolves dynamically over time; production boomed at the turn of century to reach a level of 163,000 hectares, to decrease until 2012 and peak again in 2016.

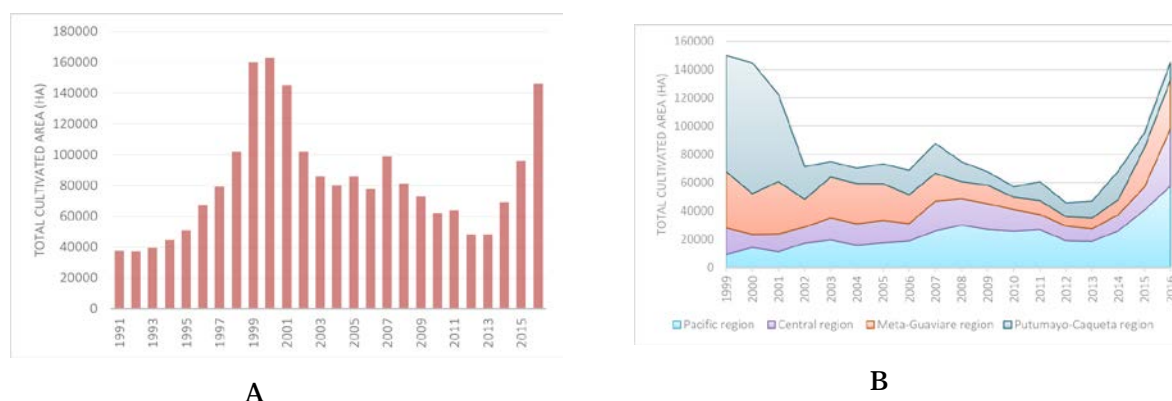


Figure 1.1: Panel A depicts the total cultivated area of coca in Colombia between 1991 and 2016. Area is measured in hectares. Panel B depicts the total cultivated area of coca per region between 1999 and 2016 for the four major producing regions in Colombia. Data comes from yearly censuses of the UNODC.

Different explanations for the behaviour of coca production have been put forward. The upsurge of coca cultivation in 2016 has been partially attributed to the cease of areal eradication of coca plantations in 2015. Affected municipalities have the perception that the risk associated to coca cultivation has decreased, as areal fumigation does not longer put their crops at risk, and the possibility to block forced manual eradication by joint forces has increased. Furthermore, terminology used to pinpoint coca production changed from “cultivation of illicit crops” to “cultivation of crops of illicit use” (UNODC, 2017). This

<sup>1</sup>On November 24<sup>th</sup> 2016 the Colombian President Juan Manuel Santos and FARC leader Rodrigo Lodoño (Timochenko), signed a peace agreement that must put hold to a 52-year lasting conflict in Colombia that has taken more than 22,000 victims.

made growers assume that the act of growing the plant was not illegal, but just everything further down the supply chain of cocaine. Furthermore, to cope with the drug supply, the Colombian government included a program to compensate coca growers to substitute out of coca production into alternative agrarian production into the Peace Accord<sup>2</sup> (La Oficina para el Alto Comisionariado de la Paz, 2016). This encouraged agricultural workers to enter the coca business, to reap the benefits when subsidies will be distributed (UNODC, 2017).

In the course of the years the Colombian government has deployed different strategies to reduce the supply of coca, ranging from substitute crops to aerial eradication. Drug-targeting strategies that focus on the supply-side can be categorized in two main policies; targeting drug suppliers via law enforcement (or crackdown), or by offering producers incentives to engage in alternative activities (Dube, García-Ponce & Thom, 2016). The law enforcement strategy focuses on interdicting drug supply, eradicating drug fields, and targeting criminal organizations. The second perspective centres on the role of rural producers and their economic incentives to produce drugs. The main idea here is that drug supply is subject to the same forces driving supply and demand in other sectors and returns to alternative legal activities play an important role in the consideration of farmers to produce illicit crops. Studies on the effectiveness of the second strategy have not reached consensus. Therefore, in this thesis, I study effects of commodity-price shocks on drug production in Colombia. I focus on fluctuations in the price of coffee and the production of coca, and extend the analysis to five other commodities that range among Colombia's top ten agricultural export products. I use the methodology employed by Dube, García-Ponce and Thom (2016), and extend the data on drug crop cultivation used by Dube and Vargas (2006).

In the following two sections I elaborate on different studies that focus on targeting drug supply via law enforcement, and the role commodity price shocks play in the trade-off of farmers between producing illicit crops or a legal alternative.

## 1.1 Targeting drug supply via law enforcement

In targeting drug supply via law enforcement aerial eradication has been a well employed method until its suspension in 2015. In 2000, the Colombian government implemented large scale aerial spraying of glyphosate on coca fields throughout much of Colombia. Coca fields in Colombia decreased in size from 163,000 hectares to about 48,000 hectares from 2000 to the end of 2013 (UNODC, 2017). After ceasing aerial spraying in 2015, coca cultivation boomed again to levels observed in figure 1.1. While the numbers seems to validate the effectiveness of the eradication practice, many analysts believe that aerial spraying has actually been inefficient in reducing coca plantings.

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<sup>2</sup>Peace Accord Article 4: Solution to the Illicit Drugs Problem, states that the Colombian government will establish a program for the substitution of illicit crops and alternative agrarian development. In a first phase, the program will distribute economic subsidies and provide immediate food assistance for the participants of the program.

An extensive evaluation of *Plan Colombia*<sup>3</sup> by Mejía and Restrepo (2009) indicates that eradication had a low effectiveness in reducing drug cultivation. While the number of hectares of coca crops decreased significantly between 2000 and 2006, this was not reflected in the reduction of potential cocaine production. The UNODC documents a decrease in potential cocaine production from 687 metric tons in 2000, to 610 metric tons in 2006. A decrease of 11.2% compared to a decrease in areas cultivated of 70.6%. This finding is consistent with an increase in the yields of coca fields.

Other studies find that law enforcement itself can not only be an ineffective mean to eradicate drugs, but can also lead to more violence, as narcotic groups resist enforcement or fight back to regain control (Angrist & Kugler, 2008; Calderón, Robles, Díaz-Cayeros & Magaloni, 2015; Mejía & Restrepo, 2013; Dell, 2015). Mejía and Restrepo (2013) posit that eradication fuels conflict by creating the possibility for paramilitaries and guerrilla's to earn rent on the territories they control. They argue paramilitary groups and guerrillas in Colombia "protect" farmers willing to take the risk to produce coca, from government eradication efforts by setting up landmines and shooting at airplanes used for aerial eradication, in return they earn rent over these territories. At the same time these groups fight each other over the control of the coca producing areas. Angrist and Krugler (2008) document that increases in coca prices spurred violence in rural districts because combatants fought over the additional rents. Dell (2015) examines the direct and spillover effects of crackdowns to drug trafficking. Her study demonstrates that, instead of eliminating drug production, drug-combating efforts only diverted drug trafficking elsewhere. This finding builds on the "Diversion Hypothesis", which argues that when drug trade is cracked down in one place, drug trade is partially diverted elsewhere without substantial reduction. The effective air interdiction of the so called "air-bridge", that transported coca paste for further processing from Peru and Bolivia into Colombia in the beginning of the 1990's, is a good example of the diversion hypothesis. After blocking the air bridge, coca production moved into Colombia's countryside where, eventually, coca production levels surpassed pre-interdiction levels (Angrist & Kugler, 2008)<sup>4</sup>. Mejía and Restrepo (2013) quantify the extent of systemic violence<sup>5</sup> caused by Colombia's drug markets since 1994. They estimate that a 10% increase in the value of coca increases homicides by 1.25%, explosion of land mines by 1% and attacks by armed groups by 2%.

Law enforcement strategies also have high associated opportunity costs. Between 2002 and 2014 total expenditures on fighting drug supply in Colombia increased from 13.2 to 42.5 billion Colombian pesos (in US dollars this is equivalent to an increase of 3.7 to 13.2

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<sup>3</sup>*Plan Colombia* was the program that, among others, formed an military alliance between Colombia and the U.S. aimed at combating illegal drugs production and the organized crime associated with this business. The new plan is called *Peace Colombia*, and intendeds to provide Colombia with aid to implement the peace accord with the FARC.

<sup>4</sup>Dell focuses on the drug trafficking part of the drug supply chain. This implies that her findings might be less applicable other chains in the supply of drugs.

<sup>5</sup>*Systemic violence* is defined as violence in drugs business used as a tool to enforce contracts, property rights, gain market power or build a reputation (Goldstein, 1985).

billion<sup>6</sup>), which corresponds to roughly 5.6% of Colombia's yearly GDP for the same period. The main components of these expenditures are law-enforcement-based, namely; Defence, Justice and Security, and the Colombian contribution to *Plan Colombia* (Otero Prada, 2016). During the first term of president Álvaro Uribe the expenditures on the drug war amounted between 15,1 and 18,3 billion USD. In his second term expenditures rose to 33.8 billion USD. During the presidency of Juan Manuel Santos expenditures were between 39.5 and 47.1 billion USD.

The failure of law enforcement strategies to fight drug production, the possible spillover effects and the high associated costs urge to find an alternative approach to target drug supply.

## **1.2 Targeting drug supply via rural producers and their economic incentives**

As pointed out before, the second strategy proposed to target drug supply focuses on offering producers incentives to engage in alternative activities. Existing literature on targeting illicit crop production via the supply side and offering rural producers legal alternatives has not reached consensus on the effectiveness of this strategy.

Moreno-Sanchez, Kraybill and Thompson (2003) find a negative relationship between plantain prices and coca production in Colombia. Dube and Vargas (2006, 2013) study the role of coffee price shocks in civil war dynamics in Colombia. In their studies, they examine the role of crop substitution, i.e. farmers switching from coffee production to coca production upon (negative) coffee price shocks, in linking coffee price shocks to conflict. They find that coffee price shocks did not result in differential coca planting in coffee growing municipalities and posit that crop substitution is not the central mechanism linking coffee prices to conflict in Colombia. Dube et al. (2016) examine how shocks to legal commodity prices affect drug trade in Mexico using shocks to maize prices. They find that maize price changes contributed to the burgeoning drug trade in Mexico, and point at increases in violence as a consequence of an expanding drug sector. They claim that “policies focusing on mitigating household economic shocks stemming from variations in returns to legal agricultural commodities may ultimately influence the operations and geographic locations of cartels”. In terms of the relation between commodity prices and illicit crop production, the findings of Dube et al. (2016) can be seen as opposed to the findings of Dube and Vargas (2006, 2013).

Other studies on the economic incentives of drug production conduct hypothetical survey experiments. Ibañez and Carlsson (2010) hypothesize that the use of aggregate data to evaluate the effectiveness of eradication and alternative (legal) crop development impedes the identification of behavioural factors affecting the decision to engage in drug supplying activities. They therefore use a choice experiment to investigate the relative effect of anti-drug policies. They find coca cultivation is inelastic to increases in perceived risk and relative profit and conclude coca eradication and alternative development would have

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<sup>6</sup>All amounts in US dollars are calculating using the 2014 Colombian U.S. real exchange rate.

a rather small effect on cultivation. In a following study Ibañez and Martinsson (2013) conduct a framed field experiment mimicking coca cultivation in the department of Putumayo, among the largest coca-producing zones of Colombia, to investigate the efficiency of carrot and stick policies<sup>7</sup> to reduce investment in coca cultivation in rural Colombia. Their results suggests that only a reduced group of producers would be responsive to the carrot and stick policies. They find that about one third of the farmers have moral costs high enough to deter them to grow coca. They suggest this heterogeneity among producers must be taken into account when designing anti-drug policy. When targeting coca growers areas better integrated to markets should be addressed with carrots, while the sticks should be used in economically depressed areas. They also find that the supply of coca is inelastic to changes in carrots and sticks unless the risk of eradication is above 30%.

To asses the benefits of targeting drug production via the supply side, i.e. offering carrots instead of sticks, it is important to gain knowledge on the economic incentives of rural producers that influence their decision making process when it comes to cultivating choices. To do so I examine the effect of a commodity price shock on the production of coca in Colombia. I construct a panel data set covering information on 1122 municipalities between 1999 to 2016. To measure coca production I use time series data on areas dedicated to coca production at municipality level. As Colombian municipalities differ in terms of commodity suitability I exploit this inter-municipal variation to capture the differential effect of a price shock on coca production. I expect municipalities that are more suitable to grow a certain commodity, to portray a larger increase in coca production upon a negative commodity price shock.

In line with Dube and Vargas (2006), I do not find any evidence indicating a coffee price shock leads to differential planting of coca in *arabica* coffee suitable regions. This can be partially explained by the differences in agro-climatic requirements to grow coca and arabica coffee. However, for *robusta* coffee the proposed relationship seems valid. My estimates indicate that for robusta coffee, a price fall of 34% between 2012 and 2016 induced a 63% increase in the area dedicated to the production of coca for municipalities moving up one standard deviation in the robusta coffee suitability distribution. This finding is robust to the exclusion of two large regions in Colombia (Amazonas and Orinoquia), which score high in terms of crop suitability. Also for banana, oil palm and sugarcane I find similar, although less strong results. Although for these commodities the proposed relationship seems to be mainly in place in regions Amazonas and Orinoquia, and less present in the rest of Colombia, the results add to the possibility that a trade-off between illicit crop production and legal alternative crops driven by income shocks is in place. My findings are robust to accounting for the time it takes for a coca planting to come into production, and are reinforced by similar calculations when including actual production data instead of potential yield.

My study differs from previous work mentioned as I use measures of commodity suit-

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<sup>7</sup>A stick policy implies that coca plants are eradicated by manual and areal eradication. A carrot policy implies persuading coca-growers to stop cultivating coca by providing them monetary subsidies.

ability, which captures the potential of municipalities to grow a specific crop based on a number of agro-climatic conditions, instead of data on actual production. This measure therefore circumvents any endogenous responses of commodity production to price shocks and coca production that could be present in actual production data. I expand the analysis of coffee by distinguishing between the two main forms of coffee; arabica and robusta, which according to their agro-climatic requirements, can be both grown in Colombia. In addition, I extend the analysis to five other commodities, which range among Colombia's top ten agricultural export products; banana, cocoa, oil palm, sugarcane and tobacco.

My findings add to the existing literature on the determinants of drug production by studying the economic incentives of engaging in illicit crop production. Furthermore, specifically for Colombia, it contributes to the studies on drug production using observational data. By distinguishing between arabica and robusta coffee, and extending the analysis to five other crops, my analysis gives a deeper insight in the economic incentives of rural agricultural producers that influence their decision making process. The results indicate a trade-off between producing illicit and legal crops is in place, and shocks to income of rural producers influence the outcome of this trade-off. Furthermore, my results provide a new insight in linking commodity price shocks to violence in Colombia. Commodity price shocks have a differential effect on conflict depending on the nature of a commodity (Dal Bó & Dal Bó, 2011), and a positive shock to a labour intensive commodities can lead to a decrease in conflict (Dube & Vargas, 2013). As coca has been found to induce violence in Colombia (Angrist & Kugler, 2008), a positive shock to agricultural commodities cannot only decrease violence decreasing the labour supply to the conflict sector, but reinforce this by decreasing coca production.

The study is relevant since the recently signed Peace Accord opens the doors for a transformation of the territories that are susceptible to the establishment of coca plantations, and implementation of policies that offer growers legal, lucrative alternatives to the production of coca. In fact, this is explicitly stated in article 1 and 4 of the final version of the Peace Accord<sup>8</sup>. These articles target the agrarian problem and search for mechanisms to close the gap between urban and rural zones in Colombia to present a solution to the Colombian drugs problem.

The remainder of the paper is organized as follows: chapter 2 provides background information on Colombia's drug war, coca production, and Colombia's agricultural sector. Chapter 3 examines the possible mechanisms through which a fall in commodity prices influence coca production. Chapter 4 presents the data; chapter 5 lays out my empirical strategy; chapter 6 presents my results and chapter 7 concludes.

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<sup>8</sup>Article 1: Comprehensive Agrarian Development Policy (in Spanish: Reforma Rural Integral) and Article 4: Solution to the Illicit Drugs Problem (in Spanish: Solución al Problema de las Drogas Ilícitas).

## 2 Background

This chapter provides background reading on some relevant aspects of this study. The history of Colombia's drug trade and the main characteristics of Colombia's agricultural sector and the commodities studied.

