Essays in the Political Economy of Conflict and Development

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Abstract

This dissertation seeks to identify causes and consequences of some of the most complex social phenomena, such as civil conflict and climate change. In the first essay I draw on existing theories of labor coercion (Acemoglu & Wolitzky, 2011, Dippel, Greif and Trefler, 2015) to examine how poor labor market institutions, as those present in places where cocaine production takes place in Colombia, prevent low-income farmers to grasp the returns of positive productivity shocks generated by good weather, and instead, witness increasing coca-profiting group confrontations in high productivity areas.

I employed an Instrumental Variables approach together with Fixed Effects estimators to calculate the effect of exogenous variation in productivity on the dynamics of the conflict, to find that citizens security improves in high-productivity period and worsens in low-yield months.

The second essay is a research project with Alberto Abadie, Maurice Kugler and Juan Vargas, where we examine the causal effect of Plan Colombia, the largest US aid package ever received by a country in the western hemisphere, on citizens security (measured by civilians and military killings) and illegal crop acreages in Colombia. To infer the causal effect of the policy on the illegal crop and violence outcomes, we rely on GMM estimators and high-frequency variations in violence. We show that the marginal effect of spraying of one acre of coca reduces the cultivated area by about 11 percent of an acre.

Since aerial spraying may shift coca crops to neighboring municipalities, this results should be interpreted as a local effect. In addition, since the same coca fields are often sprayed multiple times, this figure constitutes a lower bound of the mean eradicating effect of aerial spraying. Our results also suggest that guerrilla-led violence increases both in the short and the long term. We interpret this result as evidence that the guerrilla tries to hold on violently to the control of an asset that is of first order importance for their survival.

In the third essay I seek to understand household adaptation and labor market impacts of extreme weather events in developing countries. This project focuses its attention on labor supply in the developing world – the primary source of household income throughout the world. Also, household allocation of adult and child labor in response to precipitation represents an avenue for exploring potential adaptations that may minimize or worsen the welfare effects from extreme weather events. My econometric results provide evidence of reductions in labor income mainly through an increase in adult unemployment. Individuals try to smooth the loss of labor income by restorting to "forced entrepreneurhip" or self-employment and by sending youth to work. The worst estimate of the loss in real wages per hour is 8% in the rainy season, but this coefficient is most likely an under-estimation of the effect of floods on real wages per hour, as individuals may have been adapting to ENSO and the unavailability of labor market data from the most affected municipalities during the floods of 2010. Finally, estimates of the causal effects of floods are non-linear. While an additional 95th percentile flood raises the probability of unemployment by 0.0026 percentage points, the effect doubles with one additional 99th percentile flood.

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Chapter 1: Introduction

This dissertation seeks to identify causes and consequences of some of the most complex social phenomena, such as civil conflict and climate change. The first essay, entitled "Climate, Conflict and Labor Markets: Evidence from Colombia's Illegal Drug Production", aims at linking two strands of the literature: the recent works on climate and conflict (Burke, Hsiang and Miguel, 2015, Dube and Vargas, 2013) and the economics of labor coercion (Acemoglu and Wolitzky, 2011, Dippel, Greif and Trefler, 2015). In the first area of knowledge, my research addresses an important knowledge gap on the role that institutional quality plays to help explain the directions and magnitudes of the impact of weather fluctuations on conflict through their effect on economic outcomes. Regarding the second knowledge area, my research contributes to the creation of new knowledge by bringing rich individual data and the use of satellite-generated information to the analysis of coerced labor. Also, by analyzing the current phenomenon of coca planting and exploitation by non-State armed actors, my research can inform illegal drug policy as well as rural development policies.

More precisely, this research aims at understanding the causal effect of weather-induced agricultural shocks on labor market conditions and forced displacement in the context of the Colombian civil conflict. I first match monthly municipal rainfall to coca leaf yield, to show that rainfall is a strong predictor of coca yield. Standard economic theory predicts that the rising productivity should translate into larger wages. However, when I estimate the effect of the positive productivity shock on rural unemployment and wages in coca areas, I find that the increasing production due to good weather rises labor demand but labor income remains constant.

To estimate the effect of the positive productivity shock to coca-suitable areas on labor demand and wages, I estimate log-linear Ordinary Least Square equations of wages and the probability of unemployment on individual characteristics that determine labor market outcomes and rainfall. I also control for municipality fixed-effects that absorb time-invariant characteristics, whether observed or

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unobserved, disentangling the precipitation shock from other sources of omitted variable bias, month*year fixed effects during the period January 2004-June 2010 and a department-specific linear time trend. Coca-suitable municipalities are those where coca has been cultivated in the municipality during at least one year during the period 1999-2011. These estimates are explicitly reduced form, and they focus on the effect of the variation in precipitation in coca-suitable areas on labor market outcomes. Given that precipitation varies plausibly randomly over time, as random draws from the municipality climate distribution, this approach has strong identification properties (Dell, Jones and Olken, 2014).

To explain the unexpected result of unchanged rural wages in response to increasing productivity, I draw on labor coercion models, where the role of coercion is to decrease the outside option of the coca farmers (Acemoglu & Wolitzky, 2011, Dippel, Greif and Trefler, 2015). These models hypothesize that an increase in coca productivity should be associated with expansion efforts by the coercive non-State armed groups and a decrease in forced displacement. Forced displacement occurs when farmers are able to leave the coca farming contract. Because the coerced sector yields higher returns with better rainfall, I first test that excess rainfall causes differentially lower forced displacement in coca suitable areas than in non-suitable areas. Results confirm, that in fact, an additional millimeter of precipitation above the municipality mean decreases forced displacement by 1.22% in coca-suitable areas; by contrast in non-coca areas the effect of positive rainfall shocks is approximately ten times smaller and insignificant.

A second way to test for coercion in coca suitable labor markets is to test whether high productivity months witness lower forced displacement. I therefore match coca leaf yield data with local violence in a small sample of municipalities with rich harvest data. I employ an Instrumental Variables estimation where changes in forced displacement are explained by coca leaf yield variations, and I instrument changes in coca leaf yield with rainfall. One additional arroba of coca leaf per hectare harvested is associated with a reduction of forced displacement of 4 people on average, and this estimate is significant at all statistical levels.

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Finally, I regress coercion efforts measured by confrontations between non-State actors who profit with cocaine and government forces as well as mayor killings on coca yield, instrumented with rainfall. As suggested by the labor coercion models, the IV estimates of the effect of positive productivity shocks on violence in coca areas are statistically significant and economically important, suggesting that the effect of weather shocks on labor markets is mediated by the quality of the institutions where these markets are embedded.

The second essay is a research project with Alberto Abadie, Maurice Kugler and Juan Vargas, where we examine the causal effect of Plan Colombia, the largest US aid package ever received by a country in the western hemisphere, on citizens security (measured by civilians and military killings) and illegal crop acreages in Colombia. To infer the causal effect of the policy on the illegal crop and violence outcomes, we rely on GMM estimators and high-frequency variations in violence. We show that the marginal effect of spraying of one acre of coca reduces the cultivated area by about 11 percent of an acre.

Since aerial spraying may shift coca crops to neighboring municipalities, this results should be interpreted as a local effect. In addition, since the same coca fields are often sprayed multiple times, this figure constitutes a lower bound of the mean eradicating effect of aerial spraying. Our results also suggest that guerrilla-led violence increases both in the short and the long term. We interpret this result as evidence that the guerrilla tries to hold on violently to the control of an asset that is of first order importance for their survival.