### 2.1 Coca and Colombia's drug history

Coca leaves are the raw material necessary for the production of cocaine. Coca plants (*Erythroxylum species*) appear as native shrubs in the tropical and subtropical areas of South America. There are two main important species; *Erythroxylum coca*, which can grow at higher altitudes (until 2,000 m) in the Andes of Peru, Argentina, Bolivia, Colombia and Brazil, and *Erythroxylum novogranatense*, which can grow in the same general area but at lower altitudes, somewhat until 1,500 m from sea level. Nowadays in Colombia mostly *Erythroxylum novogranatense* is grown in the lowland areas, and the variety *ipadu* of *Erythroxylum coca*, in the lowland Amazon basin of Colombia (Purseglove, 1968). Coca is a perennial plant, which implies it lives for more than two years, and therefore requires a multi-year investment. The first harvest of coca can be gathered one to three years after planting. For many centuries, and still among a share of the rural population, (dried, unprocessed) coca leaves have been used as stimulating masticatory, but also for various religious, medicinal and nutritional purposes (Boucher, 1991; Steinberg, Hobbs & Mathewson, 2004). The narcotic ingredient of the coca leaves is alkaloid cocaine, which composes around 1% of the leaves. When chewing, the narcotic adds directly on the central nervous system acting as a stimulant, and suppressing physical and mental fatigue for periods without food or drink. Nowadays coca is mostly produced as main ingredient of the drug cocaine.

Dion and Russler (2008) estimate that 98% of global coca production is produced in Bolivia, Colombia and Peru. In the late 1970's the first coca plantations were established in Colombia in areas around the Atlantic coast and in the department of Meta. In the 1980's and 1990's, the number of plantations expanded, first as response to the successful air interdiction campaigns carried out by the Fujimori administration in Peru in the beginning of the 1990s. During the same period illegal armed groups emerged, as did drug trafficking and drug cartels. Coca cultivation flourished in certain regions due to availability of cheap land and labour, favourable climatic conditions for coca cultivation and access to the narcotic markets via maritime and aerial routes. To control the production and commercialization of coca crops, drug cartels, paramilitaries and guerrillas use armed coercion and acquisition of territories. Between 1980s to 2000 armed groups acquired approximately 4.5 million ha of land (Elhawary, 2007). Territories used for the production of coca are characterized by poverty, weak institutional authority, poorly defined property rights and presence of armed groups (UNODC, 2017). Coca growers are usually localized

in remote areas, in order to dissuade the authorities and reduce the risk of eradication. At the same time, coca-areas are sufficiently close to populated centres to obtain the supplies needed for the drug production process. The laboratories used for processing the coca leaf into cocaine are usually located close to the coca crops, to avoid risks associated with transportation of the coca bulk (Mejía, Restrepo & Rozo, 2015; Mejia & Restrepo, 2013; Mejía, Rico et al., 2010).

In 2000, the Colombian government took a militaristic approach, implementing large scale aerial spraying of glyphosate on coca fields throughout much of Colombia. This was part of *Plan Colombia*, a foreign aid, military and diplomatic initiative of the United States aimed at combating drug cartels, paramilitary groups and drug production in Colombia. In 2015 the Colombian National Narcotics Council released a resolution to suspend its aerial eradication program. Aerial fumigation had not proven to be effective, and, in addition, shown to have negative environmental and health related side effects. It destroys legal neighbour crops, soil fertility of the sprayed areas, contaminates water and pushes coca plantations further into deserted, usually biodiversity-rich regions. The World Health Organizations International Agency on Research in Cancer concluded that glyphosate, the chemical used in the eradication program, is carcinogenic to humans (IARC, 2015).

## 2.2 Agriculture in Colombia

Next two sections lay out the demographic composition of the Colombian agricultural sector and the most important agro-climatic characteristics of the commodities studied.

### 2.2.1 Demographics

Colombia has a largely urban population, with three-quarters of its inhabitants living in cities in 2013 (DANE, 2014b), however almost 95% of the country's land area can be classified as rural (DANE, 2011). The rural-urban distribution we see today in Colombia is the result of large displacements of rural population towards the urban areas starting in the beginning of the 1940s as a response to the prevailing internal conflicts. Between 1985 and 2011 more than 5.4 million people were internally displaced, mostly from the areas bordering Venezuela and Ecuador, and parts on the Pacific coast, to urban areas (CODHES, 2012). This population movements can be seen as a flight from the prevailing violence and insecurity, and has ultimately led to shift away from agricultural activities (Hudson, 2010).

Two main elements have shaped the prevailing character of rural areas in Colombia. On the one hand forced displacement as a result of armed conflict decreased availability of rural labour supply and decreased income from agriculture as most of the displaced people were mainly active in the agricultural sector. On the other hand, with the raise of illicit activities, new "jobs" emerged in the process of cultivating, processing and exporting drugs (OEDC, 2015). Earnings in this sector are often twice as what could be the proceedings from the legal agricultural sector (Hudson, 2010). Rural incomes are lower than urban incomes across all categories, and especially in the agricultural sector, due to lagging productivity

Table 2.1: Descriptive Statistics: Coca vs. Non-coca growing municipalities

	Years	Coca Municipalities		Non-Coca municipalities	
		Mean	St. Dev.	Mean	St. Dev.
Total population <sup>a</sup>	1999-2016	39.05	98.02	42.33	236.78
Urban population <sup>a</sup>	1999-2016	24.84	94.41	32.84	234.63
Rural population <sup>a</sup>	1999-2016	14.21	12.00	9.49	10.42
Total weighted population <sup>b</sup>	1999-2016	0.36	1.27	1.56	6.26
Urban weighted population <sup>b</sup>	1999-2016	0.21	1.23	1.17	5.94
Rural weighted population <sup>b</sup>	1999-2016	0.15	0.15	0.39	0.59
Rurality index <sup>c</sup>	1999-2016	0.63	0.23	0.55	0.25
Municipal area (ha)	2005	282.94	601.25	54.85	132.03
Distance to department capital (km)	2005	116.86	77.29	73.05	51.08
Distance to principal market (km)	2005	174.01	111.56	107.67	96.34
Illiteracy (%)	2005	35.77	13.23	28.10	11.96
Child labour (%)	2005	7.99	8.05	5.70	3.23
Multidimensional Poverty index	2005	81.09	11.42	67.11	16.23
Coca area (ha)	1999-2016	488.38	1,391.38	-	-
Total agricultural area (ha)	2014	7,068.91	10,612.87	8,009.81	9,921.64
Coffee area (ha)	2014	561.68	1,166.68	1,226.88	2,086.62
Coffee farm size (ha)	2014	2.95	7.54	3.40	5.90
Banana area (ha)	2014	413.30	972.33	194.70	570.24
Banana farm size (ha)	2014	8.44	27.86	9.36	28.15
Cocoa area (ha)	2014	622.77	1,657.51	184.63	797.46
Cocoa farm size (ha)	2014	3.58	7.16	3.91	11.09
Oil palm area (ha)	2014	988.07	3,484.63	471.39	2,428.44
Oil palm farm size (ha)	2014	77.16	194.90	55.38	78.39
Sugarcane area (ha)	2014	27.24	182.62	508.59	2541.84
Sugarcane farm size (ha)	2014	83.63	123.10	58.00	108.58
Tobacco area (ha)	2014	11.32	83.98	32.36	171.09
Tobacco farm size (ha)	2014	4.47	10.49	9.02	14.63
Total mun. GDP <sup>a</sup>	2000-2009	193.07	810.11	354.50	2,917.83
Mun. GDP agricultural sector <sup>a,d</sup>	2000-2009	27.52	39.91	26.02	30.51
Mun. GDP industrial sector <sup>a,d</sup>	2000-2009	47.01	244.84	110.35	698.80
Mun. GDP services sector <sup>a,d</sup>	2000-2009	104.25	497.56	188.43	1,977.07

Notes: This table describes some characteristics of coca vs. non-coca growing municipalities.

<sup>a</sup> Thousands

<sup>b</sup> Total, urban or rural municipal population weighted by total municipal area

<sup>c</sup> Total municipal rural population over total municipal population

<sup>d</sup> Colombian pesos

rates, incomes have increased slowly (Foster, Rivera, Valdés & Pérez, 2010). This sector is also characterized by high levels of poverty and labourers working below minimum wage. Furthermore, the sector portrays high levels of income and land distribution inequality (Galarza & Uribe Castro, 2007). In terms of occupation, in 2015, the rural labour market was distributed accordingly: 42% of the workers are employees of which 17% are private workers, 2% public workers, 3% domestic workers, and 20% day labourers. Of the rest of the employed 5% are employers, 44% work on own account and 10% are unpaid family workers (mostly family members working on family land) (DANE, 2005).

The agricultural sector employs approximately 3.5 million people in Colombia, this corresponds to a contribution of 5.2% to Colombia's GDP<sup>1</sup>. Agriculture's share of employment has decreased from 55% in 1958 to 17.5% in 2013 (OECD, 2015). Although this is consistent with the ordinary path of structural transformation, the forced rural-urban migration has severely affected the availability of labour and employment security in rural areas. Despite this, agriculture still generates approximately two-thirds of all employment in the rural sector (Galarza & Uribe Castro, 2007).

In terms of land usage, agricultural land covers approximately 47.2 million ha, which is approximately 41% of total land area. Of this land, 80% is dedicated to livestock, 7% to agriculture, 11% to forestry and 2% to other uses<sup>2</sup> (DANE, 2017). Around 61% of land dedicated to agriculture is used for cultivation of permanent crops and 24% for transitory crops<sup>3</sup>. Of total land dedicated to agriculture (approximately 8.48 million ha in 2014), approximately 11% is dedicated to the production of coffee. Mean coffee farm size is 3.3 ha, while average municipal cultivation area is 1,095 ha<sup>4</sup>. This implies coffee cultivation is mainly characterized by smallholder farms. The other examined commodities are less prominent in terms of land dedicated to their cultivation. Of total cultivated land, 6% is dedicated to the production of oil palm, 3% to sugarcane, 2% to cocoa, 0.2% to tobacco and 0.3% to banana. For these commodities average farm sizes comparable to coffee farm sizes apply, however, average aggregate municipal production area is smaller (DANE, 2014b).

Table 2.1 compares some characteristics of coca and non-coca growing municipalities. Coca municipalities<sup>5</sup> are slightly smaller in terms of population but on average much larger in terms of municipal total area. When weighting total municipal population by municipal area it is clear that population density is on average much higher in non-coca growing municipalities compared to coca growing municipalities. Coca municipalities score also higher on the rurality index. The larger distance to the department capital and principal market indicate coca growing municipalities are more isolated compared to non-coca grow-

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<sup>1</sup>Based on data of the 2014 Agricultural Census of DANE (Censo Agropecuario 2014); a national participation rate of 64%, employment rate of 60% and an unemployment rate of 8%.

<sup>2</sup>The National Agricultural Survey *Encuesta Nacional Agropecuaria* (ENA) 2016 takes into account 26 of the 32 Colombian departments, excluding Amazonas, Chocó, Guainía, San Andrés, Vaupés and the archipelago of San Andrés, Providencia y Santa Catalina.

<sup>3</sup>A permanent crop is one that lasts for many seasons, in contrast to transitory crops that are replanted after every harvest.

<sup>4</sup>Based on data of the 2014 Agricultural Census of DANE (Censo Agropecuario 2014)

<sup>5</sup>Identified based on if the municipality has ever grown coca in the examined time span (1999-2016)

ing municipalities. Also the level of illiteracy and child work is higher in coca-growing municipalities. Looking at municipal GDP, yields from the industry and services sector are higher in non-coca growing municipalities and proceeds from the agricultural sector are, on average, almost equal. These characteristics are in line with earlier description of coca areas and indicate coca production is inherently a rural phenomenon. In terms of commodity production, for coffee, sugarcane and tobacco, this is higher in non-coca growing municipalities, whereas for banana and cocoa the average planted area is higher in coca growing municipalities. Coffee size farms are on average slightly smaller in coca municipalities, just as banana, cocoa and tobacco farms.

In the next section, I lay out the agro-climatic characteristics of the before mentioned commodities.

### 2.2.2 Commodities

I focus on several agricultural commodities. In the first place I study coffee, to compare my results to Dube and Vargas (2006), and in addition I distinguish between arabica and robusta coffee, which has not been done in Dube and Vargas (2006). Next, I extend my analysis to several other commodities which have been chosen according to the following criteria set. Firstly, the commodity must be among the top ten agricultural export products in Colombia. Second, there must be substantial variability among municipalities in suitability to grow a specific crop to enable a feasible set of control and treatment municipalities. And third, the commodity must have a defined international price. This set yields the following five products next to coffee: sugarcane, oil palm, cocoa, banana and tobacco. Below, I lay out the most important agro-climatic standards to grow each of the mentioned commodities.

Although more detailed differences exist between coffee types, I classify coffee into two main types; arabica and robusta (the latter also called *Coffea canephora*). Arabica coffee constitutes about two-thirds of the world's coffee, robusta nearly one-third (ICO, 2017). A large part of Colombia's agricultural land is suited to grow both types of coffee. The distribution of these areas can be observed in figure 2.1. Even though a large part of Colombia is suited to grow robusta, mostly arabica coffee is cultivated. Arabica coffee is an upland species, it prefers relatively cool, rainy areas, with at least 1800 mm rainfall and temperatures not exceeding 26 degrees (Graaff de, 1986). The optimum altitude depends on the distance from the equator, and proximity to mountain masses. As can be observed from figure 2.1 robusta coffee has a broader range of adaptability compared to arabica. Worldwide robusta coffee is grown from sea level to 1500 m altitude, preferring a rainfall between 1000 to 2500 mm and temperatures ranging from 18 to 32°C (Purseglove, 1968). Arabica and robusta coffee trees come into production 3-4 years after planting, and are in full production after 6-8 years (Graaff de, 1986). In terms of taste, robusta is more neutral in cup quality and has not such good aroma as arabica coffee. As arabica coffee is more specific when it comes to agro-climatic requirements, it has a smaller niche in terms of suitable areas worldwide and thus, a smaller total yield in kilograms dry weight. Nevertheless more arabica coffee is produced world-wide as with coffee, not necessarily

higher biomass, but quality determines production. The quality and production differences yield arabica coffee a world price which lies about one-third above robusta coffee prices.

Bananas (*Musa sapientum*) are plants of tropical humid lowlands and mostly grown between 30° north and south of the equator. A mean monthly temperature of 27°C is optimal. Banana plants make high demands on water; a minimum of 25 mm weekly, and 2000-2500 mm yearly is needed for successful growth. The crop also requires abundant light. Time for planting until harvesting is between 9-18 months, depending on a range of climatic and cultural characteristics (Purseglove, 1972).

The cacao tree (*Theobroma cacao*) originates from the lower eastern equatorial slopes of the Andes. The tree is a strictly tropical crop and grows usually below 300 m, but in Colombia it is cultivated between 900 and 1200 m. The optimum temperature range is 21-32°C, and without irrigation most cocoa is grown with rainfall above 1270 mm per year. It takes about five years for a cacao tree to bear fruit (Purseglove, 1968).

Almost all the commercial forms of sugarcane are inter-specific hybrids of *Saccharum* subspecies. Most commercial sugarcane is grown between 35° north and south of the equator. The crop requires high temperatures, generous sunlight, large quantity of water (at least 1525 mm yearly), high natural fertility and good drainage. The first crop after planting, in tropical regions, is planted in the rain season and matures 15-16 months later (Purseglove, 1972).

Oil palm (*Elaeis guineensis*) grows as an unbranched tree that can reach a height of 20-30 m and live up to 200 years. Oil palms can be grown on a variety of tropical soils. The plant grows best under a mean maximum of 30-32°C and a mean minimum of 21-24°C. High solar radiation is important for growth and production. The plant begins to produce 3-4 years after planting.

Tobacco (*Nicotiana tabacum*) originated in the sub-tropics, but major producers are now China, Brazil, India and United States. It prefers rain between 250-500 mm and a temperature between 21-27°C. From sowing and harvesting tobacco takes approximately five months (Purseglove, 1968).

Figure B.2 and B.1 outline the distribution of agro-climatic suitability for banana, cocoa, oil palm, sugarcane and tobacco per municipality in Colombia.

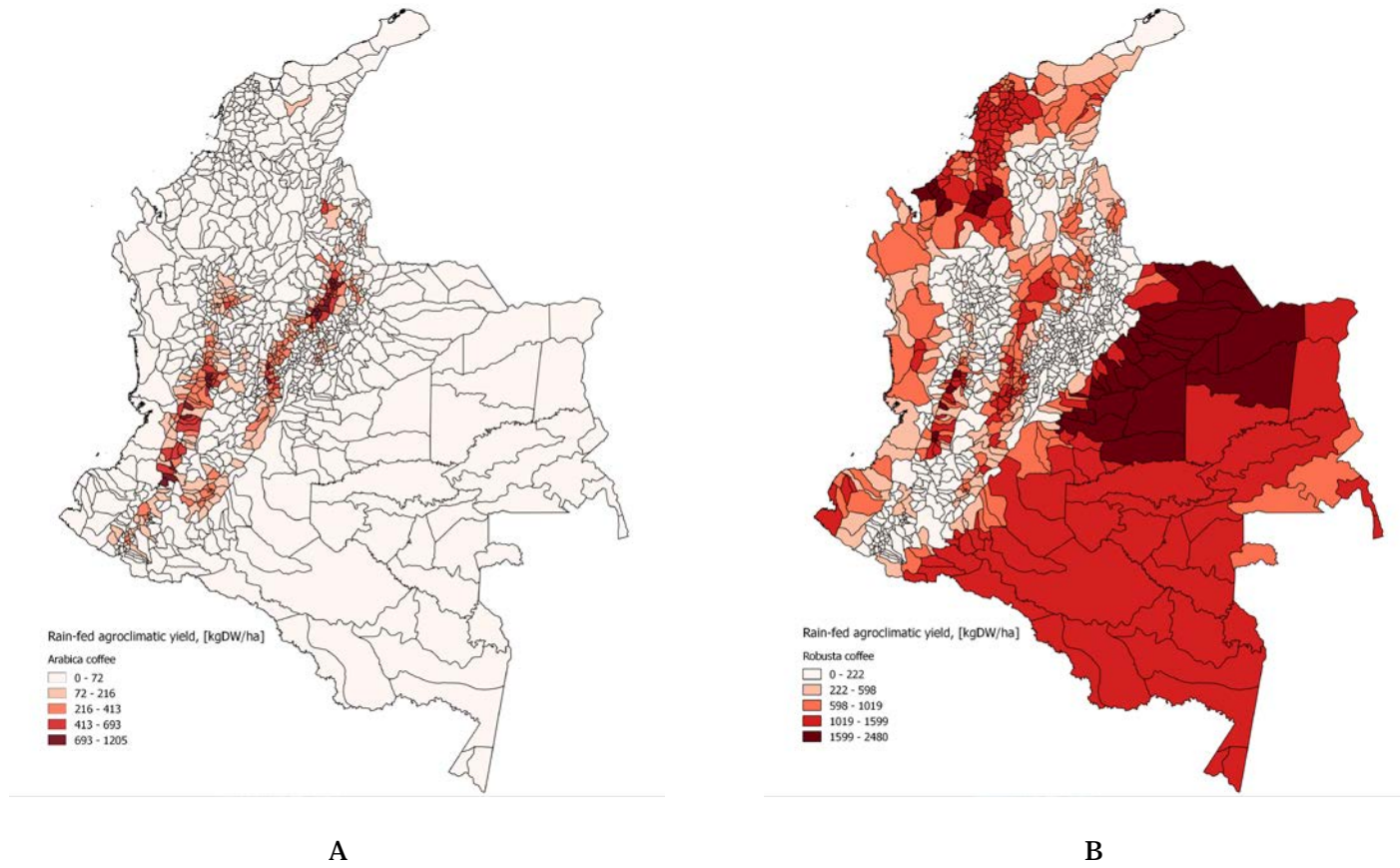


Figure 2.1: Panel A shows the rain-fed average agro-climatic yield for arabica coffee per municipality in Colombia. Panel B depicts this for robusta coffee. Yield is measured in kg DW/ha. Data was retrieved from FAO's and IIASA's Global Agro-Ecological Zones (GAEZ v4.0).

### 3 Mechanisms

In this chapter I present some possible mechanisms through which commodity price fluctuations could incentivize agricultural producers and workers to produce illicit crops.

I am interested in the effect of a commodity price shock (for the remainder of this chapter I will refer to this as “price shock”) on the production of coca in Colombia. Following Dube, García Ponce and Thom (2016), I hypothesize that a price shock will affect coca-production disproportionately in Colombian municipalities depending on their respective commodity suitability, i.e. the agro-climatic characteristics needed to be able to grow a certain commodity. In essence I hypothesize that farmers, upon a negative price shock, will face the decision of continuing to grow the same commodity and suffer from lower incomes, or substituting into a more lucrative (possibly illegal) alternative.

Firstly, a price shock should affect households for whom their income depends (for a large part) on the production of the respective commodity. A negative price shock, decreases their income, and increases their incentives to spend more time on income generating activities (Dube et al., 2016). This mechanism might be less present with perennial crops, which require a multi-year investment to get a plantation into production, and thus higher associated switching costs. However, when prices remain low, or continue falling, even agricultural households cultivating perennial crops, are tempted to substitute into more profitable, possibly illicit crops. Still, there might be a share of farmers that will not simply switch to drug production upon a price fall of the legal crop. For this share of workers risk aversion and moral considerations deter them to do so (Bernasconi, 1998). However, as the legal returns decrease and the marginal value of income out of illicit crops increases, households that stayed out of drugs production for non-monetary reasons might be tempted into the business (Ibañez & Martinsson, 2013). As observed in table 2.1 the coffee sector, and some other commodity sectors in less extent, are characterized by small holders farms, making them more vulnerable to price shocks, and therefore possibly more eager to substitute into a more profitable activity upon a price fall.

A negative price shock will not only affect farmers, but also wages of individuals working on farms, as these are tight to the commodity prices (Dube et al., 2016). As wages fall, also agricultural workers increase their income generating efforts and search for more profitable activities. The occupational distribution of Colombia’s rural sector, a large share of day labourers, denoted by uncertain employment and not affiliated to the social security system, increases the vulnerability of individual workers to negative price shocks, and forcing them to supply their labour elsewhere, including the illicit crop sector or the criminal sector (UNODC, 2017). Dube, García-Ponce and Thom (2016) even posit that a negative price shock can further propagate from one agricultural sector to others. This happens, when for example a wage reduction in the coffee translates in an increase of supply of agricultural labour to other sectors, consequently reducing wages in these sectors.

It is also important to notice that a price shock can lead to an increase in drug production without reducing overall commodity production. This happens when farmers engage in inter-cropping small amounts of illicit crops with their traditional crops. This activity increases the average income generated from their farms without decreasing the amount of traditional commodities. Inter-cropping coca with legal commodities is practice that has often been found in many coca-producing regions in Colombia (UNODC, 2017).

The opposite, positive effect, is also possible, when a positive price shock increases income from agricultural activities and wages in the same sector. Upon an increase of the income obtained from legal crops, the additional benefit of growing illegal crops decreases, making it less attractive for farmers to grow drug crops.

## 4 Data

This chapter describes the data used in my analysis and its sources. First I describe the commodity data, followed by the data used to capture coca production, and lastly, general information about my sample.

### 4.1 Commodity data

To examine the impact of crop price shocks, I look at the crop suitability and yield per municipality in Colombia. Put differently, the ability of a municipality to grow a certain crop. As mentioned in section 2.2.2, I look at six different crops which lie among the ten largest agricultural export products across the observed time-span. These are coffee (arabica and robusta), banana, cacao, palm oil, sugarcane and tobacco. Data comes from the GAEZ v4.0 platform, a combined effort of the Food and Agriculture Organization (FAO) and the International Institute for Applied Systems Analysis (IIASA). The Global Agro-Ecological Zones (GAEZ) methodology is a primary tool used for land resources assessment. It is used for assessing agricultural production potential and production capacity, actual and potential yields, and yield gaps. The agro-ecological zones are defined as homogeneous and continuous areas with similar soil, land and climate characteristics. The GAEZ platform provides 5 arc-minute and 30 arc-second resolution (for Colombia this results in about 9 by 9 km grid cells around the equator) raster data on the suitability and agro-climatically attainable yields for different crops, for specified management assumptions and input levels, both for rain-fed and irrigated conditions. Using a geographic information system (QGIS)<sup>1</sup>, I extracted municipal-level data on the agro-climatic suitability of a range of crops in Colombia from the raster images.

I use two different measures to assess the ability of a municipality to grow a certain crop; crop suitability range and the average attainable output density. Both are defined as the area weighted sum of, respectively, the suitability or output density in the area composing the grid cell. The suitability range has an amplitude of 1 to 10, with 10 corresponding to a 100% suitability level, thus the maximal attainable fit for growing a specific crop. The average attainable output density is measured in thousand kilogram's dry weight (DW) per hectare. I only observe rain-fed agro-climatic conditions to mitigate any agro-climatic variability's stemming from variations in the irrigation infrastructure over the examined time-span. In addition, GAEZ measures of suitability and crop productivity under irrigation conditions are only available for grid cells with land equipped for irrigation. As agriculture in Colombia is mostly exercised surface-based, only 2% of overall agriculture area is irrigated agricultural land (WorldBank, 2013), this yield insufficient overlap with

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<sup>1</sup>QGIS is an open-source cross-platform desktop geographic information system application. The application enables viewing, editing, and analysis of geospatial data.

coca-producing land to assess any possible substitution mechanism. I also use a measure of land workability, obtained through the GAEZ v3.0 platform. The Workability dataset refers to the soil workability constraints that comprise conditions that may cause physical hindrance to cultivation, or cause limitations to cultivation imposed by soil texture/clay mineralogy and soil bulk-density. I use this measure to account for cross-sectional differences in soil quality that can cause differential crop yield across municipalities.

The data has some limitations. As these measures take the average of the agro-climatic conditions corresponding to the grid cell some problems can arise. For example, a grid cell composed for 50% of good soil and slope conditions and 50% bad conditions, would provide a suitability range of 50%. A grid cell consisting of homogeneous conditions but some limitations that restrict the suitability of a specific crop can however yield the same suitability range. Furthermore, as the municipal data is constructed from information extracted from the different grid cells composing the total municipal area, all measures are an average of the above-lying raster data. As explained, the data has been extracted using a geographic information system. I use a GADM<sup>2</sup> shapefile of Colombia to calculate the different measures at municipality level. However, the shapefile used, even though it covers the whole country, contains 1064 municipalities compared to the 1122 existing municipalities, reducing my dataset with suitability information on 58 municipalities per year over a time span of 17 years. Of these municipalities, 26 have produced coca at some point in my time span. An overview of the missing municipalities can be found in the appendix table A.10.

Despite these limitations, the proposed measures are preferred over the use of direct measures of crop cultivation as the latter are susceptible to direct price shocks and other external shocks that can influence total cultivation via other channels than through crop-substitution. Furthermore, GAEZs' measures for crop suitability and potential yield are more sophisticated compared to measures of rainfall and temperature, as Dube and Vargas (2006, 2013) use to mimic agro-climatic suitability of a certain crop. Nevertheless, for completeness, and to be able to compare my work to Dube and Vargas (2006), I also use municipal-level data on average rainfall and temperature in 2005. This data comes from the Centre for Study of Economic Development (CEDE). As the GAEZs' measures reflect the potential of a municipality to grow a certain crop and not actual production I also use municipal data on actual yield for all examined commodities. This data is available between 2007 and 2016 and was retrieved from Municipal Agricultural Evaluations (Evaluaciones Agropecuarias Municipales (EVA)) of the Colombian Ministry of Agriculture and Rural Development (Ministerio de Agricultura y Desarrollo Rural (MADR)).

Annual data on internal crop prices (except for coffee) comes from the MADR. Data on internal coffee price comes from the National Federation of Coffee Growers (NFCG). The internal crop price reflects the internal price paid to growers. Per analyzed crop, I also use data on export volumes of the leading exporting countries across the studied time period. An overview of these countries can be found in appendix table A.11. For all crops except coffee this data is retrieved from FAOSTAT. For coffee the data comes from the

<sup>2</sup>GADM is an open source platform to acquire administrative areas data.

International Coffee Organization (ICO). Exchange rate data of the Colombian peso with respect to the US dollar comes from the International Monetary Fund (IMF).

## 4.2 Coca data

My data on the cultivated area of coca comes from the Colombian department of the United Nations Office on Drugs and Crime (UNODC). The UNODC monitors coca crop cultivation in Colombia since 1999. Monitoring of coca crop cultivation is part of the SIMCI project (Systema Integrado de Monitoreo de Cultivos Ilícitos.), which is a cooperation between the UNODC and the Colombian Government. The SIMCI project produces annual land coverage to identify the dynamics of illicit crops production in Colombia. Monitoring is based on the interpretation of satellite images and the validation of data obtained through aerial recognition. The data obtained hereafter is annual municipal-based data on total cultivated hectares of coca<sup>3</sup>. Panel A of figure 4.1 depicts the average coca density between 1999 and 2016, measured in the number of hectares of coca production per municipality.

## 4.3 General information sample

General data on my sample comes from the the Centre of Economic Development Studies (Centro de Estudios sobre Desarrollo Económico (CEDE)). The panel of general municipal characteristics collects information on 1122 municipalities such as total, rural and urban population and other social-economic characteristics. CEDE collects its information mainly through censuses carried out by the Statistics Department of Colombia (Departamento Administrativo Nacional de Estadística, (DANE)). The observed panel uses observations from 1999-2005 and projections from 2005-2016. I use data on linear distance to the department capital and main wholesale market, total municipal GDP and the contributions of the agricultural, industrial and services sector to municipal GDP. Data on the latter is available between 2000 and 2009 and retrieved from the DANE 2005 general census. For all outcomes I restrict my sample to municipalities that are classified as rural. I do so as I am interested in the impact of crop price shocks on coca cultivation, which is merely a rural phenomenon. I follow the definition of “rural population” of the Encuesta Continua de Hogares, a survey carried out by the DANE to classify municipalities as rural or urban. Additionally, I exclude all municipalities with average population exceeding 250,000 over 1999-2016 to align my analysis to Dube and Vargas (2013). This reduces total municipalities from 1064 to 998. An overview of the criteria used for this classification can be found in Appendix C.1.

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<sup>3</sup>For a detailed description of how the satellite images are processed to obtain the calculation of total coca cultivation area I refer to the UNODC/SIMCI 2017 Coca Census.

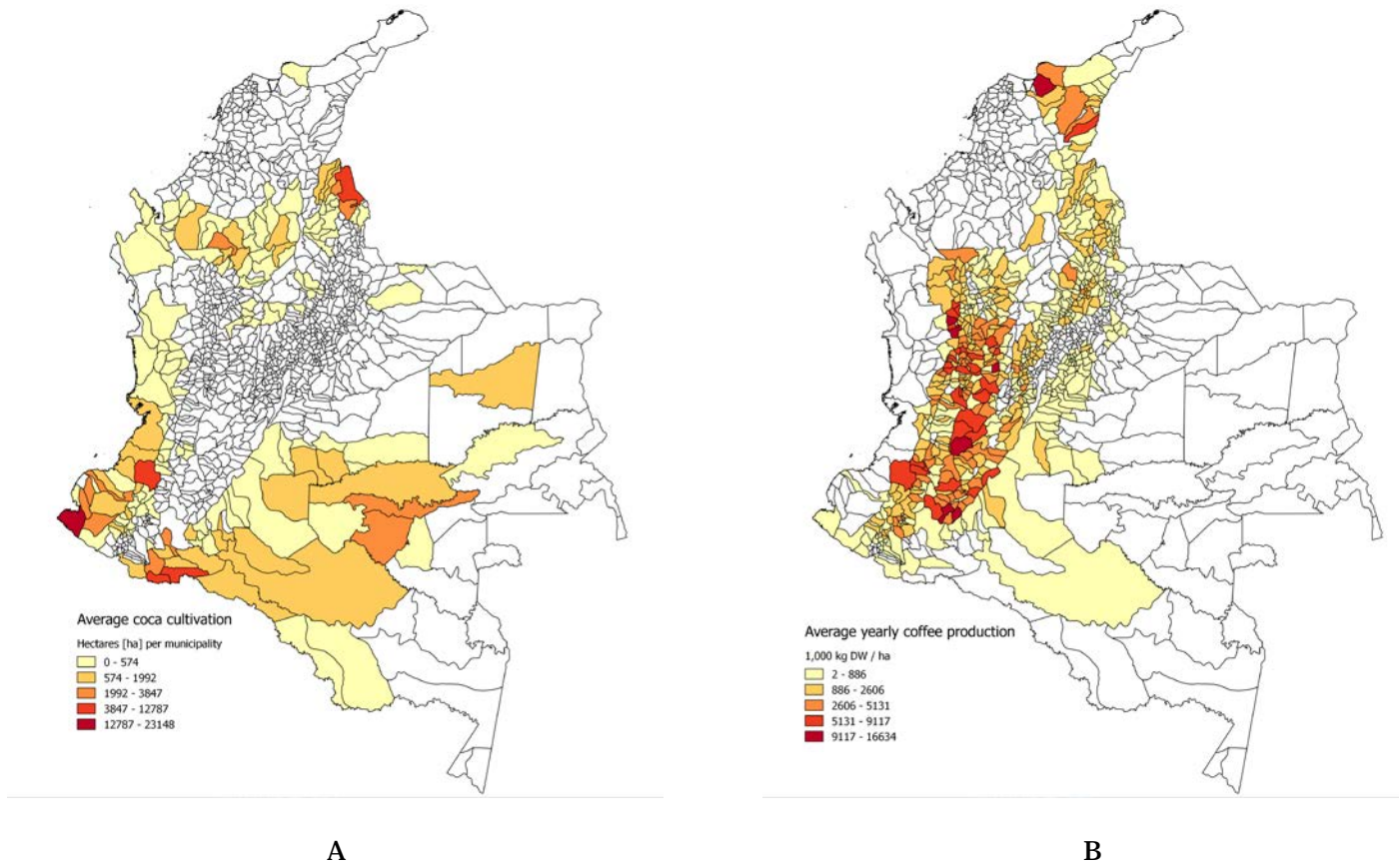


Figure 4.1: Panel A shows the average yearly coca production produced per municipality measured in hectares between 1999 and 2016. The data comes from the UNODC, SIMCI project. Panel B shows the average yearly coffee production per municipality measured in hectares between 2007 and 2016. The data comes from the Statistics Department of Colombia (DANE).