In the third essay I seek to understand household adaptation and labor market impacts of extreme weather events in developing countries. This project focuses its attention on labor supply in the developing world – the primary source of household income throughout the world. Also, household allocation of adult and child labor in response to precipitation represents an avenue for exploring potential adaptations that may minimize or worsen the welfare effects from extreme weather events. My econometric results provide evidence of reductions in labor income mainly through an increase in adult

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unemployment. Individuals try to smooth the loss of labor income by restoring to "forced entrepreneurhip" or self-employment and by sending youth to work. The worst estimate of the loss in real wages per hour is 8% in the rainy season, but this coefficient is most likely an under-estimation of the effect of floods on real wages per hour, as individuals may have been adapting to ENSO and the unavailability of labor market data from the most affected municipalities during the floods of 2010. Finally, estimates of the causal effects of floods are non-linear. While an additional 95th percentile flood raises the probability of unemployment by 0.0026 percentage points, the effect doubles with one additional 99th percentile flood.

Chapter 2: Climate, Conflict and Labor Markets: Evidence from Colombia's Illegal Drug Production

2.1 Introduction

Forced displacement by violence has been called the new 21st century challenge (UNHCR, 2012). In 2012, developing countries hosted over 80 percent of the world's refugees, and the 49 least developed countries were providing asylum to 2.4 million refugees by year-end. This paper aims at understanding the causal effect of weather-induced agricultural shocks on labor market conditions and forced displacement in the context of the Colombian civil conflict. I first match monthly municipal rainfall to coca leaf yield, to show that rainfall is a strong predictor of coca yield. Then, I estimate the effect of the positive productivity shock on rural unemployment and wages in coca areas, finding that increasing production due to good weather rises labor demand but is not translated into larger wages. I then turn to a municipal violence dataset and in a structural equation for violence, I regress confrontations between non-State actors who profit with cocaine and government forces, mayor killings as well as forced displacement on coca yield, instrumented with rainfall. My Instrumental Variables estimates of the effect of positive productivity shocks on violence in coca area are statistically significant and economically important.

The study of the intersection of climate and conflict has moved center stage over the past decade (Burke, Hsiang and Miguel, 2015). This shift is due in part to greater awareness about the role of climate in driving economic outcomes, and the broader fact that conflict remains widespread in most low and middle income regions. In fact, civil conflicts inflict more suffering on humanity than any other social phenomenon, they are central to political evolution and key impediments to global development (Miguel and Blattman, 2010), and the estimates from a meta-study that evaluated data from 60 studies and 45 conflict datasets from different regions of the world and a time period that spans from 10,000 BCE to the present, show that each standard deviation change in climate toward warmer temperatures or more extreme rainfall increases the frequency of interpersonal violence by 4% and interconflict violence by 14% (Hsiang, Burke and Miguel, 2013). These results underline the importance of further examination of the open questions in the literature relating to mechanims, heterogeneity, and which types of weather shocks matter most (Dell, Jones and Olken, 2014).

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While there is a consensus in the literature that bad economic conditions increase casualties from war (Miguel, Satyanath and Sergenti, 2004, Barron, Kaiser and Pradhan, 2004; Chen, 2007; Murshed and Gates, 2005; Quy-Toan Do and Lakshmi Iyer, 2007; Oeindrila Dube and Juan F. Vargas, 2013), and that climate plays a role in the link between economic conditions and conflict, numerous pathways linking climate and conflict have been proposed. This research posits a new channel through which climate impacts conflict: changes in the expectation of profits that non-State actors derive from cocaine production, which relies heavily and differently from legal crops on rainfall patterns, explains the variation in violence and welfare of rural workers in coca areas.

A related literature has examined how disfavorable changes in income may exacerbate the conflict over resources. For example, Hidalgo et al (2010) find that rural poor invade and occupy large landholdings more when rainfall is worse, in the context of Brazilian municipalities between 1988 and 2004. In subnational regions in Africa, Fjelde and von Uexkull (2012) show that negative rainfall shocks increase communal conflict, and in particular, in areas dominated by groups outside the political mainstream. In the Americas, Dell (2012) finds that municipalities that experienced more severe drought in the early 20th century were more likely to have insurgency during the Mexican Revolution than nearby municipalities with less severe drought. I contribute to that literature by examining how random deviations in local weather from its long term mean directly modifies the payoffs of coca-profiting illegal armed groups, changing the expectations of coca income that can be sourced from different locations. In other words, a positive weather shock in one place at a certain time means a higher coca income stream from coca cultivated in that place versus another, or from the same place at a different moment in time. This has implications for the confrontations of different groups for the control of these areas. Since there are multiple armed groups fighting over resources, any shock which raises the return to appropriation will increase conflict over land control by increasing the war prize if the contest is won (rapacity effect). On the other hand, the positive productivity shock directly affects the coca farmers' participation constraint: if excess rainfall favors coca disproportionally over other legal crops, and under the presence coercive

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activity, wetter months associated with higher yields should produce higher labor demand for coca planting as well as larger violence activity (Acemoglu & Wolitzky, 2011), and lower displacement.

To estimate the effect of the positive productivity shock to coca-suitable areas on labor demand and wages, I estimate OLS equations of (log) wages and the probability of unemployment on individual characteristics that determine labor market outcomes and rainfall, controlling for municipality fixed-effects that absorb time-invariant characteristics, whether observed or unobserved, disentangling the precipitation shock from other sources of omitted variable bias, month*year fixed effects during the period January 2004-June 2010 and a department-specific linear time trend. Coca-suitable municipalities are those where coca has been cultivated in the municipality during at least one year during the period 1999-2010. These estimates are explicity reduced form, and they focus on the effect of the variation in precipitation in coca-suitable areas on labor market outcomes. Given that precipitation varies plausibly randomly over time, as random draws from the municipality climate distribution, this approach has strong identification properties (Dell, Jones and Olken, 2014).

Despite the increase in labor demand as measured by a decrease in unemployment, my results show that the positive producitivity shock to coca production does not translate into better rural wages. To better understand the market-clearance mechanism in this context, I then match coca leaf yield data with local violence in a small sample of municipalities with rich harvest data. I employ an Instrumental Variables estimation where changes in confrontations, mayor killings and forced displacement are explained by coca leaf yield, and I instrument changes in coca leaf yield with unexpected rainfall shocks. Since the seminal work of Miguel, Satyanath and Sergenti (2004) on the impact of unforseeable weather conditions on economic growth and the outbreak of civil conflict and war in Africa, a body of literature has relied on rainfall to establish causality when looking at a host of political and economic outcomes (Bruckner and Ciccone, 2011, Mehlum, Miguel and Torvik, 2006, Bohlken and Sergenti, 2010). Since rainfall can affect many social phenomena simultenously (see Dell, Jones and Olken, 2014, for a review), I restrict my sample to a small set of municipalities that are highly dependent on coca plantation and transformation into cocaine, and follow cocaleros (coca farmers) during every month for one year from

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these municipalities, matching their yields to local monthly violence. I also show, using yield information from 11,624 harvests, that rainfall and coca yield are strongly correlated. Excess rainfall is less good for legal crops than coca since the coca leaf plant has been modified through history to maximize the levels of its alcaloid (which maximizes the level of cocaine that can be obtained from it but kills the pests that are associated with abnormaly high precipitation).

This research also contributes to the literature on the origin of States, broadly defined as a monopoly of violence that violent actors impose in order to extract taxes (Carneiro, 1970, Olson, 1993, Tilly, 1985, Weber, 1946). A related empirical work is the study of stationary bandits in the Democratic Republic of Congo by Sanchez de la Sierra (2014). The author finds that the decision of violent actors to impose monopolies of violence on their ability to tax the local population. Sanchez de la Sierra uses a sharp change in the price of coltan, the main raw material of electronic products, to show that an increase in its price caused the armed actors to impose a taxation system and the monopoly of violence systematically in coltan villages. My research studies forced displacement in the context of State formation, which has been overlooked in this literature. Colombia is a good context to stuy forced displacement as a result of violence given that it is currently the country with the second largest number of forcefully displaced population after Siria (Comision Historica del Conflicto y sus Victimas, 2015, GMH, 2013), and that the availability of data at municipal level on a monthly basis facilitates the analysis of short term changes in violence outcomes generated by variation in short term economic production and climate.