## 5 Methodology

My empirical strategy is based on a difference-in-differences technique that will assess whether there is a differential effect of a crop price shock on coca production across municipalities in Colombia. The variation comes from inter-municipal differences in a specific crop suitability and shocks to crop prices. To exploit inter-municipal variation in crop suitability I use a measure of average agro-climatic suitability of different crops across municipalities in Colombia. As explained in section 4.1, this measure captures the crop production capability per municipality based on a set of climatic and geographic input variables. Figure 2.1, for coffee, and appendix figures B.2 and B.1 for all other examined crops, map my suitability measures across municipalities. As can be observed from these figures, for all observed crops, there is substantial variation in crop suitability across Colombian municipalities. This is important as differences across municipalities in terms of crop suitability allow to observe whether a shock to the crop price causes a differential effect across municipalities which are more or less suitable to grow a specific crop. If this depends on whether the municipality lies in the coca-producing region, I can say something relevant about the relation between crop price and coca production.

In terms of the coffee price, using the domestic coffee price to examine coffee shocks will cause problems as this price is probably endogenous. A shock external to coffee markets that causes farmers in coffee suitable areas to produce more coca at the expense of coffee would cause coffee prices to increase via the supply side, generating an underestimation of the true effect. For example, recent press releases indicate that FARC elements have been urging coca growers to plant more coca, purportedly motivated by the belief that Colombian government post-peace accord investment and subsidies will focus on regions with the greatest quantities of coca (INCSR, 2016). Also, if increased levels of conflict in coffee suitable areas cause growers to decrease coffee production and simultaneously increase coca production, using the internal coffee price would lead to an underestimation of the proposed effect<sup>1</sup>. As Colombia is one of the leading exporters of coffee, and therefore dictates the world coffee price, using the international coffee price as an instrument for the internal coffee price would also directly bias my results. Therefore, following Dube and Vargas (2013), I construct an instrument for coffee price using the coffee export volume of three other leading coffee nations: Brazil, Vietnam and Indonesia. This will ensure that movements in the coffee price are solely driven by the export supply of other countries. I interact coffee price with coffee suitability to capture the differential effect of a coffee price shock on coca production in municipalities more suited to grow coffee. As explained in section 2.2.2, I apply my analysis to six different commodities: coffee, banana, sugar cane, cocoa, palm oil and tobacco. There is substantial variability across municipalities in

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<sup>1</sup>Angrist and Krugler (2008) describe a positive relationship between conflict and coca.

terms of commodity suitability (figure B.1 and B.2) and, among all chosen commodities, Colombia ranges across the top ten exporters on the international market (table A.11). Therefore, the above proposed reasoning in terms of coffee, also applies for all other five commodities I include in my analysis.

Taken this together this results in the following first stage equation:

$$Crop_i \times Price_t = \alpha_{1i} + \tau_{1i} + \mu_{1it} + \theta_1 (Crop_i \times \sum_{j=1}^n Export_{j,t}) + \rho X_{1it} + \omega_{it} \quad (5.1)$$

And the following second stage:

$$CocaArea_{it} = \alpha_{2i} + \tau_{2i} + \mu_{2it} + \theta_2 (Crop_i \times \hat{X} Price_t) + \phi X_{2it} + \varepsilon_{it} \quad (5.2)$$

In which  $\alpha_{1,2i}$ ,  $\tau_{1,2i}$  are the municipality and year fixed effects for the first and second stage respectively;  $\mu_{1,2it}$  is a municipality- or department-specific linear trend depending on the specification, and  $X_{1,2it}$  is a vector of controls, which varies across specifications.  $Crop_i$  is the GAEZ suitability measure for a specific crop per municipality  $i$ . As described in section 4.1, I use two measures of crop suitability; crop suitability range, ranging from 1 - 10, with 10 corresponding to a 100% suitability level, and average attainable output density (further on denoted as “yield”) for all land, in thousand kg dry weight (DW) per hectare.  $Price_t$  is the natural log of the internal crop price in USD per ton per year.  $CocaArea_{it}$  refers to the area dedicated to the production of coca per municipality  $i$ , year  $t$ , in thousand hectares. As  $Crop_i$  is the attainable yield per hectare, I scale  $CocaArea_{it}$  by municipal area, and take the natural log of  $CocaArea_{it}$  after adding a 1 to ensure municipalities with no coca production do not drop out.  $Export_{j,t}$  denotes the time-varying natural log of the sum of the specific crop yearly export volumes for the top three<sup>2</sup> exporting countries worldwide, in tonnes.

I estimate all parameters via two-stage least squares (2SLS) unless otherwise noticed and cluster standard errors at department level to control for potential serial correlation over time and across municipalities within a department. As my regressors are municipality-level variables, this step groups the 998 municipalities in my final sample into 32 departments, assuming zero correlation across these groups, but allowing for within-group correlation.

The included controls vary across specifications. To control for the time-varying scale of the municipalities I include the log of total population. Furthermore, it is possible that cross-sectional characteristics other than crop suitability drive coca-production. For example, if coffee production is correlated with proximity to markets or state capital, and at the same time coca production diverges depending on the proximity to markets and state capitals, this could bias my results. Therefore I include municipality- and department-specific linear trends to control for these potential trends. This is a stringent test as it basically imposes a separate trend for each municipality or department, controlling for

<sup>2</sup>For banana I use the top five export countries and for cocoa the top four export countries.

anything varying linearly. Therefore I only include this control in certain specifications of my model. To control for land quality differences or physical conditions that hinder cultivation, I include a measure of land workability interacted with year effects. Other controls that are included are linear distance to markets and department capital in interaction with year dummies and the log of exchange rate with respect to the USD in interaction with the used suitability measure (suitability range or yield). I specify each control when included in the regression in chapter 6, where I present my regression estimates.

Table 5.1: Descriptive statistics of annual, cross-sectional and panel-level variables

	Obs.	Mean	St. Dev.	Min.	Max.
<i>Annual-level variables</i>					
Log top 3 coffee exporting countries <sup>a</sup>	17	40.931	0.634	39.825	41.862
Log top 5 banana exporting countries <sup>a</sup>	17	80.023	1.029	78.458	81.449
Log top 3 cocoa exporting countries <sup>a</sup>	17	40.936	0.535	39.762	41.623
Log top 3 palm oil exporting countries <sup>a</sup>	17	60.971	1.189	58.740	62.570
Log top 3 sugar cane exporting countries <sup>a</sup>	17	58.127	0.625	57.179	59.005
Log top 3 tobacco exporting countries <sup>a</sup>	17	18.138	0.203	17.659	18.412
Log internal coffee price <sup>b</sup>	17	7.958	0.411	7.238	8.731
Log internal banana price <sup>b</sup>	17	6.668	0.198	6.321	7.209
Log internal cocoa price <sup>b</sup>	17	8.334	0.289	7.717	8.867
Log internal oil palm price <sup>b</sup>	17	7.292	0.284	6.690	7.659
Log internal sugarcane price <sup>b</sup>	17	3.962	0.269	3.414	4.300
Log internal tobacco price <sup>b</sup>	17	8.544	0.296	8.104	9.199
Log exchange rate	17	7.699	0.164	7.471	8.024
Log distance department capital	17	4.168	0.701	1.509	5.888
Log distance principal market	17	4.553	0.791	1.509	6.831
<i>Cross-sectional municipal variables</i>					
Av. output density coffee <sup>c</sup>	1,065	0.613	0.513	0.000	2.405
Suitability coffee <sup>d</sup>	1,065	2.083	1.936	0.002	9.637
Av. output density arabica coffee <sup>c</sup>	1,065	0.228	0.351	0.000	1.205
Suitability arabica coffee <sup>d</sup>	1,065	0.664	0.956	0.000	6.587
Av. output density robusta coffee <sup>c</sup>	1,065	0.487	0.554	0.000	2.480
Suitability robusta coffee <sup>d</sup>	1,065	1.539	2.028	0.000	9.637
Av. output density banana <sup>c</sup>	1,065	1.841	2.166	0.000	7.891
Suitability banana <sup>d</sup>	1,065	2.185	2.560	0.000	9.899
Av. output density cocoa <sup>c</sup>	1,065	0.448	0.613	0.000	2.335
Suitability cocoa <sup>d</sup>	1,065	1.863	2.517	0.000	9.999
Av. output density palm oil <sup>c</sup>	1,065	1.134	1.739	0.000	6.341
Suitability palm oil <sup>d</sup>	1,065	1.731	2.657	0.000	9.899
Av. output density sugar cane <sup>c</sup>	1,065	2.286	2.672	0.000	10.706
Suitability sugar cane <sup>d</sup>	1,065	1.989	2.322	0.000	9.994
Av. output density tobacco <sup>c</sup>	1,065	0.251	0.214	0.000	0.767
Suitability tobacco <sup>d</sup>	1,065	8.449	9.546	0.000	42.949
Rainfall (cm <sup>3</sup> )	990	1878.794	985.567	160	9200
Average temperature (°Celsius)	990	21.355	4.969	3.900	28.900
<i>Panel-level variables</i>					
Log coca production (ha <sup>e</sup> )	2,750	2.153	1.445	0.004	7.546
Log population	17,772	9.470	0.994	5.323	12.425
Municipal GDP per capita	4,734	7.320	5.738	0.008	80.100
Municipal GDP agricultural sector <sup>e</sup>	9,723	23.962	29.962	0.013	391.198
Municipal GDP industrial sector <sup>e</sup>	9,723	48.069	139.895	0.124	3,637.512
Municipal GDP service sector <sup>e</sup>	9,723	66.526	126.696	0.095	2,221.836
Total municipal GDP <sup>e</sup>	9,723	150.087	259.794	0.912	4,223.580

*Notes:* All panel and annual level variables are defined for period 1999-2016 unless otherwise noticed. The variables are described after classifying the sample as rural according to the characteristics in section 4.3. See section 4 for a complete description of the variables.

a) Measured in tonnes; b) Measured in USD/ton; c) Measured in thousand kg DW/ha; d) Range from 1 to 10; e) Measured in thousands

## 6 Results

In this chapter I present visual evidence for the proposed mechanisms and my regression estimates. I first present my results for coffee, and then extend the analysis to banana, cocoa, oil palm, sugarcane and tobacco. After, I undertake some robustness checks to see whether my results are robust to alternate specifications. I conclude this chapter by elaborating on some possible threats to my identification methodology.

### 6.1 Commodity price shocks and coca cultivation in Colombia

Table 5.1 summarizes the main characteristics of my key variables. Figure 6.1 depicts the average of log of coca production<sup>1</sup> between 1999 and 2016 alongside the different internal crop prices. Across all panels crop prices and coca production seem to behave in roughly opposite ways. Especially for coffee, sugarcane, banana and palm oil, differences increased between 2005 and 2014, as coca production decreased and prices trended upward. Also between 2000 and 2005, crop prices trended upward as coca production decreased for all depicted crops except coffee. This figure is far from complete, as no further controls are included, however, some suggestive relationship between crop price shocks and coca production across Colombian municipalities can be derived from these graphs. To investigate this relationship into more detail, I present my first regression estimates. I first dig into the relation between coffee prices and coca production, differentiating between two types of coffee; arabica and robusta coffee. After this, I expand my analysis to the other five commodities presented in figure 6.1.

#### 6.1.1 Coffee

To analyze coffee I distinguish between arabica and robusta coffee. As explained in section 2.2, the two types grow under different climatic conditions. Colombia's climate is suitable to grow both types of coffee, however robusta coffee can be grown in far more places compared to arabica (figure 2.1). Despite this, the country grows mainly arabica coffee. Of total coffee production, around 89% is green arabica coffee (ICO, 2017).

To examine this relationship into more detail I construct three difference-in-difference estimates for coffee, whose results are depicted in table 6.1; (A) without distinguishing (based on suitability) between arabica and robusta, (B) solely arabica, and (C) solely robusta coffee. The two independent variables used are the respective suitability and average attainable output interacted with the internal coffee price<sup>2</sup> for each type of coffee. In all

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<sup>1</sup>Measured as total number of hectares used for the production of coca per year.

<sup>2</sup>I do not distinguish between arabica and robusta internal coffee prices due to the lack of available data.



Figure 6.1: Time series plot of the log of average yearly coca production against several crops; coffee, banana, sugarcane, oil palm, cocoa and tobacco. Data of coca production was retrieved from the UNODC SIMCI project. Data on internal crop prices comes from the NFCG, for coffee and the MADR, for all other crops.

specifications the dependent variable is the natural log of coca production per municipality scaled by total municipal area. Column (1) shows the OLS outcomes for the three specifications, and columns (2) to (5) the IV estimates. Across all specifications the included controls are natural log of population, and the interaction between natural log of exchange rate and the respective suitability measures. In column (3) I control for soil quality by including interactions of the land workability measure with year effects. Columns (4) and (5) additionally incorporate a linear time trend at municipality- and department level, respectively, which will account for anything that varies linearly over time within the specific level of aggregation (either at municipality or department level). Panel A of table 6.1 depicts the results for the suitability of coffee without distinguishing between arabica and robusta coffee. The coefficients are negative and significant, and increase in absolute terms when changing the estimation strategy and adding controls. However, in the second panel, which analyses the suitability for solely arabica coffee, coefficients are positive and loose significance when accounting for municipality-specific trends. Comparing panel A of figure 2.1, which depicts the suitability of arabica coffee, with panel A of figure 4.1, presenting the distribution of coca production across Colombian municipalities, suggests that the positive coefficients in panel B are a result of a difference in climatic conditions needed to grow coca and arabica coffee; coca seems not to be grown in area's suitable for arabica coffee. Panel C takes solely suitability of robusta coffee into account. Here coefficients are smaller compared to panel A, but still negative and significant for both measures of suitability. Notable is that coefficients loose significance when adding a linear trend at department level (column (5), table 6.1) for robusta coffee, but turn negative and significant for arabica coffee. As the results for arabica coffee are not consistent across the presented specifications I believe that something else, which varies linearly over time at department level, is driving the results for arabica coffee. This, rather than that the presented estimated coefficient in column (5) is the true effect of a differential shock in coffee price on coca production for arabica coffee.

Table 6.2 presents the first stage results for coffee for my baseline specification (column (4), table 6.1). The results indicate a strong relationship between the instruments and the endogenous variable. To assure the coefficients of the first stage are not driven by the used suitability measure in the interaction terms of the first stage I perform a “zero-stage” regression. Here I examine the relation between sum of the used export volumes and the log of commodity price, i.e. without the interaction with my cross-sectional variable for commodity suitability. Appendix table A.9, panel A, presents the results of this stage and shows that, for coffee, export volume is a strong predictor of the internal commodity price, and hereby assures that the instruments of table 6.2 are valid predictors of my endogenous regressor of the second stage.

Referring back to figure 2.1, we observe the agro-climatic yield for arabica coffee in panel A, and for robusta coffee in panel B. When then comparing these maps to the distribution of coca production and coffee production (figure 4.1), we observe that coca producing regions coincide merely with robusta coffee suitable regions, while coffee producing regions coincide with arabica suitability. This seems trivial taking into account that Colombia is mainly an arabica coffee exporting country, but is still of very much importance for the

Table 6.1: Relation between internal coffee price, coffee suitability, and coca production

VARIABLES	Log coca area				
	(1)	(2)	(3)	(4)	(5)
<b>Panel A: Coffee, best of arabica and robusta</b>					
<i>Yield</i> × <i>Price</i>	-1.025*** (0.218)	-1.121*** (0.290)	-1.119*** (0.381)	-2.287*** (0.692)	-0.565 (0.405)
<i>Suit</i> × <i>Price</i>	-0.266*** (0.056)	-0.293*** (0.074)	-0.290*** (0.098)	-0.596*** (0.179)	-0.154 (0.095)
Controls?			yes	yes	yes
Linear trends?				yes	yes
Estimation method	OLS	2SLS	2SLS	2SLS	2SLS
Observations	2,684	2,684	2,684	2,684	2,684
R-squared	0.135	0.047	0.054	0.346	0.175
Number of municipalities	234	234	234	234	234
<b>Panel B: Coffee, arabica</b>					
<i>Yield</i> × <i>Price</i>	4.372*** (1.616)	4.322** (2.115)	3.751* (1.925)	27.259 (22.768)	-2.429** (1.130)
<i>Suit</i> × <i>Price</i>	0.843*** (0.310)	0.879** (0.384)	0.655** (0.322)	3.983 (3.421)	-0.510** (0.219)
Controls?			yes	yes	yes
Linear trends?				yes	yes
Estimation method	OLS	2SLS	2SLS	2SLS	2SLS
Observations	2,702	2,702	2,684	2,684	2,684
R-squared	0.100	0.010	0.029	0.308	0.159
Number of municipalities	235	235	234	234	234
<b>Panel C: Coffee, robusta</b>					
<i>Yield</i> × <i>Price</i>	-0.993*** (0.200)	-1.075*** (0.268)	-1.076*** (0.352)	-2.175*** (0.652)	-0.536 (0.388)
<i>Suit</i> × <i>Price</i>	-0.270*** (0.053)	-0.294*** (0.070)	-0.294*** (0.093)	-0.584*** (0.180)	-0.150 (0.104)
Controls?			yes	yes	yes
Linear trends?				yes	yes
Estimation method	OLS	2SLS	2SLS	2SLS	2SLS
Observations	2,702	2,702	2,684	2,684	2,684
R-squared	0.135	0.049	0.057	0.345	0.176
Number of municipalities	235	235	234	234	234

Notes: Robust standard errors are clustered at department level and shown in parenthesis. In every specification I control for year and municipality fixed effects and log population. The stated controls include the interaction of coffee suitability and output, respectively, with the log of US-Colombia exchange rate. Column (3) controls for land quality and column (4) and (5) include a linear time trend for each municipality and department, respectively. Suitability is measured in percentages, output is measured as the rain-fed average attainable output density for coffee in thousand kg DW/ha. Log coca production is measured as log of area used for the production of coca per thousand hectares plus 1. In columns (2) to (5) the independent variable is instrumented with the interaction between, respectively, the coffee suitability and output density, and the log export volumes of Brazil, Vietnam and Indonesia.

\*\*\* Significant at the 1% level; \*\* Significant at the 5% level; \* Significant at the 10% level.

Table 6.2: First stage results: Coffee

VARIABLES	(1) Suit*Price	(2) Yield*Price
<b>Panel A: Coffee, best of Arabica and Robusta</b>		
<i>Gaez × Top3Export</i>	-0.191*** (0.013)	-0.190*** (0.013)
F-statistic of excluded instruments	773.74	737.49
<b>Panel B: Coffee, Arabica</b>		
<i>Gaez × Top3Export</i>	-0.341*** (0.069)	-0.330*** (0.083)
F-statistic of excluded instruments	223.25	225.79
<b>Panel C: Coffee, Robusta</b>		
<i>Gaez × Top3Export</i>	-0.196*** (0.013)	-0.194*** (0.013)
F-statistic of excluded instruments	759.88	754.58
Controls?	yes	yes
Municipio trends?	yes	yes
Estimation method	2SLS	2SLS
Observations	2,349	2,349
Number of municipalities	246	246

Notes: This is the first stage of my baseline specification (column 4, table 6.1). Variables not shown but included in this regression are municipality and year fixed effects, log of population, interaction of coffee suitability and output, respectively, with the log of US-Colombia exchange rate and municipality-specific linear trends. For each coffee type, the “Gaez” term stands for “Yield” or “Suitability”, corresponding to measure used in the interaction term of the dependent variable in this first stage. Gaez is interacted with log export volume of the top three coffee exporting countries; Vietnam, Brazil and Indonesia. The F-statistic refers to the Sanderson-Windmeijer multivariate F-test of excluded instruments.

\*\*\* Significant at the 1% level; \*\* Significant at the 5% level; \* Significant at the 10% level.

interpretation of my results and the linkage to the results of Dube and Vargas (2006). This observation explains why Dube and Vargas find no significant result for coffee, as they solely take into account regions where coffee is *currently* produced. The results of table 6.1 and 6.2, and the visualization of the data presented in figure 2.1, suggests that a coffee price shock leads to a differential effect on the production of coca, and does this for municipalities more suited to grow *robusta* coffee.

In appendix table A.1, I reconstruct the results of Dube and Vargas (2006) following their estimation strategy, which resembles the strategy specified in equations 5.1 and 5.2, but varies on the input variables used. To construct the instrument they use interactions of average yearly rainfall, temperature and the (log) coffee export volume of Brazil, Indonesia and Vietnam. For their endogenous regressor they use actual coffee production interacted with the internal coffee price. I reconstruct their results adopting their variables, but vary the data in terms of the time stretch. Instead of using the municipal level of land devoted to coffee production in 1997, I use data from 2011. Furthermore I expand the time span of municipal coca production from three to seventeen years (1999-2016). The results in appendix table A.1, which are slightly negative or lie close to zero, and are not statistically significant, are in line with the results of Dube and Vargas (2006).

In the next section, I examine whether the proposed relation between *robusta* coffee prices and coca production also applies to a range of other commodities; banana, cocoa, palm oil, sugarcane and tobacco.

### 6.1.2 Other commodities

Table 6.3 presents the difference-in-difference estimates for banana, cocoa, palm oil, sugarcane and tobacco. I use the same estimation strategy, specifications and controls as for the estimation with coffee. For each commodity, the used data on the suitability measures, internal prices and export volumes corresponds to the specified commodity. Across all commodities, in almost all specifications the coefficients are negative and significant. For banana, cocoa and sugarcane coefficients and standard errors increase when including a municipality linear trend. As the price of these commodities is trending linearly over time (visualized in figure 6.1), including a linear trend at municipality level captures this price evolution completely, causing the coefficients to increase in magnitude. To account for this I include a linear trend at a higher level of aggregation (department level column (5)). The estimates are now smaller, negative, statistically significant, and in line with columns (1) to (3).

For all commodities except tobacco, using either “yield” or “suitability” in the regressor does not alter much the obtained coefficients. For tobacco however, using either “yield” or “suitability”, gives opposing results. A possible explanation for this is the difference between suitability and output density (or yield) distribution, visualized in figure B.1. As can be observed, “suitability” depicts a higher inter-municipal variation (panel A, figure B.1), as compared to “yield” (panel B, figure B.1). The variation can be explained by the different methodology employed to construct the measures. According to the GAEZ methodology, the variable “yield” also accounts for temperature and moisture constraints

Table 6.3: Relation between internal commodity prices, suitability, and area used for coca production

VARIABLES	Log coca area				
	(1)	(2)	(3)	(4)	(5)
<b>Panel A: Banana</b>					
<i>Yield × Price</i>	-0.318*** (0.098)	-0.370*** (0.087)	-0.429*** (0.122)	-4.711*** (1.414)	-0.276*** (0.086)
<i>Suit × Price</i>	-0.263*** (0.082)	-0.307*** (0.071)	-0.351*** (0.099)	-4.040*** (1.236)	-0.227*** (0.073)
<b>Panel B: Cocoa</b>					
<i>Yield × Price</i>	-0.149*** (0.036)	-0.182*** (0.044)	-0.191*** (0.066)	-1.275 (1.215)	-0.154 (0.114)
<i>Suit × Price</i>	-0.586*** (0.145)	-0.711*** (0.185)	-0.747*** (0.272)	-4.805 (4.708)	-0.620 (0.467)
<b>Panel C: Palmoil</b>					
<i>Yield × Price</i>	-0.220*** (0.057)	-0.295*** (0.067)	-0.344*** (0.105)	-0.757** (0.324)	-0.220*** (0.084)
<i>Suit × Price</i>	-0.144*** (0.037)	-0.193*** (0.044)	-0.223*** (0.068)	-0.498** (0.205)	-0.143*** (0.053)
<b>Panel D: Sugarcane</b>					
<i>Yield × Price</i>	-0.243*** (0.059)	-0.263*** (0.070)	-0.305*** (0.103)	-0.605 (0.442)	-0.163** (0.068)
<i>Suit × Price</i>	-0.295*** (0.073)	-0.321*** (0.084)	-0.363*** (0.122)	-0.671 (0.546)	-0.199** (0.084)
<b>Panel E: Tobacco</b>					
<i>Yield × Price</i>	-0.573 (0.469)	2.594 (1.978)	1.915 (1.910)	0.511 (1.226)	1.084 (1.447)
<i>Suit × Price</i>	-0.042*** (0.010)	-0.099** (0.045)	-0.096** (0.049)	-0.063*** (0.023)	-0.087*** (0.022)
Controls?			yes	yes	yes
Linear trends?				yes	yes
Estimation method	OLS	2SLS	2SLS	2SLS	2SLS
Number of municipalities	2,462	2,462	2,462	2,462	2,462
Observations	229	229	229	229	229

Notes: Robust standard errors are clustered at department level and shown in parenthesis. In every specification I control for year and municipality fixed effects and log population. The stated controls include the interaction of crop suitability and output, respectively, with the log of US-Colombia exchange rate, and interaction for year effects with the measure of land workability. Column (3) controls for land quality and column (4) and (5) include a linear time trend for each municipality and department, respectively. Suitability is measured in percentages. Output is measured as the rain-fed average attainable output density for coffee in thousand kg DW/ha. Log coca production is measured as log of area used for the production of coca per thousand hectares plus 1. In columns (2) to (5) the independent variable is instrumented with the interaction between, respectively, the respective crop suitability or output density, and the log export supply of the major exporting countries for each commodity respectively.

\*\*\* Significant at the 1% level; \*\* Significant at the 5% level; \* Significant at the 10% level.

Table 6.4: First stage results: Other commodities

VARIABLES	(1) Suit*Price	(2) Yield*Price
<b>Panel A: Banana</b>		
<i>Gaez × T op5Export</i>	0.223*** (0.003)	0.222*** (0.003)
F-statistic of excluded instruments	3411.47	3659.66
<b>Panel B: Cocoa</b>		
<i>Gaez × T op3Export</i>	0.417*** (0.017)	0.410*** (0.018)
F-statistic of excluded instruments	196.18	173.40
<b>Panel C: Palmoil</b>		
<i>Gaez × T op4Export</i>	0.153*** (0.010)	0.152*** (0.010)
F-statistic of excluded instruments	136.07	134.98
<b>Panel D: Sugarcane</b>		
<i>Gaez × T op3Export</i>	0.373*** (0.008)	0.374*** (0.008)
F-statistic of excluded instruments	757.85	800.91
<b>Panel E: Tobacco</b>		
<i>Gaez × T op3Export</i>	1.003*** (0.016)	0.986*** (0.036)
F-statistic of excluded instruments	4286.87	925.78
Controls?	yes	yes
Linear department trends?	yes	yes
Estimation method	2SLS	2SLS
Observations	2,495	2,495
Number of municipalities	262	262

*Notes:* This is the first stage of my base line specification (table 6.3 column (4) for oil palm and tobacco and column (5) for banana, cocoa and sugarcane). Variables not shown but included in this regression are municipality and year fixed effects, log of population, interaction of commodity suitability and output, respectively, with the log of US-Colombia exchange rate and, depending on the studied crop, municipality- or department-specific linear trends. For each commodity, the “Gaez” term in the independent variable stands for “Yield” or “Suitability”, corresponding to measure used in the interaction term of the dependent variable in this first stage. Gaez is interacted with the log summed export volume for each commodity. The F-statistic refers to the Sanderson-Windmeijer multivariate F-test of excluded instruments.

\*\*\* Significant at the 1% level; \*\* Significant at the 5% level; \* Significant at the 10% level.

that are affecting growth and development, and yield reducing effects caused by pests, diseases and weeds, which is not taken into account in the “suitability” measure. As the results for tobacco seem not robust to the applied regressor, these should be interpreted with caution. For all other commodities I do not observe noticeable variation between “suitability” and “yield”, which translates into comparable coefficients.

Table 6.4 presents the first stage results for all observed commodities in the same way table 6.2 does for coffee. Again the results point toward a strong relationship between the chosen instruments and the endogenous variable. Also, for each commodity, the chosen instruments, without interaction with the respective cross-sectional suitability measure, are strong predictors for the internal price. The results are shown in appendix table A.9, panel B to F.

Although not all commodities show a consistent negative and significant effect across the presented specifications, these results, and the results of robusta coffee, suggest that a differential effect of a shock to commodity prices on the production of coca in municipalities more suitable to grow this particular crop is in place. To investigate whether this is the case I perform some additional robustness checks which I lay out in section 6.2.

## 6.2 Additional checks

### 6.2.1 Regions Amazonas and Orinoquia

Colombia can be subdivided in five regions<sup>3</sup> of which the Amazonas and Orinoquia region have larger municipalities in terms of surface compared to the rest of the country. These two regions also score high in terms of suitability across all crops (visualised in figure 2.1, B.2 and B.1). To test whether these regions drive the results of tables 6.1 and 6.3, I exclude these regions progressively from my baseline regression. In appendix table A.2 I show that results remain similar for robusta coffee when excluding separately Amazonas and Orinoquia region. When excluding both regions simultaneously, the effect is still negative, but standard errors increase. Table A.3 does the same for all other studied commodities. Also in this case results remain similar when excluding regions Orinoquia, Amazonas, but standard errors increase when dropping Amazonas and Orinoquia regions simultaneously. It is possible that the lack of significance among the coefficients when excluding both Amazonas and Orinoquia regions is a result of insufficient variation in my data, rather than that the effect in these regions drives the overall effect found in tables 6.1 and 6.3. To shed light on this I construct a new variable using a dummy for regions Amazonas and Orinoquia interacted with the corresponding suitability measure and internal price, and include this in my baseline regression, which gives the following second stage:

$$\begin{aligned} CocaArea_{it} = & \alpha_{2i} + \tau_{2i} + \mu_{2i}t + \theta_2(Crop_i \hat{\times} Price_t) + \theta_3(Crop_i \times Price_t \hat{\times} DumOA_i) \\ & + \phi X_{2it} + \varepsilon_{it} \end{aligned} \quad (6.1)$$

In which  $DumOA_i = 1$  when including regions Orinoquia and Amazonas. Here  $\theta_2$  gives the effect of a crop price shock on coca production for Colombia excluding regions Amazonas

<sup>3</sup>An overview of this subdivision can be found in appendix B.3

and Orinoquia. The sum of  $\theta_2$  and  $\theta_3$  denotes the effect of a crop price shock on coca production for solely regions Amazonas and Orinoquia.  $\theta_3$  gives the difference between the effect in solely regions Amazonas and Orinoquia and the rest of Colombia. The results can be found in table A.4, for coffee, and A.5, for all other commodities. In these tables, columns (1) and (3) depict  $\theta_2$ , and columns (2) and (4) show  $\theta_3$ . Furthermore, in columns (1) and (2) I use “suitability” in the interaction term of independent variable, and in columns (3) and (4) “yield”. Additionally, in order to assess whether the obtained coefficients  $\theta_2$  and  $\theta_3$  are jointly significantly different from zero, i.e. the effect in solely regions Amazonas and Orinoquia is significantly different from the rest of Colombia, I perform a Wald test, in which I test  $H_0: \theta_2 + \theta_3 = 0$  against  $H_1: \theta_2 + \theta_3 \neq 0$ . The obtained chi-squared test statistics are also detailed in tables A.4 for coffee, and A.5 for all other commodities.

For robusta coffee the effect is negative for regions Amazonas and Orinoquia together ( $\theta_2 + \theta_3$ ), and significantly different from zero, as the null hypothesis can be rejected at a 1% significance level. For the rest of Colombia ( $\theta_2$ ), the effect is also negative, slightly larger in absolute terms, and significantly different from zero. This implies that the effect found for robusta coffee in regions Amazonas and Orinoquia differs from the effect in the rest of Colombia, and is less negative in these two regions compared to the rest of Colombia. However, the difference in effect found for Amazonas and Orinoquia and the rest of the country is very small (denoted by  $\theta_3$ ). For arabica coffee, the coefficients of solely regions Amazonas and Orinoquia ( $\theta_2 + \theta_3$ ), and the rest of Colombia ( $\theta_2$ ), are positive and not significant, which is in line with the baseline results (table 6.1, panel B).