The result that institutional quality is of the utmost importance in labor markets and that therefore it can even offset market forces is consistent with findings by Dippel, Greif and Trefler (2015), who find that an institutional channel explains labor market outcomes in the coercive environment of the 14 sugar British Caribbean colonies. The authors conclude that the collapse of the coercive plantation system in these places raised wages (offseting the fall in wages generated by the market channel) and lowered coercion, measured by incarceration rates. While the collapse of the coercive plantation system decreased

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labor demand in the sugar sector (which should have depressed wages), workers were more able to move to non-plantation opportunities, which increased earnings.

The effect that shocks to the coca leaf planting and processing sector have on civil conflict dynamics is relevant to study for policy reasons as well. From a policy perspective, understanding the effects of changes in the production of illegal goods that fuel internal conflicts is of pressing concern. Eradication of these goods has been globally devoted increasing amounts of resources under the premise that decreasing the income of rebels will make them more likely to disappear or negotiate.

Cocaine is the second-most consumed illegal drug in the United States -after marijuana- and the third in most European countries -after marijuana and heroin- (Mejia and Posada, 2010). The coca bush can grow almost everywhere in the country, in areas from 100 meters of altitude to 2000 meters. Farmers who plant and harvest the leaf add 9% of the total added value. Cocaine production and commercialization high investments and are the most profitable activities of the production chain.

Colombia's current civil war involves left-wing guerillas, private militias with no political objectives, and government forces. Both guerrilla groups and private militias are heavily involved in the production and trade of coca leaf and its derivatives, from which they benefit abundantly (Mejia and Rico, 2010). They offer seeds, technical assistance and credit to coca farmers (Cano, 2002), control prices acting either as a monopsonistic buyer or as a market regulator and enforces «contracts» with violence.

This research is closely related to Dube and Vargas (2013) study of commodity price shocks and civil conflict in Colombia, and Angrist and Kugler (2008) research about coca, income and civil conflict in Colombia. Angrist and Kugler (2008) study the consequences of the shift of coca production of coca from neighboring Andean countries to Colombia on labor market outcomes and violent death rates. They find some evidence of increases in self-employment income, though not in the likelihood of of having income from this source, in the probability of working more generally, or in wage and salary earnings. Their results also show increased violent death rates in growing areas after the increase in coca cultivation (but these results are weaker in models that include department trends). Even though the autors cannot

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identify the channels through which coca cultivation might abet violence their results are consistent with the notion that coca supports rural insurgents and paramilitaries (Angrist and Kugler, 2008, p. 210).

Dube and Vargas (2013) research exploits exogenous price shocks to coffee and oil to find that a sharp fall in the coffee prices during the 1990s lowered wages and increased violence differentially more in municipalities cultivating more coffee. This is consistent with the coffee shock inducing an opportunity cost effect. In contrast, a rise in oil prices increased both municipal revenue and violence differentially in the oil region. This is in line with the oil shock inducing a rapacity effect. My paper differs from Dube and Vargas (2013) paper in a very fundamental way: coca planting, harvesting and processing into cocaine are economic activities enforced with violence. If living in coca-growing contested areas, outside options for coca farmers are very limited or nonexistent (Fichtl, 2004:4), if they are not explicitly coerced to coca planting and harvesting. Therefore, the mechanism at work in their research, which is the increasing opportunity cost of joining the armed groups does not hold here.

The rest of the paper describes firstly the institutional context where coca growing and associated violence takes place. This section is followed by a simple conceptual framework on labor coercion. Next, the paper presents the data sources and summary statistics of the main outcomes (labor market and violence). I then describe the empirical strategy to estimate the effect of weather-induced agricultural productivity shocks on labor market outcomes in coca-suitable municipalities, as well as on forced displacement. The following section presents Instrumental Variable estimations of the effect of coca productivity instrumented with rainfall on violence in coca growing municipalities (forced displacement, confrontations and mayor killings). Finally, I interpret the results and conclude.

2.2 Institutional Context

2.2.1 Colombian Civil Conflict

Colombia has a long history of state weakness and civil conflict (Acemoglu, Garcia-Jimeno and Robinson, 2014). Nonstate armed actors and many of the most recent emerged from a civil war known as La Violencia which lasted from the late 1940s into the early 1960s (Acemoglu, Robinson and Santos,

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2013). This civil war was initially the consequence of fighting between the Liberal and Conservative political parties. The Revolutionary Armed Forces of Colombia, FARC and National Liberation Army, ELN, formed in 1964 (ibid). As a corollary to both, the State's weakness and the bipartisan conflict, private armed militias were created during the Cold War era. They emerged in the fifties as individualized attempts to quell regional and local foci of unrest. Some members of the military, large landowners, and/or politicians welcomed, fostered, and financially assisted motley groups of guards and defense escorts, who came to be known under different appellations ("chulavitas," "pajaros," "guerrillas limpias," "guerrillas de paz" ...) according to the area (Garces, 2005). Their existence was legally sanctioned in 1968, a decision eventually overturned in April 1989, when their collusion with some sections of the armed forces awoke criticism from Amnesty International and other human rights groups. Initially, the law had approved the "collective defense" and the creation of groups to support the Army (Pardo, 1997).

The paramilitary consolidated themselves considerably in the 1980s and 1990s. Three main causes explain the expansion of the paramilitaries during the 80s (Pardo, 2007). Firstly, the pre-existence of private armed militias mentioned before, some of them created by Colombian Army. Secondly, the peace treaty with left-wing guerrillas during the 80s, which obliged the Army to stay in their camps without fighting any groups, while the leftist guerrilla groups expanded considerably, from 1,600 to 3,600 men between 1984 to 1986. Not only drug traffickers but businessmen decided to organize small or big groups to defense themselves from the guerrilla, according to their capacity. C) The third factor was the kidnap of Martha Ochoa, member of one of the drug cartels, by one of the guerrillas. All the mafia members grouped to rescue the woman and informed during a soccer game in Cali that they had conformed the "Kill Kidnappers" group, in order to defend their interests, members and properties.

In 1987, the groups had become a single terrorist unity with the main goal of providing the mechanisms for drug trade without any complications. The businessmen that had participated at the beginning in the creation of the groups got involved and many of them became the victims of the movements they had helped to create, having had to sell their lands at very low prices. Others preferred to stay despite being aware of the new goals of the organization (Pardo, 1997). Like the guerrillas, the

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paramilitaries benefited abundantly from drug money. Illegal funds were even used for their training by Israeli instructors. And like the guerrillas, they also relied for their financing on fees charged for protection. They generalized the practice of mass killings, seeking to eliminate peasants even when only vaguely suspected of colluding with the guerrillas. They mimicked the guerrillas in their carefully led insurrectional war, establishing local fronts to cleanse them from rebel-guerrilla presence (Garces, 2005). They also killed Luis Carlos Galan in 1989, presidential candidate who could have led a socialist party in Colombia (Robinson, 2005).

The United Self-Defense Forces of Colombia (AUC) were formed in April 1997 as an umbrella paramilitary federation. They sought to consolidate many local and regional paramilitary groups in Colombia, each intending to protect different local economic, social and political interests by fighting insurgents in their areas. AUC itself previously estimated that it had authority over most of the paramilitary forces within Colombia, with the remainder being independent or splinter factions. This organization was conformed by 9 groups initially and then expanded to coca growing areas controlled by the leftist guerrillas afterwards. The illegal drug business became a major source of funding for many, if not all, paramilitary groups; in 2005, Colombia's General Comptroller estimated that around 48 percent of the best lands in the country are controlled by drug trafickers (General Comptroller of the Republic, 2005). For some paramilitary commanders, profiting from illegal drug trafficking was not new as they had been deeply involved in the activity even before they joined or started paramilitary groups (Revista Semana, 2005).

During the mid 2000's, the emphasis on obtaining control over valuable areas grew to the point that there is evidence of paramilitary groups fighting against each other because of the business and some paramilitary groups even forged alliances with leftist guerrillas in some drug trafficking operations (Human Rights Watch, 2005, based on interviews to demobilized parmilitary members). In interviews made by the human rights organization Human Rights Watch to former paramilitary leaders, it was established that paramilitary groups' involvement in the drug business frequently included taxing growers, and includes processing and direct trafficking (ibid). They also declared that they could profit

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from coca crops previously cultivated by areas controlled by guerrillas once that land was "recovered".

FARC's own strategy of locating its armies in the resource-richest areas of the country (gold, emeralds and coca) had started at the end of the eighties, in contrast with their previous objective of occupying the poorest regions of the country (Labrousse, 2005 , p.9). This would allow the group to strongly increase their finances and their presence all over the nation. In 1982, the Secretariat increased the coca area armies contribution to the central authorities which allowed them to make themselves independent from the assistance provided by the Communist countries (Duncan, 2005). In practice, FARC has obtained resources from the coca business in a myriad channels. In rural areas, FARC has collected coca leaf sales and/or production taxes, as well as for the security provided to drug lords' built airports to export cocaine (Labrousse, 2005, p.4). This allowed FARC to become the richest guerrilla in the world (Richani, 1997).

In 2002, AUC leaders expressed their willingness to negotiate a peace treaty with the government, and they had previously presented their political objectives. Thanks to changes in some Colombian laws that prohibited negotiations with paramilitary groups, the government could start negotiations with AUC, that ended up with the Ralito Agreement in 2003, with the main objective of the demobilization of the AUC members. When they finished their demobilization in December 2006, they were present in 223 Colombian municipalities (out of the 1,100), controlled by between 15,000 and 17,000 men (Pardo, 2007). At this point in time, there were around 15,100 people enrolled in left-wing guerrillas (Revolutionary Armed Forces of Colombia, FARC and National Liberation Army, ELN).

There is controversy regarding to what extent paramilitary members actually demobilized and their role in the creation of the so-called criminal bands (BACRIM, bandas criminales). There is evidence that these criminal bands also engaged in drug trafficking (Human Right Watch, 2010).

In summary, during the period of study of this research, all armed groups fight to appropriate resources.

Because the paper focuses on the role that shocks to coca productivity plays on the displacement changes, the next two sections present more information on displacement and on coca cultivation.

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2.2.2 Forced Displacement

Colombia is currently the country with the second largest number of forcefully displaced population (Comision Historica del Conflicto y sus Victimas, 2015, GMH, 2013) in the world. Colombian Law defines a victim of forced displacement as "every person who has been forced to migrate within the Colombian territory, abandoning his place of residence or economic activities because his life, physical integrity, safety or personal freedom have been infringed or they are directly threatened" (Law 1448, 2008). The direct consequence of displacement is an abrupt loss of assets and impoverishment.

Displacement caused with the objective of illegally appropriate land is one of the reasons displacement occurs in the context of the Colombian civil conflict and this research seeks to identify solely the causal effect of shocks to coca productivity that affect the returns to coca suitable land on forced displacement[1].

The land that has been grabbed by the displacement mechanism reaches 4 million hectares, or 33% of all Colombian land (Ibañez and Querubin, 2003, p. 56). The extension of land illegally appropriated through displacement and other land grabbing mechanisms is larger than the amount of land redistributed during the main agrarian reform in 1961 (Kalmanovitz, 2009). Land grabbing mechanisms include coercion to transfer title to non-State armed groups[2]; illegal change of limits of one parcel to "include" the neighbor's parcel into thief's land limits if the neighbor has left the area (has been displaced); sell to a false name (testaferro); land rights adjudication to combatant farmers, in many cases who have been displaced by enemy armies; if farmers could not re-pay land loans, the commander in

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[1] The conflict's armed actors use displacement within the framework of struggles for territorial control of strategic areas (Molano, 2005): 1) to control corridors or those areas used for the trafficking of weapons and/or the transport of illegal products; 2) to destroy the enemy's real or potential social bases. For example, the paramilitary groups use displacement in regions that support a significant presence of social actors and a tradition of organization in the form of unions, farmer's associations, and/or indigenous organizations; 3) depending on the region, displacements take place in areas sought after for export-oriented stockbreeding or one-crop farming exploitation (such as African palm or banana); where mega-projects (an interoceanic canal) are planned; where land has been appraised based upon foreign investment plans (road, port and air projects); where energy and natural resources are extracted (gold, hydroelectric dams in Choco).

[2] In interviews several forced displaced individuals explained that, non-State armed actors came to their farms with the same bone-chilling offer: "Sell us your land, or we'll negotiate with your widow." What followed was a crescendo of terror that locals simply call 'la violencia' (the violence), an odyssey that would eventually leave thousands either dead or landless (Ballve, 2011).

charge of the area made the repayment and grabbed the land; legally purchase land by drug traffickers with or without simultaneous money laundering (Reyes, 2011)[3].

Displaced households enjoyed better living conditions, higher educational attainment, and higher access to informal risk-sharing mechanisms and were, in general, less vulnerable to poverty before the displacement shock than other poor rural households (Ibanez and Moya, 2007). Once in the reception site, displaced households face extreme difficulties in generating income, and overall adult labor income declines an average of 50%, or from an average of $994 per year before displacement to $394 after a year of settlement. As a result, consumption decreases to 64% of the pre-displacement levels, and food expenditures represent almost 65% of total consumption of this population (Ibanez and Moya, 2009, p.653).

A variety of factors can explain inter-group confrontation and forced displacement, and my research seeks to identify the role of shocks to coca productivity, which I focus on next.

2.2.3 Coca Production

The coca bush can grow almost everywhere in the country, in areas from 100 meters of altitude to 2000 meters. The coca tree is harvested around 6 months after it was planted, and after that coca leaves are harvested throughout the year, three to six times per year (Lopez-Rodriguez and Blanco-Libreros, 2008). Coca bushes younger than 18 months produce little or no coca leaf-yield; Bushes from 18 months-7 years produce experience a linear increase in yield each year; a mature coca bush (age >7 years) produce a consistent yield of harvest to harvest and after 11 years the yield begin to decline due to soil impoverishment and disease (Keller and Aitken 1974).

Coca leaf yield depends positively on rainfall: holding constant soil and location characteristics of the coca plot, higher levels of precipitation is associated with higher yields. However, rainfall affects coca plants differently than other legal crops. Rainfall and plagues are positively correlated, and the alkaloid contained in the coca plant helps it fight plagues more efficiently than other legal plants, which have been

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[3] Both guerrilla and paramilitary groups provide a right to use the land to their own supporters, after those peasants against them have left the area under their control. This is called "repopulation" (Reyes, 2009).

adapted to offer desirable characteristics (such as larger sizes). Coca leaf cultivation depends entirely on rainfall as irrigation is nonexistent.

Non-State armed groups procure coca leaves from farmers in their local areas of control. Once farmers are growing coca under contract for these illegal armed groups, they may offer seeds, technical assistance and credit (Cano, 2002). Prices are set by these armed groups as a monopsony in their regions of control and enforce the «contracts» with violence. Coca plantations are found in places of agricultural frontier: the average distance to a local market is 60 kilometers (37 miles) (UNODC, 2005). Coca farmers depend heavily on coca-related income: 82% of coca farmers report coca as their main household income, and their outside options are limited due to the coercive environment where they live and their low educational attainment. Elementary school is the highest educational attainment of 50% coca farmers and their average per capita net income is less than a dollar a day (UNODC, 2005).