For all other commodities, the effect is negative and significant in regions Amazonas and Orinoquia ( $\theta_2 + \theta_3$ ), as all null hypotheses can be rejected at, at most, a 10% significance level. For the rest of Colombia ( $\theta_2$ ), results across commodities vary. For banana,  $\theta_2$  is positive and significant. The coefficient  $\theta_3$  is large, negative and significant, implying that the measured effect of a banana price shock on coca production differs between regions Amazonas and Orinoquia, and the rest of Colombia. This reinforces the possibility that the effect found in table 6.3 for banana is driven by regions Amazonas and Orinoquia. For cocoa and oil palm the estimates of  $\theta_2$  are positive, while for sugarcane  $\theta_2$  is negative. However for these three commodities  $\theta_2$  is not significant. As I do not find a significant result for cocoa in my baseline regression (panel B, column (5), table 6.3), the estimate in table A.5 suggests that the effect, for cocoa, is only present in regions Amazonas and Orinoquia. For oil palm and sugarcane the results in table A.5 suggest that the effect found for Colombia as a whole seems to be driven by regions Amazonas and Orinoquia. However, as the estimates of  $\theta_2$  are not significant and even negative for sugarcane, I cannot exclude the possibility that, for oil palm and sugarcane, the effect is still present in Colombia excluding regions Amazonas and Orinoquia, but is not revealed due to reduced variation in my data when dropping the latter two regions. For tobacco the results are not consistent across the independent variables used, which is in line with the baseline results and probably driven by the difference in suitability and potential yield distribution, as outlined in section 6.1.2. Nevertheless, also here, the effect is negative and significant for regions Amazonas and Orinoquia.

Summarising, this section sheds light on the possibility that the results found in table 6.1 and 6.3 are driven by two regions; Amazonas and Orinoquia. Across all examined commodities, except for arabica coffee, I find that the effect in regions Amazonas and Orinoquia is significantly different from the effect in the rest of Colombia. For robusta coffee I find that the effect is slightly more negative and significant for Colombia excluding regions Amazonas and Orinoquia. This advocates for accounting for Colombia as a whole in the estimations of robusta coffee. For banana, oil palm, sugarcane and tobacco, the effect for Colombia as a whole seems to be driven by regions Amazonas and Orinoquia. For cocoa the effect is only present in these regions. For arabica, excluding regions Amazonas and Orinoquia does not alter my baseline results, which is as expected, as these two regions are not suited to grow arabica coffee (panel A, figure 2.1).

### 6.2.2 Perennial crops

As mentioned in section 2.1, coca is a perennial crop<sup>4</sup>, and it can take up to three years to gather the first harvest from a coca plant. This implies coca-production might not respond as smoothly to changes in commodity prices as insinuated in the model presented in equation 5.2. If coca production reacts to changes in commodity prices, I would expect this to become visible (at most) three years after a price shock has taken place. To implement this into my model, I add a forward looking lag to my dependent variable. This results in the following second stage:

$$CocaArea_{i,t+n} = \alpha_{2i} + \tau_{2i} + \mu_{2i}t + \theta_2(Crop_i \hat{\times} Price_t) + \phi X_{2i,t} + \varepsilon_{i,t} \quad (6.2)$$

In which the superscript  $t+n$  in  $CocaArea_{i,t+n}$  accounts for, at most, a three year forward looking component. In appendix table A.6 for coffee, and A.7 for all other commodities, I present the estimates of my baseline regression (table 6.1 column (4) for coffee, table 6.3 column (4) for oil palm and tobacco and column (5) for banana, cocoa and sugarcane). Coefficients remain negative and significant upon the inclusion of a forward looking lag for all commodities except tobacco. For banana, cocoa, oil palm and sugarcane the estimates even increase in magnitude (in absolute terms) as the lag gets larger. For tobacco, the effect disappears upon the inclusion of a forward looking lag, which is expected, as tobacco is the only annual crop included in the analysis. These observations support the theory of a shock to commodity prices becoming visible in coca plantations after these have had time to establish themselves. Overall the coefficients indicate that for all perennial commodities, the results found in previous sections are robust to the inclusion of a forward looking component.

### 6.2.3 Actual production

Until now I have been using measures of suitability and potential yield to comprise the ability of a municipality to grow a certain crop. I found that for robusta coffee, banana, oil palm and sugarcane a shock to the respective commodity price leads to differential

<sup>4</sup>Perennial crops are crops that persist for many seasons.

coca production across municipalities depending on their suitability to grow the studied commodity. These measures of suitability and potential yield reflect the potential of a municipality to grow a certain crop based on a range of agro-climatic input variables<sup>5</sup>, but do not say anything about actual production. In section 4.1 I argued why using measures of potential yield and suitability is preferable over actual production. However, in terms of completeness, I re-estimate equation 5.1 and 5.2 replacing  $Crop_i$  in the interaction term of the dependent variable in the first stage, by a continuous measure of actual crop yield per municipality between 2007 and 2016. The obtained coefficients, in appendix table A.8, are negative for coffee<sup>6</sup>, banana, cocoa, sugarcane and tobacco. The coefficients of banana and sugarcane are also significant but must be interpreted with caution as the number of observations is very low, especially for sugarcane. Nevertheless, the obtained results using actual production data instead of suitability or potential yield, are in line with previous results and hereby reinforce the my baseline outcomes (tables 6.1 and 6.3).

### 6.3 Economic impact

To assess the economic impact of my results I estimate the effect of a price shock to the area devoted to coca production for municipalities when moving up one standard deviation in the respective crop suitability distribution. Looking at the suitability range, for robusta coffee this corresponds to a standard deviation of  $\sigma = 2.028$ . The suitability estimate of robusta coffee of column (4) of table 6.1 is  $\theta_2 = \Theta.584$ . Between between 2012 and 2016 the coffee price decreased by 0.41 log points (34%). This price decrease translates into an increase of 63% in the area dedicated to coca production between 2012 and 2016<sup>7</sup>. For other commodities, for a similar price shock, I observe comparable, though smaller results. For banana a price decrease of 34% translates into a increase in area used for coca production of 27%. For sugarcane and oil palm these price shocks correspond to increase in coca production of 17% and 21%, respectively. Observing the distribution in terms of potential yield instead of suitability gives roughly the same estimates. Appendix tables A.12 and A.13 show the percentile distribution of my suitability measures and the yearly logged internal prices per commodity.

<sup>5</sup>For an extensive description of the input variables used to construct the measures of suitability and output density used I refer to FAO's and IIASA's GAEZs' methodology (FAO/IIASA, 2010).

<sup>6</sup>I am not able to distinguish between arabica and robusta coffee when it comes to actual production data as all available data on coca is the aggregate of robusta and arabica production data. The only distinction comes from the different suitability's used in the interaction term of the instrument.

<sup>7</sup>To assess the economic impact of my results I use  $CocaArea = e^{(\theta_z \times \sigma_i \times \Delta Price)}$ , in which  $\theta_2$  is the coefficient found in table 6.1 for coffee, and table 6.3 for other commodities,  $\sigma_i$  is the respective standard deviation per crop  $i$ , with respect to the examined suitability distribution, and  $\Delta Price$  is the price difference between two years, in the text I examine the difference between 2012 and 2016.

## 6.4 Possible threats to identification and recommendations for future research

When using a difference in difference estimation technique it is important to look at possible endogeneity concerns of the intervention studied. In my study I identify several issues that might confound the interpretation of my results, and therefore deserve to be mentioned. Furthermore, I introduce some possibilities to circumvent these concerns in future research.

In section 6.2.2, I account for the multi-year investment to get a coca planting into production. However, especially with perennial crops, which face higher investment costs compared to annual crops, eradication efforts can alter the incentives of coca growers to grow the drug in the future<sup>8</sup>. If eradication levels differ across municipalities, depending for example on the regional political party holding office<sup>9</sup>, so could the incentives of coca growers to cultivate coca, causing coca cultivation not to depend only on the income shock, but also on the level of preceding eradication. Further research could address this problem by introducing data on municipal eradication levels and examining the effect of the policy shift after the implementation of *Plan Colombia*, or during the second term of the presidency of Álvaro Uribe, when drug combating expenditures almost doubled.

As with coca, also for coffee, cocoa and oil palm, it takes at least three years, and up to five years before a plantation comes into production (detailed in section 2.2.2). To account for the delay between a (legal) commodity price shock, and the proposed response of coca plantations to this shock, in section 6.2.2 I included forward looking lags in my regression. For all examined (legal) crops, the inclusion of a lag is not necessary as I use suitability levels to identify commodity-producing municipalities instead of actual production data. Nevertheless, the multi-year investment needed to grow coca, coffee, cocoa and oil palm can increase the barrier for crop-substitution, as the costs associated with switching from growing one crop to another become larger. Overall my results point towards a negative relationship between a crop price shock and the production of coca in Colombia, even when the nature of most of the examined crops increase the costs to substitute between crops. This finding suggests that the measured effect, if present, might become even larger for annual crops, as it becomes easier for farmers to switch between crops. Furthermore, as the multi-year investment can impede rural producers to enter into growing coca, at the same time it can impede producers to exit the business. Future research could address (illicit) crop substitution mechanisms focusing on how crop management can take advantage of the nature of annual and perennial crops to combat drug crop production, i.e. increasing the barrier to enter in illicit crop production and facilitating switching to legal alternatives.

I only study one substitution mechanism at a time, however, multiple crop substitutions into coca production might take place at the same time. When different crop suitability's are correlated and at the same time their prices co-move this could confound my estimates.

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<sup>8</sup>This is less present for drug crops such as marijuana and poppy, which are annual crops and need to be replanted each year.

<sup>9</sup>Dell (2015) shows that eradication levels differ with respect to the political party and mayor holding office in each municipality in Mexico.

For example banana and sugarcane have substantial overlap in terms of suitability and their prices exhibit roughly similar patterns over time; figures 6.1 and B.2. Therefore a positive banana price shock occurring simultaneous to a positive sugarcane shock can bias my estimate found with sugarcane upwards. This can happen for all commodity price shocks that co-move over a given time span and of which suitability's are correlated.

When constructing the commodity suitability measure, I only look at *rain-fed* agro-climatic conditions and *intermediate* managerial input levels, while some farms might use irrigation systems for cultivation and managerial input levels differ across municipalities. The use of irrigation systems increases commodity yields as the quality and appropriate quantity of water needed to maximize yield can be regulated. In the same way a higher managerial input level is likely to increase the yield per hectare. If irrigation systems and managerial input level differs disproportionately over suitable and non-suitable areas this could alter the measured effect. I expect differences in the application of irrigation systems across municipalities to have a negligible influence on my results as only 2% of agricultural land in Colombia is irrigated agricultural land (WorldBank, 2013). However, the distribution of managerial input levels in agriculture across Colombia is less clear cut. If managerial input levels are (lower) higher in less suitable areas the measured effect could be (over-) understated.

Commodity price is instrumented with export volumes of the leading export countries with respect to the studied commodity. However, if other countries' production decisions were related to coca-cultivation levels or violence levels in Colombia this might lead to endogeneity in the instrument. The latter might also lead to some sort of endogeneity when countries observe violence levels in Colombia and relate them to coca production<sup>10</sup>.

In my estimation strategy I assume all farmers observe price shocks and make crop cultivation decisions upon price shocks, however if some farmers are more able to incorporate price shocks into their cultivation decisions compared to others, this could also influence my results. For example if cultivation decisions differ across municipalities based on education levels, isolation from more urban areas, posing that farmers are less able to incorporate income shocks to their farming decisions when in more remote areas and having a lower education level, this could influence my estimates.

Lastly, I do not include data on illegal drug prices in my analysis as no data series are available on farm gate prices received by cultivators of coca leaves. Overall the exclusion of drug prices should not be a problem as I focus on exogenous changes in commodity prices. However, excluding drug prices might become disputable if commodity prices are related to exogenous determinants of drug prices. As it is clear that drug prices are related to drug production, in the case that crop prices are falling and at the same time the demand for drug is increasing exogenously, my estimates could suffer from downward bias. In principle, this should affect farmers in all municipalities. However, if somehow, exogenous changes in demand for drugs affect producers differentially, my estimates could suffer from the proposed biased.

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<sup>10</sup>Angrist and Kugler (2008) find that civil conflict in Colombia is fuelled by the financial gains of coca.

## 7 Conclusions

This study analyzes the effect of commodity price shocks on the production of coca in Colombia. The relation between coca production and coffee production has been examined before, using actual coffee production data. Instead of using data on actual commodity production I use municipal measures of commodity suitability to circumvent endogenous responses of commodity production to commodity prices and coca cultivation. In addition, I distinguish between arabica and robusta coffee and extend the analysis to five other commodities including banana, cocoa, oil palm, sugarcane and tobacco, which range among Colombia's top ten agricultural export products. I instrument commodity prices with the export supply of the leading countries in terms of export volume per analyzed commodity.

I show that, for robusta coffee, a price shock leads to differential coca planting in municipalities more suited to grow these crops. This effect persists, even when accounting for two large regions, which score high in terms of commodity suitability, and for the fact that coca is a perennial crop. According to my estimates a coffee price decrease of 34% between 2012 and 2016 accounts for an increase in land devoted to coca production of 63% for municipalities moving up one standard deviation in the coffee suitability distribution. For banana, oil palm, sugarcane and tobacco, a price shock also leads to increased coca cultivation in municipalities more suited to grow the respective crop, however the effect seems to be driven by regions Amazonas and Orinoquia. For cocoa the proposed effect is mainly present in the regions Amazonas and Orinoquia.

For arabica coffee the effect is not present, and this can be mainly explained by the differences in agro-climatic requirements to grow arabica coffee and coca. This finding provides an explanation why earlier work on coffee and coca production has not been able to find any relation between both commodities as the differences between arabica coffee and robusta coffee, in terms of their agro-climatic suitability, have not been taken into account. Arabica coffee suitable municipalities do not coincide with coca growing municipalities and therefore, as Colombia produces mainly arabica coffee, when using actual coffee production to explain differences in coca plantations upon coffee price shocks yields no significant result. Overall my results for robusta coffee, and to a less extent, banana, sugarcane, oil palm and tobacco, suggest that commodity price shocks influence the decisions households make with respect to cultivation, and a negative shock can induce households to engage in illicit crop producing activities.

The extent to which households depend on the proceeds of a particular commodity should influence their decision making process in terms of cultivation. Further research should address the characteristics that make households more vulnerable to price shocks. It could assess how cultivation management between annual and perennial crops, practices as inter-cropping (growing two or more crops in proximity), or agro-forestry (a land-use system where trees are managed together with crops and/or livestock) can mitigate price shocks for rural producers. Interesting for further research is to gain insights into how a

commodity price shock propagates along the income chain and to urban sectors, as now only rural areas are taken into account. Ultimately, as coca has been found to sustain civil conflict in Colombia, it is possible that commodity price shocks influence, to some extent, violence dynamics in Colombia via the coca production channel. Further research on commodity prices and violence dynamics in drug producing areas should address this possible mechanism.

Although further research should address before mentioned topics, the preliminary results of this study provide some insights in the economic determinants of drug production, and imply that drug cultivation is susceptible to the same market forces as any other commodity. Therefore, these results have the following policy implications. Implementing a program of subsidies as stated in Article 4 of the Peace Accord should foster voluntary substitution out of coca production as income considerations play a role in coca production decisions. Furthermore, price stabilization schemes on commodities that have a large overlap with coca in terms of agro-climatic conditions can possibly counteract future substitution into drug crop cultivation by mitigating income shocks for rural producers.

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## A Tables

Table A.1: Relation between coffee production, rainfall, temperature, and coca production

VARIABLES	Log coca area				
	(1)	(2)	(3)	(4)	(5)
<i>Cof Prod × Price</i>	0.132 (0.091)	0.143 (0.479)	0.192 (0.461)	1.239 (0.821)	-0.182 (0.499)
Controls?			yes	yes	yes
Municipio trends?				yes	
Department trends?					yes
Estimation method	OLS	2SLS	2SLS	2SLS	2SLS
Observations	2,462	2,462	2,412	2,412	2,412
Municipalities	142	142	140	140	140

Notes: Robust standard errors are clustered at department level and shown in parenthesis. In every specification I control for year and municipality fixed effects, log population and the log of US-Colombia exchange rate interacted with coffee production. Column (3) controls for land quality and columns (4) and (5) include a linear time trend for each municipality and department respectively. When the estimation is via 2SLS, the independent variable is instrumented with the interaction between average municipal rain and temperature, and the log export volumes of Brazil, Vietnam and Indonesia. Log coca production is measured as log of area used for the production of coca per thousand hectares plus 1. \*\*\* Significant at the 1% level; \*\* Significant at the 5% level; \* Significant at the 10% level.

Table A.2: Alternate controls for coffee, Arabica and Robusta

VARIABLES	(1) SuitxPrice	(2) YieldxPrice	(3) SuitxPrice	(4) YieldxPrice	(5) SuitxPrice	(6) YieldxPrice	(7) SuitxPrice	(8) YieldxPrice	(9) SuitxPrice	(10) YieldxPrice
<b>Panel A: Coffee, both arabica and robusta</b>										
Log coca production	-1.346** (0.523)	-5.135*** (1.983)	-0.303*** (0.097)	-1.158*** (0.379)	-0.578*** (0.204)	-2.231*** (0.763)	-0.600*** (0.215)	-2.334*** (0.841)	-0.326 (0.321)	-1.315 (1.225)
R-squared	-0.073	-0.059	0.066	0.066	0.373	0.373	0.333	0.333	0.367	0.367
<b>Panel B: Coffee, arabica</b>										
Log coca production	-2.242 (1.580)	-13.700 (9.913)	0.375 (0.325)	2.287 (1.990)	3.464 (3.123)	24.117 (20.568)	3.552 (3.311)	24.690 (21.840)	2.533 (2.785)	18.472 (17.968)
R-squared	0.318	0.308	0.037	0.038	0.354	0.335	0.317	0.298	0.349	0.335
<b>Panel C: Coffee, robusta</b>										
Log coca production	-1.418** (0.578)	-5.194** (2.037)	-0.301*** (0.094)	-1.103*** (0.354)	-0.574*** (0.205)	-2.144*** (0.718)	-0.585*** (0.217)	-2.207*** (0.790)	-0.345 (0.315)	-1.309 (1.137)
R-squared	-0.172	-0.139	0.069	0.068	0.372	0.372	0.332	0.332	0.366	0.366
Alternate controls	Excl. exchange rate		Excl. linear trend + alt. controls		Excl. Amazon region		Excl. Orinoquia region		Excl. Amazon + Orinoquia region	
Observations	2,684	2,684	2,600	2,600	2,069	2,069	2,459	2,459	1,844	1,844
Number of origmun	234	234	228	228	195	195	219	219	180	180

Notes: Robust standard errors are clustered at department level and shown in parenthesis. In every specification I control for year and municipality fixed effects and log population. Across columns my baseline regression (table 6.1, column (4)) is altered by the specification stated under "Alternate controls".

\*\*\* Significant at the 1% level; \*\* Significant at the 5% level; \* Significant at the 10% level.

Table A.3: Alternate controls: Other commodities

VARIABLES	(1) SuitxPrice	(2) YieldxPrice	(3) SuitxPrice	(4) YieldxPrice	(5) SuitxPrice	(6) YieldxPrice	(7) SuitxPrice	(8) YieldxPrice	(9) SuitxPrice	(10) YieldxPrice
<b>Panel A: Banana</b>										
Log coca production	-0.374*** (0.113)	-0.455*** (0.129)	-0.365*** (0.108)	-0.443*** (0.134)	-0.110* (0.063)	-0.144* (0.076)	-0.218*** (0.077)	-0.268*** (0.092)	-0.071 (0.062)	-0.100 (0.077)
R-squared	0.153	0.153	0.054	0.056	0.207	0.208	0.165	0.165	0.200	0.200
<b>Panel B: Cocoa</b>										
Log coca production	-0.158 (0.117)	-0.625 (0.476)	-0.213*** (0.077)	-0.842*** (0.322)	0.028 (0.118)	0.131 (0.487)	-0.199* (0.113)	-0.832* (0.459)	-0.000 (0.112)	0.007 (0.463)
R-squared	0.175	0.175	0.054	0.056	0.206	0.206	0.174	0.174	0.199	0.199
<b>Panel C: Oil palm</b>										
Log coca production	-0.159*** (0.053)	-0.776** (0.328)	-0.234*** (0.075)	-0.357*** (0.114)	-0.053 (0.043)	-0.268 (0.418)	-0.143*** (0.054)	-0.796** (0.351)	-0.048 (0.044)	0.022 (0.460)
R-squared	0.176	0.319	0.051	0.052	0.207	0.383	0.170	0.306	0.198	0.379
<b>Panel D: Sugarcane</b>										
Log coca production	-0.213*** (0.074)	-0.177*** (0.061)	-0.375*** (0.136)	-0.317*** (0.114)	-0.078 (0.066)	-0.064 (0.051)	-0.182** (0.087)	-0.148** (0.071)	-0.040 (0.064)	-0.029 (0.050)
R-squared	0.178	0.178	0.064	0.064	0.208	0.208	0.171	0.171	0.200	0.200
<b>Panel E: Tobacco</b>										
Log coca production	-0.075*** (0.017)	0.279 (1.114)	-0.126** (0.050)	0.610 (2.301)	-0.085** (0.040)	1.557 (1.278)	-0.091*** (0.032)	0.715 (1.390)	-0.094 (0.095)	2.251 (1.445)
R-squared	0.183	0.347	0.184	0.028	0.192	0.378	0.354	0.336	0.369	0.367
Alternate controls	Excl. exchange rate	exchange	Excl. linear trend + alt. controls		Excl. Amazon re- gion		Excl. Orinoquia re- gion		Excl. Amazon + Orinoquia region	
Observations	2,462	2,463	2,384	2,385	1,898	1,899	2,251	2,252	1,687	1,688
Number of origmun	229	230	223	224	190	191	214	215	175	176

Notes: Robust standard errors are clustered at department level and shown in parenthesis. In every specification I control for year and municipality fixed effects and log population. Across all columns my baseline regression (Column 4, table 6.3 for palm oil and tobacco and column 5, table 6.3 for banana, cocoa and sugarcane) is altered by the specification stated under "Alternate controls".

\*\*\* Significant at the 1% level; \*\* Significant at the 5% level; \* Significant at the 10% level.

Table A.4: Confidence interval analysis: Coffee

VARIABLES	Log coca area			
	(1)	(2)	(3)	(4)
<b>Panel A: Coffee, best of Arabica and Robusta</b>				
<i>Gaez</i> × <i>P rice</i>	-0.572*** (0.182)	0.012* (0.007)	-2.325*** (0.702)	-0.020 (0.022)
Chi2 test statistic	9.27		11.00	
<i>P</i> > ( <i>chi2</i> )	0.0023		0.0009	
<b>Panel B: Coffee, arabica</b>				
<i>Gaez</i> × <i>P rice</i>	4.111 (3.463)	-0.070*** (0.024)	28.112 (23.124)	-0.067*** (0.025)
Chi2 test statistic	1.35		1.47	
<i>P</i> > ( <i>chi2</i> )	0.2453		0.2255	
<b>Panel C: Coffee, robusta</b>				
<i>Gaez</i> × <i>P rice</i>	-0.560*** (0.183)	0.012* (0.007)	-2.191*** (0.657)	-0.010 (0.018)
Chi2 test statistic	8.76		11.11	
<i>P</i> > ( <i>chi2</i> )	0.0031		0.0009	
Observations	2,684	2,684	2,684	2,684
Number of municipalities	234	234	234	234

Notes: In column (1) and (2) the “Gaez” term in the independent variable stands for “Suitability”, and in column (3) and (4) for “Yield”. In column (1) and (3) the coefficient catches the effect of a coffee price shock to the coca production in Colombia excluding the regions Amazonas and Orinoquia. Columns (2) and (4) depict this effect for the regions Amazonas and Orinoquia. Robust standard errors are clustered at department level and shown in parenthesis. In every specification I control for year and municipality fixed effects and logpopulation.

\*\*\* Significant at the 1% level; \*\* Significant at the 5% level; \* Significant at the 10% level.

Table A.5: Confidence interval analysis: Other commodities

VARIABLES	Log coca area			
	(1)	(2)	(3)	(4)
<b>Panel A: Banana</b>				
<i>Gaez x P rice</i>	0.565** (0.233)	-1.873** (0.914)	0.647** (0.260)	-2.137** (0.988)
Chi2 test statistic	3.07		3.39	
<i>P &gt; (chi2)</i>	0.0799		0.0654	
<b>Panel B: Cocoa</b>				
<i>Gaez x Price</i>	0.056 (0.095)	-0.388*** (0.122)	0.247 (0.392)	-1.497*** (0.498)
Chi2 test statistic	5.05		4.36	
<i>P &gt; (chi2)</i>	0.0246		0.0367	
<b>Panel C: Oil palm</b>				
<i>Gaez x P rice</i>	0.125 (0.319)	-0.691*** (0.224)	0.191 (0.481)	-1.066*** (0.329)
Chi2 test statistic	8.70		8.25	
<i>P &gt; (chi2)</i>	0.0032		0.0041	
<b>Panel D: Sugarcane</b>				
<i>Gaez x P rice</i>	-0.030 (0.077)	-0.456*** (0.121)	-0.021 (0.061)	-0.383*** (0.099)
Chi2 test statistic	18.45		18.67	
<i>P &gt; (chi2)</i>	0.0000		0.0000	
<b>Panel E: Tobacco</b>				
<i>Gaez x P rice</i>	-0.032 (0.034)	-0.035 (0.035)	2.585* (1.391)	-5.041*** (1.872)
Chi2 test statistic	6.98		2.87	
<i>P &gt; (chi2)</i>	0.0083		0.0900	
Observations	2,462	2,462	2,462	2,462
Number of municipalities	229	229	229	229

Notes: In column (1) and (2) the “Gaez” term in the independent variable stands for “Suitability”, and in column (3) and (4) for “Yield”. In column (1) and (3) the coefficient catches the effect of a commodity price shock to the coca production in Colombia excluding the regions Amazonas and Orinoquia. Columns (2) and (4) depict this effect for the regions Amazonas and Orinoquia. Robust standard errors are clustered at department level and shown in parenthesis. In every specification I control for year and municipality fixed effects and log population.

\*\*\* Significant at the 1% level; \*\* Significant at the 5% level; \* Significant at the 10% level.

Table A.6: Including lags for coca production: Coffee

VARIABLES	Log coca area			
	(1)	(2)	(3)	(4)
<b>Panel A: Coffee, best of arabica and robusta</b>				
<i>Yield</i> × <i>Price</i>	-2.287*** (0.692)	-1.916*** (0.541)	-1.706 (1.050)	-1.721* (0.984)
<i>Suit</i> × <i>Price</i>	-0.596*** (0.179)	-0.509*** (0.137)	-0.473* (0.269)	-0.451* (0.249)
<b>Panel B: Coffee, arabica</b>				
<i>Yield</i> × <i>Price</i>	27.259 (22.768)	2.807 (2.355)	-19.503*** (4.795)	0.090 (2.249)
<i>Suit</i> × <i>Price</i>	3.983 (3.421)	0.424 (0.443)	-3.781*** (0.746)	0.016 (0.383)
<b>Panel D: Coffee, robusta</b>				
<i>Yield</i> × <i>Price</i>	-2.175*** (0.652)	-1.751*** (0.502)	-1.446 (0.990)	-1.562* (0.915)
<i>Suit</i> × <i>Price</i>	-0.584*** (0.180)	-0.466*** (0.131)	-0.386 (0.261)	-0.413* (0.236)
Observations	2,684	2,607	2,456	2,323
Number of municipalities	234	233	223	220

Notes: Robust standard errors are clustered at department level and shown in parenthesis. In every specification I control for year and municipality fixed effects and log population. Across all columns I estimate my baseline specification (column (4), table 6.1) including different forward looking lags in my dependent variable (log of area used for the production of coca per thousand hectares plus 1). Column (1) is my baseline specification without any lags, in column (2) the dependent variable is lagged one year ahead, column (3) two years, and column (4) three years.

\*\*\* Significant at the 1% level; \*\* Significant at the 5% level; \* Significant at the 10% level.

Table A.7: Including lags for coca production: Other commodities

VARIABLES	Log coca area			
	(1)	(2)	(3)	(4)
<b>Panel A: Banana</b>				
<i>Yield × P rice</i>	-0.276*** (0.086)	-0.320*** (0.086)	-0.407*** (0.086)	-0.336*** (0.117)
<i>Suit × P rice</i>	-0.227*** (0.073)	-0.265*** (0.072)	-0.343*** (0.075)	-0.280*** (0.101)
<b>Panel B: Cocoa</b>				
<i>Yield × P rice</i>	-0.620 (0.467)	-0.597* (0.343)	-0.777*** (0.258)	-0.988*** (0.321)
<i>Suit × P rice</i>	-0.154 (0.114)	-0.151* (0.084)	-0.193*** (0.064)	-0.237*** (0.079)
<b>Panel C: Oil palm</b>				
<i>Yield × P rice</i>	-0.757** (0.324)	-0.719** (0.289)	-1.337*** (0.405)	-2.461*** (0.854)
<i>Suit × P rice</i>	-0.498** (0.205)	-0.476** (0.186)	-0.855*** (0.257)	-1.580*** (0.548)
<b>Panel D: Sugarcane</b>				
<i>Yield × P rice</i>	-0.163** (0.068)	-0.233*** (0.072)	-0.312*** (0.065)	-0.277*** (0.066)
<i>Suit × P rice</i>	-0.199** (0.084)	-0.278*** (0.088)	-0.375*** (0.077)	-0.332*** (0.076)
<b>Panel E: Tobacco</b>				
<i>Yield × P rice</i>	0.511 (1.226)	-0.338 (1.448)	-0.250 (1.473)	-1.359 (1.146)
<i>Suit × P rice</i>	-0.063*** (0.023)	0.012 (0.018)	-0.000 (0.017)	0.001 (0.029)
Observations	2,462	2,456	2,323	2,188
Number of municipalities	234	233	223	220

Notes: Robust standard errors are clustered at department level and shown in parenthesis. In every specification I control for year and municipality fixed effects and log population. Across all columns I estimate my baseline specification (table 6.3, column (4) for banana, cocoa and sugarcane, column (5) for oil palm and tobacco) including different forward looking lags in my dependent variable (log of area used for the production of coca per thousand hectares plus 1). Column (1) is my baseline specification without any lags, in column (2) the dependent variable is lagged one year ahead, column (3) two years, and column (4) three years.

\*\*\* Significant at the 1% level; \*\* Significant at the 5% level; \* Significant at the 10% level.

Table A.8: Actual production

VARIABLES	Log coca area							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Crops	Coffee	Arabica	Robusta	Banana	Cocoa	Oil palm	Sugarcane	Tobacco
ActualYield*Price	-0.880 (2.688)	-0.533 (2.740)	-0.015 (0.421)	-0.030** (0.013)	-0.603 (1.491)	0.002 (0.110)	-0.010*** (0.000)	-0.072 (0.105)
Number of municipalities	730	730	730	44	162	34	4	5
Observations	110	110	110	322	1,135	217	23	49
Controls?	yes	yes	yes	yes	yes	yes	yes	yes
Linear trends?	yes	yes	yes	yes	yes	yes	yes	yes
Estimation method	2SLS	2SLS	2SLS	2SLS	2SLS	2SLS	2SLS	2SLS

Notes: Robust standard errors are clustered at department level and shown in parenthesis. In every specification I control for year and municipality fixed effects, log population, the interaction of crop suitability with the log of US-Colombia exchange rate, land quality and include a linear time trend for each municipality (in columns (1) to (3) and (6) and (8)) and department (in columns (2) to (5) and (7)). The independent variable is the interaction between a continuous variable of actual crop yield per municipality between 2007 and 2016 measured in tonnes/ha, and the log of the internal commodity price. The independent variable is instrumented with the interaction between the respective commodity suitability and the log of sum export volumes of the major exporting countries. Log coca production is measured as log of area used for the production of coca per thousand hectares plus 1.

\*\*\* Significant at the 1% level; \*\* Significant at the 5% level; \* Significant at the 10% level.

Table A.9: Zero stage

VARIABLES	(1) Price	(2) Price	(3) Price
<b>Panel A: Coffee</b>			
Export volume	0.434*** (0.003)	0.424*** (0.002)	-0.274*** (0.005)
Real exchange rate		-1.364*** (0.010)	-1.482*** (0.006)
Year trend			0.090*** (0.001)
F-statistic of excluded instruments	17,772	17,772	17,772
R-squared	0.449	0.744	0.863
<b>Panel B: Banana</b>			
Export volume	0.159*** (0.001)	0.230*** (0.001)	0.028*** (0.002)
Real exchange rate		0.897*** (0.003)	0.743*** (0.002)
Year trend			0.041*** (0.000)
F-statistic of excluded instruments	17785.9	1,80E+05	298,91
R-squared	0.592	0.894	0.941
<b>Panel C: Cocoa</b>			
Export volume	0.503*** (0.003)	0.530*** (0.003)	0.137*** (0.004)
Real exchange rate		0.373*** (0.010)	0.743*** (0.008)
Year trend			0.048*** (0.000)
F-statistic of excluded instruments	21469,4	34194,3	1187,8
R-squared	0.623	0.656	0.776
Observations	15,797	15,797	15,797

Notes: Robust standard errors are clustered at department level and shown in parenthesis. Price refers to the log of the internal price, respectively for each commodity. Export volume is the sum of the logged export volumes of the major exporting countries for each commodity.