2.3 Economic Framework

Increasing coca production raises rents from cocaine trade that accrue to non-State armed groups, and yields more resources for investing in coercive institutions (guns, weapons, among others). These factors generate an expansion of the coercive sector and therefore an increased demand for labor (Acemoglu & Wolitzky, 2011). However, given the coercive nature of the coca trade, an increase in coca production do not translate into better wages due to the fact that non-State armed actors also use their power to limit coca farmers' opportunities for earning a living outside off coca plantation and trade.

To help me formulate hypothesis about the directions of the changes in forced displacement caused by increasing coca productions, I follow Acemoglu and Wolitzky (2011)'s labor coercion model in the presence of moral harzard and limited liability. In this model, the participation constraint of the coca farmer can be expressed as:

$$Wage - Effort \geq u - coercion$$

Where u is the outside option of the farmer, and $u - coercion$ is the effective outside option, which takes into account the reduction in expected utility due to the coercive system (Acemouglu & Wolitzky, 2011, Dippel, Greif and Trefler, 2015). This includes cattle stealing from farms, road blockings and illegal taxation of legal activities.

I use changes in production that are not caused by non-State actors or coca farmers, but are due solely to random weather draws from the climate distribution, to examine forced displacement in coca-suitable areas. In this research, farmers become displaced if they leave their farms rather to stay and accept their coca planting contract if their payoff from cultivating coca plants is larger than their outside option. Their outside option is limited by the coercive system, as non-State armed actors limit farmers' opportunities for earning a living in non-coca opportunities. The increasing production and associated violence that results from the expansion of the coercive institutions therefore reduces the "effective" outside option (which takes into account the reduction in opportunities due to coercion).

As a result, I expect that as coercion levels increase and the effective outside option reduces, less likely for the farmer to leave coca growing areas (more likely to stay in the coca business). Therefore, an increase in coca productivity should be associated with expansion efforts by the coercive non-State armed groups and a decrease in forced displacement.

2.4 Data sources and measurement of key variables

2.4.1 Rainfall

My precipitation measure is a monthly-municipal estimate of mean precipitation. To obtain this estimate, I initially downloaded the publicly available precipitation data set produced by NASA's Tropical Rainfall Measurement Mission (TRMM) platform. The output of this database is precipitation in mm/hr for 0.25x0.25 degree grid boxes on the latitude band 50 ° N-S every 3 hours. I calculated a daily accumulated rainfall product from this 3-hourly product, and then, using standard geographic information system software, matched these daily estimates with the Colombian municipalities. Finally, I computed a

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weighted average daily precipitation for each month-municipality pair, where weights correspond to the proportion of the municipality area that falls inside each NASA grid.

2.4.2 Coca Suitability

The coca suitability variable is a binary indicator of whether coca has been cultivated in the municipality during at least one year during the period 1994, or 1999-2011. The source of this data is satellite-identified coca fields by the United Nations Office on Drugs and Crime (UNODC)[4]. UNODC has supported the monitoring of illicit crops in Colombia since 1999, and has produced annual surveys through a special satellite-based analysis program called SIMCI (from the Spanish initials). Figure 2.1 shows the geographic distribution of coca suitability in the Colombian territory.

2.4.3 Coca Leaf Yield

Coca leaf yield data comes from UNODC's coca farmer survey. The survey collected household and coca production technology information during 2004 to 2010, allowing me to obtain data from 2,535 farmers located in 72 municipalities in Colombia. This data set contains monthly yield information for each farmer, for the year previous to the survey. For each farmer, I have close to 5 observations on average. This generates a sample size of 11,124 observations at the harvest level.

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[4] The 1994 indicator source is the National Police
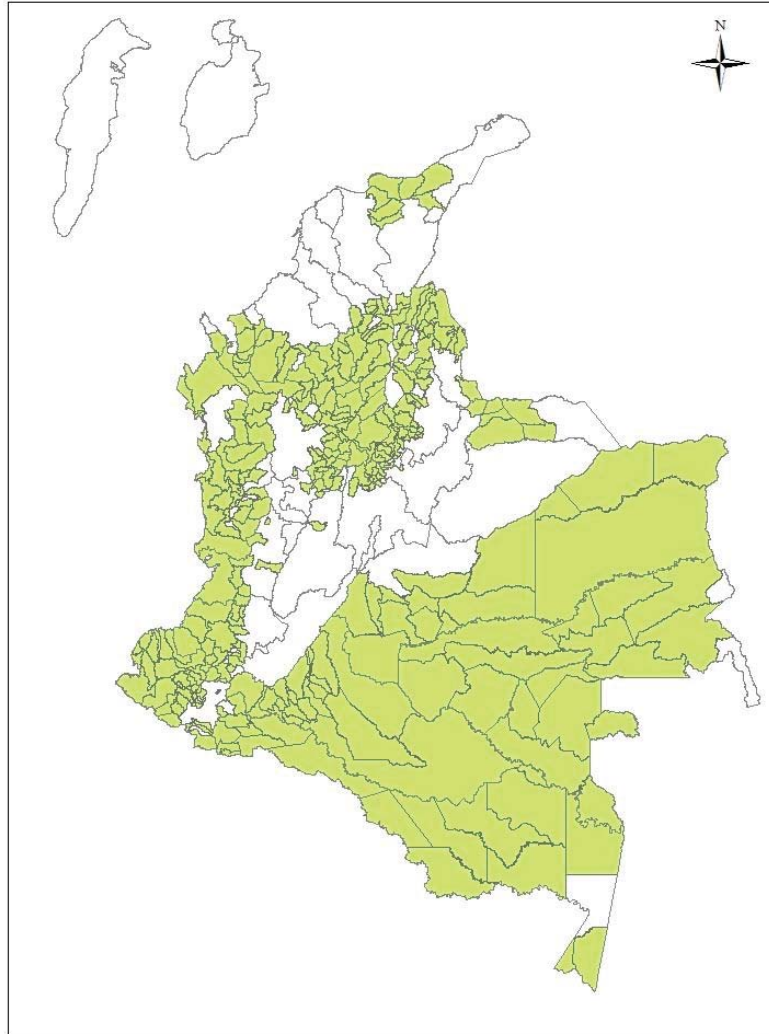
Figure 2.1: Coca Suitability Map

Notes: Municipalities in green correspond to coca-suitable municipalities. Coca suitability is defined as a binary variable that takes on the value of 1 if the municipality has had coca presence as identified by satellite during at least one year since 1999-2011.

Sources: Coca satellite data by UNODC, municipality limits by Agustin Codazzi.

To collect data for the first national survey, the country was divided into 7 regions, each one covering 2 or 3 departmentos (equivalent to US States) where coca had been identified by satellites in 2003. Each region was then divided into 1Km2 grids. Each grid was classified according to geographic characteristics relevant to coca planting, and assigned to pre-determined strata. 12 strata were defined.

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Each grid had a likelihood of being chosen equal to the area planted with coca in the grid divided by the area planted with coca in the strata. Subsequent regions after the national survey in 2005 were chosen according to budgetary reasons.

2.4.4 Labor Market Outcomes

The Colombian Statistics Office (DANE) collects individual labor market information on its "Great Integrated Household Survey". The Great Integrated Household Survey (GEIH) gathers information about employment conditions of individuals (whether they work, what they work in, how much they earn, if they have social security for health care, or if they are looking for a job), as well as about the general characteristics of the population, such as gender, age, marital status, and educational level, sources of income and expenses (what they buy, how often they buy, and where they buy). Currently, the survey specializes in the measurement of the labor market structure and household incomes; it has an annual total sample of approximately 240,000 households, which makes it the largest survey in coverage in the country. This data is rich in both temporal and spatial dimension, as it is collected multiple times a year in each municipality.

The particular questions that I employ in the context of this study are the following: Employment status (employed, self-employed, unemployed), labor income last week, demographic characteristics (gender, age, marital status, and educational attainment).

The main labor market outcomes studied here are two: 1) Labor earnings and 2) Unemployment in coca-suitable areas.

Labor earnings

The measure of labor income in this research is the logarithm of the real wage per hour + 1. To obtain this variable, I took the self-reported weekly nominal labor earnings from DANE's Great

Integrated Household Survey in pesos, deflated all the series to constant Colombian pesos, and divided by weekly hours worked. Finally, I calculated the log of the real wage per hour.

Unemployment

In this research, an unemployed person is someone who is older than 18 years old in DANE's Great Integrated Household Survey, who indicated his/her willingness to work the week of the survey but his/her inability to find a job. Unemployment, then, is an inverse approximation to labor demand in the studied coca areas. Self-reported unemployment is preferred to a self-reported indicator of employment, given that people who perceive rural income may do so in different capacities: as an employee, as a self-employed worker, as a landowner, or contractor.

28% of the labor market observations fall within coca-suitable municipalities, corresponding to 164 municipalities. The rest (71% of observations, from 408 municipalities) correspond to non-coca suitable municipalities.

2.4.5 Forced Displacement

The source of violence data is the Vicepresidencia de la Republica, who has in turn gathered the conflict information originally collected by the National Police, the National Army and the Department of Social Prosperity. The frequency of this data is monthly and is reported per municipality. In order for households to be recognized as displaced by the civil conflict, and obtain access to State aid programs, households must be registered in the State Registry for the Displaced Population (RUPD by its Spanish acronym), an information system whose purpose is to legally identify Internally Displaced Population. To be registered in the RUPD, individuals must declare, under oath, and inform about the dates of displacement, the facts leading to their displacement, and the household's socio-demographic characteristics. Once the declaration is complete, the State evaluates within 15 days whether the declaration is valid or not (Ibanez and Moya, 2009, p.650).

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2.4.6 Sample

My interest lies in studying labor market conditions and violence caused by the cultivation of coca leaf. The dynamics of displacement may be very different in urban areas, where they may be consumers of coca-processed derivatives rather than producers.

Therefore, for all estimations, I restrict the sample to rural municipalities. In practice, I follow Dube, Garcia-Ponce and Thom (2014) and exclude largely urban municipalities, as measured by municipalities with populations of 100,000 or more according to the 2005 Population Census. This reduces the sample from 1,119 to 1,066 municipalities.

2.5 Empirical Strategy

2.5.1 Rainfall and Coca Leaf Yield

I first present evidence that rainfall is a predictor of coca leaf yield, and estimate :

$$\textbf{(1) } Y_{pt} = \delta_p + v_t + \psi Rainfall_{mt} + \varepsilon_{pt}$$

where Y_{pt} is the coca yield obtained from harvesting the coca plants located in plot p at time t. t is the month-year pair when the harvest that produced the yield occurred. I measure monthly yield at plot level dividing the quantity of coca leaves harvested by the harvested area, which are both specific to the harvest observation. Rainfall represents mean rainfall in the municipality where plot j is located at time t. δ_p represents a plot indicator, which controls for time-invariant observable and unobservable characteristics of the plots that could bias the weather coefficients if these characteristics were associated with both, weather conditions and yield. v_t represents a linear time trend, and ε_{pt}, plot-specific monthly shocks. I expect ψ to be positive due to the positive association between rainfall and agricultural yield.

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2.5.2 Labor Market Effects of Weather-Induced Productivity Shocks

I then study the labor market outcomes of positive rainfall shocks, caused by wetter-than-average months in coca suitable municipalities. Coca municipalities are not a random sample of the Colombian universe of municipalities. To overcome the endogenous stratification of municipalities between coca and non-coca areas, I created a variable called "coca-suitability". As explained below, the coca suitability variable is a binary indicator of whether coca has been cultivated in the municipality during at least one year during the period 1994, or 1999-2011. In particular, I estimate the labor income and demand effect of rainfall shocks in coca suitable areas as follows:

$$(2) \ Y_{ijmy} = \delta_j + v_{my} + \beta t_s + \psi Rainfall_{jmy} + X_{ijmy}'\alpha + \varepsilon_{ijmt}$$

where i indexes individuals, j indexes municipalities, m indexes months and y indexes year. In equation 2, Y_{ijmy} represents both the logarithm of real labor earnings per hour (plus one) and probability of unemployment of individual i located in municipality j during month m of year y. X_{ijmy} is a vector of observed measures of productivity and outside options. These measures include gender, educational attainment, age, age squared, married status and urban/rural location.

v_{my} are month*year fixed effects during the period January 2004-June 2010. These time effects further isolate the effect of the weather variation from any common trends in the Colombian municipalities and therefore help ensure that the relationship I am estimating is identified from idisyncratic local shocks. Complementary, spatially-specific trends are taken into account by including a department-specific linear time trend (βt_s).

2.5.3 Forced Displacement Effects of Weather-Induced Productivity Shocks

To infer the effect that productivity changes in coca-suitable areas have on forced displacement, I rely on time-series variation of rainfall and displacement for identification in a municipal panel data context. In this research design, inference is then based on how a municipality responds to different

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climatic conditions (in this case, rainfall), which vary over time. Here the assumptions necessary for causal inference are more likely to be met than in cross-sectional approaches, since the structure, history and geography of comparison populations (that is, populations within the same municipality) are nearly identical (Burke, Hsiang and Miguel, 2015).

To identifiy the effect of rainfall in displacement originated in coca-suitable areas, I interact the coca-suitability indicator with the municipal-monthly rainfall measure, and initially test the hypothesis that rainfall has a differential effect on forced displacement in coca suitable areas compared to non-coca suitable areas. To this end, I estimate Equation 3:

$$\textbf{(3)}\ D_{jmy} = \delta_m + v_{my} + \beta t_s + \psi Rainfall_{jmy} + \alpha Rainfall_{jmy} * Coca_m + \varepsilon_{jmy}$$

where D_{jmy} represents forced displacement in municipality j during month m in year y. t is defined in month*year units, $Rainfall$ is the mean rainfall in municipality j during month m in year y. $Coca$ is a binary indicator of coca suitability, which is a binary indicator of whether coca has been cultivated in the municipality during at least one year during the period 1999-2011. This measure is preferred to a coca variable observed in municipality j in year y because coca cultivation may be the response to agricultural migration flows explained by forced displacement. δ_m are municipality fixed-effects that absorb time-invariant characteristics, whether observed or unobserved, disentangling the precipitation shock from other sources of omitted variable bias. If different municipalities exhibit different average levels of conflict because of any number of cultural, historical, political, economic, gepgraphic or institutional differences between these municipalities, this will be accounted for by municipality-specific fixed-effect δ_m (Buerke, Hsiang and Miguel, 2015)[5].

v_{my} are month*year fixed effects during the period January 2004-June 2010. These time effects further isolate the interaction of the weather shock with the coca suitability variable from any common trends in the Colombian municipalities and therefore help ensure that the relationship I am estimating is

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[5] Temperature is not included in the analysis because over time variations are very small holding constant location

identifying from idiosyncratic local shocks. Complementary, the estimating equation also captures spatially-specific trends by including a department-specific linear time trend (βt_s).

The effect of rainfall on forced displacement in coca areas is $\psi + \alpha^6$.