\*\*\* Significant at the 1% level; \*\* Significant at the 5% level; \* Significant at the 10% level.

Table A.9: Zero stage

VARIABLES	(1) Price	(2) Price	(3) Price
<b>Panel D: Oil palm</b>			
Export volume	0.230*** (0.001)	0.238*** (0.001)	0.190*** (0.005)
Real exchange rate		0.139*** (0.009)	0.149*** (0.009)
Year trend			0.012*** (0.001)
F-statistic of excluded instruments	54059,9	67842,9	1622,3
R-squared	0.732	0.736	0.739
<b>Panel E: Sugarcane</b>			
Export volume	0.421*** (0.001)	0.417*** (0.001)	0.097*** (0.003)
Real exchange rate		-0.032*** (0.005)	-0.138*** (0.004)
Year trend			0.042*** (0.000)
F-statistic of excluded instruments	1,20E+05	84206,7	884,03
R-squared	0.864	0.864	0.913
<b>Panel F: Tobacco</b>			
Export volume	0.767*** (0.011)	0.523*** (0.012)	1.001*** (0.016)
Real exchange rate		-0.813*** (0.018)	-0.851*** (0.017)
Year trend			-0.024*** (0.001)
F-statistic of excluded instruments	5277,31	2001,89	4161,6
R-squared	0.278	0.404	0.430
Observations	15,797	15,797	15,797

Notes: Robust standard errors are clustered at department level and shown in parenthesis. Price refers to the log of the internal price, respectively for each commodity. Export volume is the sum of the logged export volumes of the major exporting countries for each commodity.

\*\*\* Significant at the 1% level; \*\* Significant at the 5% level; \* Significant at the 10% level.

Table A.10: Overview missing municipalities from QGIS analysis

	Department name	Department code	Municipality name	Municipality code
1	Bolívar	13	Arenal	13042
2	Bolívar	13	El Peñón	13268
3	Bolívar	13	Norosí	13490
4	Bolívar	13	San Jacinto del Cauca	13655
5	Caldas	17	Norcasia	17495
6	Caquetá	18	Solita	18785
7	Cauca	19	Piamonte	19533
8	Cauca	19	Sucre	19785
9	Córdoba	23	La Apartada	23350
10	Córdoba	23	San José de Uré	23682
11	Chocó	27	Atrato	27050
12	Chocó	27	Carmen del Darien	27150
13	Chocó	27	Medio Atrato	27425
14	Chocó	27	Medio Baudó	27430
15	Chocó	27	Medio San Juan	27450
16	Chocó	27	Río Iro	27580
17	Chocó	27	Río Quito	27600
18	Chocó	27	Unión Panamericana	27810
19	La Guajira	44	Dibulla	44090
20	Magdalena	47	Pijiño del Carmen	47545
21	Putumayo	86	Mocoa	86001
22	Amazonas	91	La Victoria	91430
23	Amazonas	91	Puerto Alegría	91530
24	Amazonas	91	Puerto Arica	91536
25	Guainía	94	Mapiripana	94663
26	Guainía	94	Morichal	94888
27	Antioquia	5	La Pintada	5390
28	Bogotá, D.C.	11	Bogotá, D.C.	11001
29	Bolívar	13	Arroyohondo	13062
30	Bolívar	13	Clemencia	13222
31	Bolívar	13	Magangué	13430
32	Bolívar	13	Regidor	13580
33	Bolívar	13	San Cristóbal	13620
34	Cauca	19	Villa Rica	19845
35	Cesar	20	Pueblo Bello	20570

Table A.10: Overview missing municipalities from QGIS analysis

	Department name	Department code	Municipality name	Municipality code
36	Córdoba	23	Cotorra	23300
37	Córdoba	23	Tuchín	23815
38	Cundinamarca	25	El Rosal	25260
39	Cundinamarca	25	Granada	25312
40	La Guajira	44	Distracción	44098
41	La Guajira	44	Hatonuevo	44378
42	La Guajira	44	La Jagua del Pilar	44420
43	Magdalena	47	Algarrobo	47030
44	Magdalena	47	Concordia	47205
45	Magdalena	47	El Retén	47268
46	Magdalena	47	Nueva Granada	47460
47	Magdalena	47	Sabanas de San Angel	47660
48	Magdalena	47	Santa Bárbara de Pinto	47720
49	Magdalena	47	Sitionuevo	47745
50	Magdalena	47	Zapayán	47960
51	Magdalena	47	Zona Bananera	47980
52	Nariño	52	El Peñol	52254
53	Nariño	52	Nariño	52480
54	Sucre	70	Coveñas	70221
55	Sucre	70	El Roble	70233
56	Tolima	73	Palocabildo	73520
57	Archipiélago de San Andrés	88	San Andrés	88001
58	Archipiélago de San Andrés	88	Providencia	88564

Notes: This table depicts the missing municipalities from the QGIS analysis. The municipalities above the mid-rule (the first 26 municipalities) are also coca producing municipalities at some point in the observed time span (1999-2016).

Table A.11: Overview largest export countries per analyzed commodity

Commodity	Banana	Coffee	Cocoa	Oil palm	Sugarcane	Tobacco
Countries	India	Brazil	Côte d'Ivoire	Malaysia	Brazil	Brazil
	Ecuador	Vietnam	Indonesia	Indonesia	India	India
	Brazil	Indonesia	Ghana	Nigeria	China	China
	Philippines			Thailand		
	China					

Notes: For banana from 2013 the export volumes of Indonesia are used instead of Ecuador.

Table A.12: Descriptive statistics for suitability and yield measures

		Mean	St. Dev.	10th perc.	25th perc.	75th perc.	90th perc.
<b>Coffee</b>	Suitability	2.363	1.979	0.208	0.683	3.715	5.232
	Yield		0.512	0.036	0.127	0.902	1.326
<b>C. arabica</b>	Suitability	0.929	1.135	0.051	0.149	1.315	2.420
	Yield		0.215	0.007	0.024	0.229	0.463
<b>C. robusta</b>	Suitability	2.522	2.119	0.165	0.601	4.056	5.433
	Yield		0.549	0.039	0.146	1.041	1.403
<b>Banana</b>	Suitability	3.095	2.477	0.275	0.829	4.942	7.007
	Yield		2.092	0.209	0.659	4.241	5.782
<b>Cocoa</b>	Suitability	3.072	2.475	0.200	0.813	4.959	6.921
	Yield		0.607	0.045	0.189	1.170	1.702
<b>Oil palm</b>	Suitability	3.952	2.610	0.456	1.568	5.875	7.579
	Yield		1.716	0.274	1.080	3.883	4.989
<b>Sugarcane</b>	Suitability	2.815	2.236	0.220	0.711	4.816	5.899
	Yield		2.561	0.235	0.804	5.549	6.899
<b>Tobacco</b>	Suitability	12.384	9.013	1.692	4.425	18.718	25.365
	Yield		0.168	0.103	0.250	0.495	0.546

Notes: This table presents the mean, standard deviation, and percentile distribution of the suitability range and average attainable output density for each commodity.

Table A.13: Yearly logged internal prices for all observed commodities

Year	Banana	Cocoa	Oil palm	Sugarcane	Tobacco	Coffee
1999	6.28	7.36	6.39	3.50	7.99	7.89
2000	6.32	7.72	6.69	3.41	8.15	7.81
2001	6.47	7.72	6.79	3.70	8.21	7.43
2002	6.54	8.17	7.06	3.73	8.28	7.24
2003	6.67	8.42	7.35	3.67	8.45	7.28
2004	6.60	8.29	7.26	3.68	8.51	7.40
2005	6.52	8.22	6.99	3.76	8.48	7.81
2006	6.58	8.27	7.05	3.95	8.71	7.82
2007	6.53	8.41	7.32	3.94	8.19	7.90
2008	6.59	8.41	7.54	3.94	8.81	8.08
2009	6.77	8.44	7.42	4.12	8.80	8.19
2010	6.77	8.57	7.47	4.24	8.88	8.44
2011	6.69	8.61	7.66	4.28	9.20	8.73
2012	6.73	8.29	7.58	4.25	8.64	8.50
2013	6.79	8.33	7.40	4.23	8.62	8.17
2014	6.91	8.61	7.50	4.20	8.67	8.27
2015	7.21	8.87	7.59	4.30	8.10	8.21
2016	6.97	9.00	7.67	4.37	8.13	8.09

Notes: For each commodity, the yearly logged internal price is depicted between 1999 and 2016.

## B Figures

### B.1 Inter-municipal variation in crop-suitability

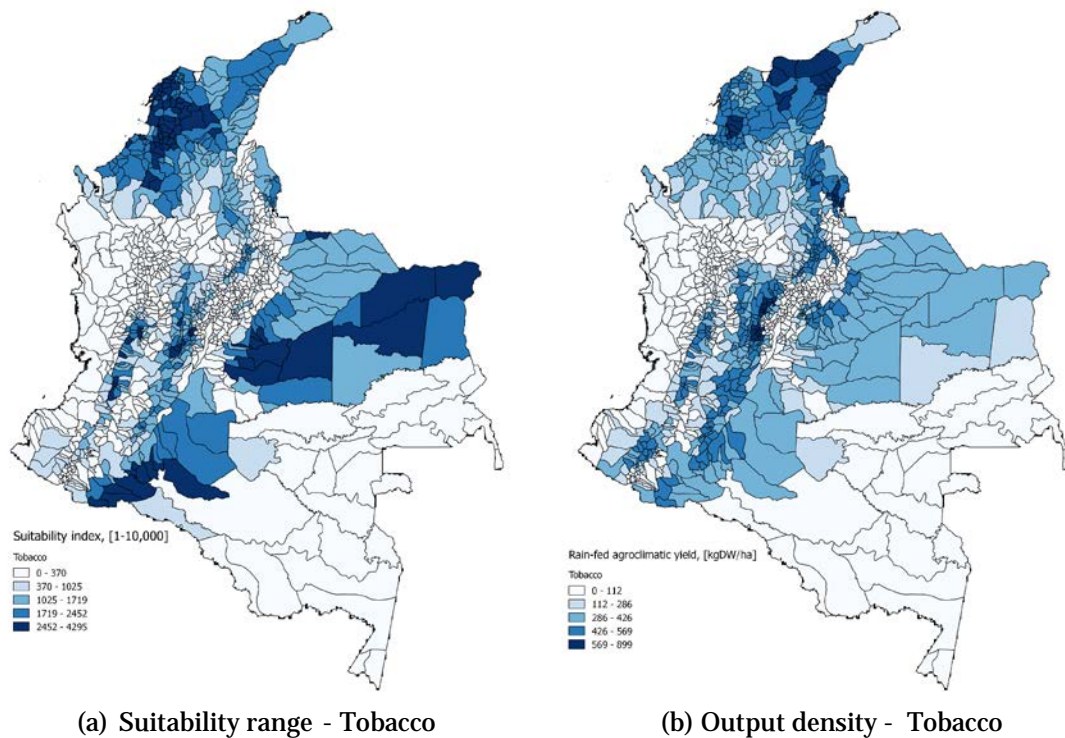


Figure B.1: Comparison between suitability range and rain-fed average agro-climatic yield per municipality in Colombia for tobacco. Data was retrieved from FAO's and IIASA's Global Agro-Ecological Zones (GAEZ).

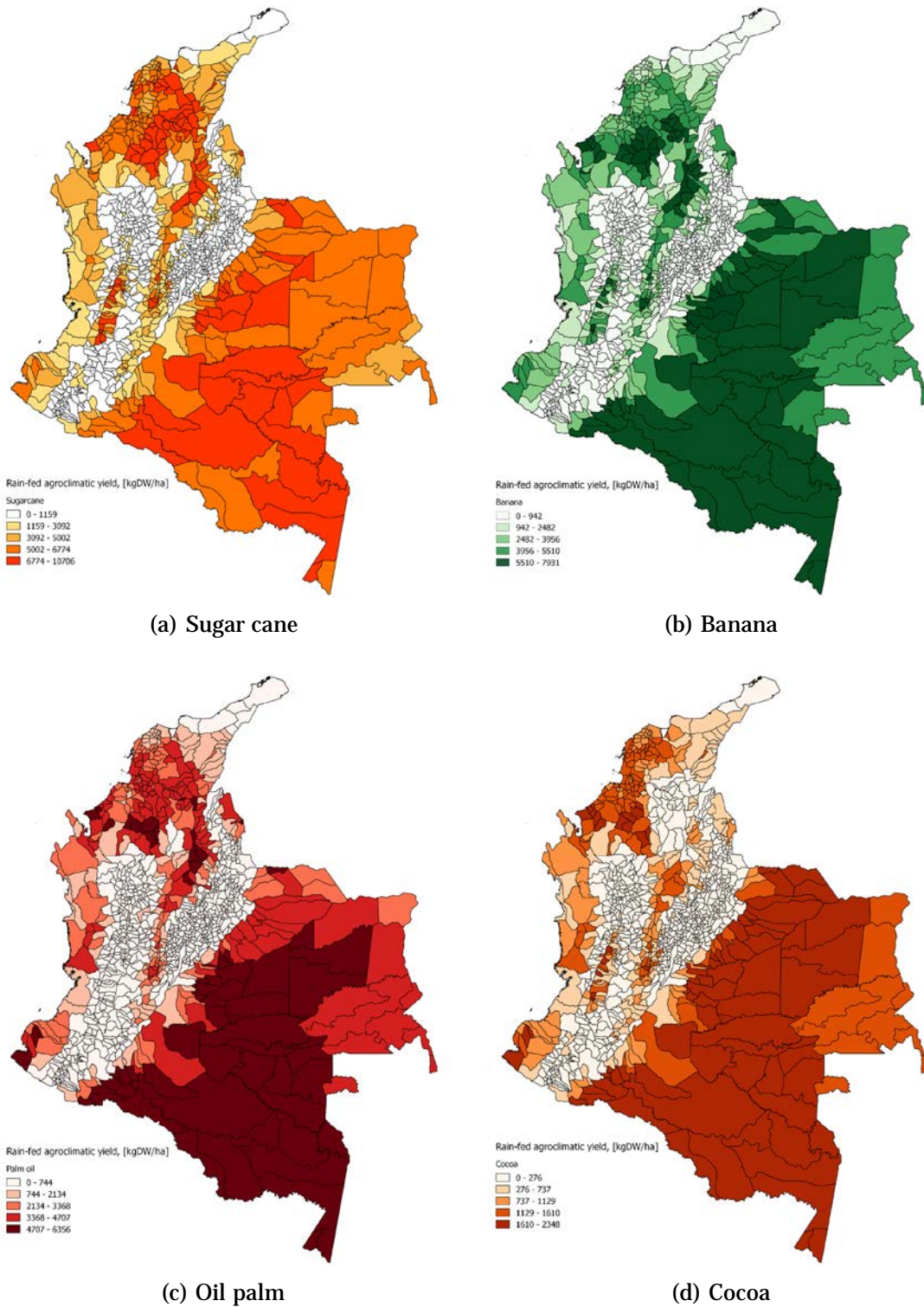


Figure B.2: Rain-fed average agro-climatic yield per municipality in Colombia for banana, cocoa, sugarcane and palm oil. Data was retrieved from FAO's and IIASA's Global Agro-Ecological Zones (GAEZ).

## B.2 Classification of regions in Colombia



Figure B.3: Classification of regions in Colombia. Information on the political-administrative division of Colombia was retrieved from the National Administrative Department of Statistics of Colombia (DANE).

## **C Data**

### **C.1 Rural classification criteria**

The Colombian Statistics Department (Departamento Administrativo Nacional de Estadística (DANE)) classifies rural population using the following criteria:

1. Population of the city where the municipal government is located if the city has fewer than 10,000 residents.
2. Population of the city where the municipal government is located if the city exceeds 10,000 residents but (1) the percentage of city's residents do not exceed 50% of total municipalities population, (2) the percentage of housing units without basic services exceeds 20%, or (3) the percentage of active people engaged in agricultural activities exceeds 50%.
3. All persons living in towns with fewer than 10,000 residents.
4. All persons not living in either cities or towns.