Equation 3 is explicitly reduced form, and it focuses on the effect of the variation in precipitation in coca versus non-coca suitability on forced displacement. Given that precipitation varies plausibly randomly over time, as random draws from the municipality climate distribution, this approach has strong identification properties (Dell, Jones and Olken, 2014).

2.6. Summary Statistics

2.6.1 Forced Displacement

The objective of this research is to identify the role of increasing coca leaf productivity on forceful displacement and local labor markets. Therefore, one of the main outcome variables of this research is forcefully displaced population, as measured by the number of people registered in Colombian government agencies as Internally Displaced. The frequency of this data is monthly and is reported per municipality. During the period of study, which covers January, 2004 to June, 2010, forced displacement reached very high numbers: 86.48 people per 100,000 inhabitants became internally displaced in Colombia per month (see Table 2.2, and Figure 2.2).

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[6] Note that it is not possible to estimate a coefficient for the coca suitability indicator as the estimating equation includes a municipality fixed-effect variable; therefore, the two coefficients would be collinear since neither varies in time.
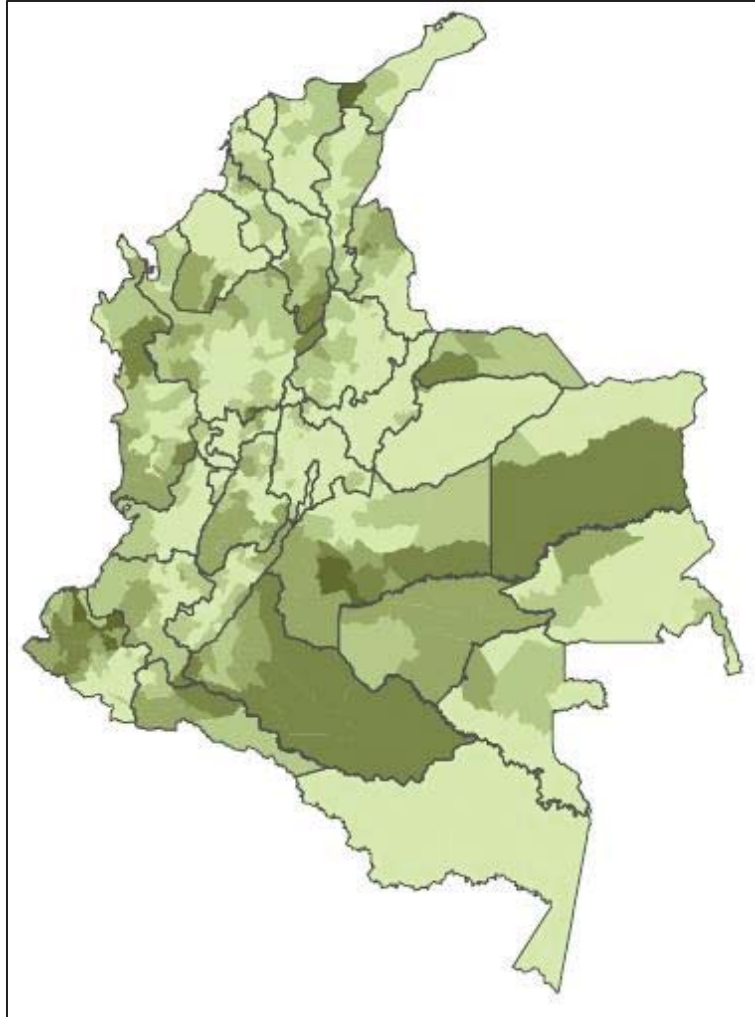
Figure 2.2: Forced Displacement Map (2004-2010)

Notes: Darker municipalities exhibit greater intensity of forced displacement per 10,000 people in the municipality.

Sources: Violence data by Observatorio de Violencia, Vicepresidencia de la Republica de Colombia, municipality limits by Agustin Codazzi.

Table 2.1: Descriptive Statistics

	Mean	sd	Obs.
Forced displacement[2]			
Displacement per 100,000 people in municipality	86.484	366.573	82,644
Source: Vicepresidencia de la Republica			
based on several gov agencies			
Labor Market Outcomes[4]			
Log(wages)	7.219	1.998	69,468
Unemployment	0.060	0.238	152,986
Source: DANE			
Rainfall[2]			
Rain (mm/mean daily average)	4.065	3.073	114,138
Source: NASA			
Coca suitability			
Coca suitability index	0.27	0.44	1,119
Source: Simci, UNODC			
Coca productivity[3]			
Yield (arrobas per hectare)	92.269	38.225	11,124
Quantity harvested (arrobas)	120.240	124.236	11,124
Harvested area (hectares)	1.261	1.094	12,971
Number of harvests/year	4.851	1.670	11,124
Source: UNODC			

Notes:
1. This table presents summary statistics for the main variables used in this paper.
2. Observations are at the municipality-month-year level, during the period January 2004-June 2010.
3. Observations are at the harvest level, during the period 2004-2010.
4. Observations are at the individual level, and include adults (older than 18 years old) in the labor market who are either employed, self-employed or unemployed.

2.6.2 Labor Market Outcomes

6% of the adult population (older than 18 years old) in my sample report being unemployed. This means that the remaining 94% of the working force was either employed or self-employed. The mean of (log) wages is 7.21, which roughly corresponds to 4 dollars per hour.

2.6.3 Rainfall

The mean precipitation in the municipalities I am studying is near 4 mm/day, or close to 120 mm per month. There is great variation in regional rainfall; while some municipalities witnessed no rain during certain periods of time, precipitation was reported as high at 27 mm a day in other locations.

Geographic conditions and ocean-atmosphere-topography interactions generate extreme precipitation amounts over the Pacific coast of Colombia, including one of the rainiest regions on Earth - averaging 10,000–13,000 mm per year- (Poveda and Mesa, 2000).

There are regional variations in the precipitation cycles in the country. Central and western Colombia experience a bimodal annual cycle of precipitation with marked high-rain seasons (April–May and September– November), and low-rain seasons (December–February and June–August), while rainfall exhibits a uni-modal annual cycle (May– October) at the northern Caribbean coast of Colombia and at the Pacific flank of the southern isthmus. Another single annual peak (June–August) occurs at the eastern slope of the eastern Andes, resulting from the encounter of the moisture-laden trade winds from the Amazon with the Andes. The El Niño/Southern Oscillation (ENSO) is the main forcing mechanism of interannual climate variability from hours to seasons to decades. In general, the warm phase of ENSO (El Niño) begins during the boreal spring, exhibiting a strong phase locking with the annual cycle, and encompassing two calendar years characterized by increasing sea surface temperature anomalies during the boreal spring and fall of the onset year, peaking in winter of the following year. Anomalies then decline in spring and summer of the ensuing year. The annual cycle of average maximum daily flows indicates that ENSO effects are larger and felt earlier over the western Andes, whereas effects are smaller and felt later over the eastern Andes (Alvarez, Poveda and Rueda, 2011).

2.6.4 Coca Leaf Yield

Coca farmers harvest the coca leaf 4.85 times each year on average. Farmers report when (which month) they harvested coca leaf plants and how much the harvest was. The mean quantity harvested is 120 "arrobas", or 3,000 pounds[7]. I then calculated the monthly yield per plot dividing the quantity harvested by the harvested area. Averaging over all plots, the mean monthly yield in my sample is 92.26 arrobas/ha or 2,400 pounds per hectare.

2.7. Results

2.7.1 Rainfall and Coca Leaf Yield

Table 2.2 presents the estimated coefficients of Equation 1. Column (1) shows the estimated ψ if no time trend nor plot indicators are added. Each additional millimeter of rain is associated with an increase in coca yield of 0.44, and this coefficient is significant at all standard confidence levels.

This result suggests that there is a positive and significant relation between rainfall levels in the municipality and the observed coca yield. If a plot indicator is included in the estimations -column (2)-, the effect of rainfall on coca yield decreases to 0.337 but the coefficient is still significant (albeit at the 10% level). Column (3) shows the results of the OLS regression of yield on rainfall, including both a linear time trend (that controls for common shocks to all municipalities at time t) and a plot indicator. The coefficient is now 0.402. The plot time-invariant effect, the linear time trend and rainfall explain 17% of the variation in yield change.

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[7] 1 arroba is equivalent to 25 pounds

Table 2.2: Effect of Rainfall on Coca Leaf Yield (Plot Data)

	(1)	(2)	(3)
	Dep. variable: Coca yield, t (2004-2010)		
Rain, t	0.440	0.337	0.402
	(0.138)***	(0.148)*	(0.117)***
Time trend	No	No	Yes
Plot indicator	No	Yes	Yes
R-squared	0.036	0.036	0.172
N	11,624	11,624	11,624

Notes: Clustered standard errors at municipal level are in parentheses. Sample includes only coca municipalities. Each observation is at the plot-municipality-month-year level. *** is significant at the 1% level, ** is significant at the 5% level, * is significant at the 10% level.

2.7.2 Labor Market Effects of Weather-Induced Productivity Changes in Coca Areas

Results of the estimation of Equation 2 are showed in Table 2.4, which was estimated for the sample of individuals whose place of residence was a coca suitable municipality (164 municipalities, see Table 2.3).

Table 2.3: Match Between Labor Market Survey and Climate-Conflict Database

	N	%
Coca municipalities	164	28.67
Non-coca municipalities	408	71.33

Notes: Coca is a time-invariant variable defined as an indicator (1 or 0) of coca presence during the period 1999-2010. If a municipality shows a least one positive value of coca presence in the municipality during the period 1999-2010, this variable takes a value of 1, and 0 otherwise.

Controlling for economic determinants of labor earnings, time-invariant municipality characteristics and time indicators, the estimated coefficient of the effect of the productivity shock generated by favorable precipitation is zero for labor earnings (Column 1). However, labor demand increases as a result of excess rainfall in coca suitable municipalities, as measured by the coefficient of rainfall in the unemployment equation (Column 2). The probability of unemployment decreases by 0.0013 percentage points as a result of an additional millimeter of rain in municipalities suitable for coca leaf cultivation, net of the effect of other (un)employment characteristics such as gender, educational

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attainment, age, age squared and married status. The standard error of the estimator is 0.00078 and the p-value of the hypothesis that the coefficient is zero is 0.107.

Table 2.4: Labor Earnings Effect of Rainfall Shocks in Coca Areas

Dependent variable	(1) Log real labor earnings per hour	(2) Unemployment
Rain	0.00989	-0.00130
	(0.0100)	(0.000799)
Municipality fixed effects	Yes	Yes
Month*Year fixed effects	Yes	Yes
State time trends	Yes	Yes
Socio-demographic controls	Yes	Yes
R-squared	0.107	0.025
Observations	69,468	152,986
Number of municipalities	164	164

Notes: Each observation represents a municipality-year-month. Variables not shown include municipality fixed effects, month*year fixed effects and linear time trends per State. Socio-demographic controls include gender, educational attainment, age, age squared, married status and urban/rural location. Sample includes only Coca municipalities. Coca is a time-invariant variable defined as an indicator (1 or 0) of coca presence during the period 1999-2010. If a municipality shows a least one positive value of coca presence in the municipality during the period 1999-2010, this variable takes a value of 1, and 0 otherwise. Rainfall is measured in mm. Clustered standard errors at municipal level are in parentheses. *** is significant at the 1% level, ** is significant at the 5% level, * is significant at the 10% level.

2.7.3 Forced Displacement Effects of Weather-Induced Productivity Changes in Coca Areas

Table 2.5 Column (1) presents the estimated coefficient of the effect of the productivity shock generated by favorable precipitation. The effect of excess rainfall on forced displacement in coca-suitable municipalities is $\psi + \alpha$ (2.517 - 3.526), -1.009, holding constant municipality and month*year fixed effects, as well as State linear trends. This result, shown in column (1), suggests that each additional millimeter of rainfall in excess of the municipality precipitation mean causes a decrease of an average of 1 person forcefully displaced per 100,000 people in the municipality.

Table 2.5: Effect of Rainfall on Forced Displacement in Coca vs. Non-Coca Municipalities (Least

Squares Estimation)

	(1)	(2)
	Displacement Rate per 100,000 people	
Dependent variable		
Rain	2.517**	2.839**
	(1.050)	(1.183)
Rain*Coca	-3.526**	-3.863**
	(1.650)	(1.778)
F-test State time trends (p-value)	11.60	9.13
	(0.000)	(0.000)
F-test Rainfall terms (p-value)	2.92	2.95
	(0.05)	(0.05)
F-test Guerrilla*year terms (p-value)		4.62
		(0.00)
Municipality fixed effects	Yes	Yes
Month*Year fixed effects	Yes	Yes
State time trends	Yes	Yes
Observations	86,814	76,674
R-squared	0.016	0.017
Number of municipalities	1,113	983

Notes: Each observation represents a municipality-year-month. Standard errors clustered at the municipal level are shown in parentheses. Variables not shown include municipality fixed effects, month*year fixed effects and linear time trends per State. Guerrilla presence is a time-invariant variable defined as an indicator (1 or 0) of guerrilla activity in the municipality in 1996. Coca is a time-invariant variable defined as an indicator (1 or 0) of coca presence during the period 1999-2010. If a municipality shows a least one positive value of coca presence in the municipality during the period 1999-2010, this variable takes a value of 1, and 0 otherwise. The dependent variable is defined as displaced population in the municipality per 100,000 people. Rainfall is measured in mm. *** is significant at the 1% level, ** is significant at the 5% level, * is significant at the 10% level.

Next, I test whether local idiosyncratic shocks to coca productivity have an independent effect on

displacement controlling for conditions that are favorable for the insurgency. Equation 4 further controls

for insurgency-favorable conditions as measured by an indicator of guerrilla presence in municipality j in

the year 1996[8].

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[8] This variable is a binary indicator (0 or 1) of any insurgency action in the municipality in the year 1996, which is the earliest available year in the Universidad del Rosario dataset. On average, there are close to 30% of the

$$\textbf{(4) } D_{jmy} = \delta_m + v_{my} + \beta t_s + \psi Rainfall_{jmy} + \alpha Rainfall_{jmy}*Coca_m + \lambda_y G_j + \varepsilon_{mt}$$

In Equation 4, G_j represents the binary indicator of guerrilla presence in municipality j as measured by whether there was at least one guerrilla attack or confrontation with government forces during the year 1996 in that municipality. λ_y is the coefficient of the interaction of the guerrilla presence indicator in municipality j interacted with the year variable.

Column (2) explores if shocks to coca productivity have an independent effect on displacement controlling for conditions favorable to insurgent presence. The effect of rainfall on force displacement in coca municipalities is -1.02 (2.839-3.863).

Because of the count nature of the outcome, in Equation 5 I adopt an exponential model (Cameron and Trivedi, 2005, pp. 802-808) and further estimate separately for coca and non-coca suitable areas:

$$\textbf{(5) } D_{jmy} = \delta_m exp(v_{my} + \beta t_s + \psi Rainfall_{jmy} + \varepsilon_{jmt})$$

Table 2.6 presents estimated coefficients for Equation 5. Columns (1) and (2) present the negative binomial estimates of the effect of a positive rainfall shock on displacement in coca and non coca areas respectively. Consistent with the evidence above, positive productivity shocks measured by rainfall above the average municipality precipitation decrease forced displacement in coca areas but not so in non-coca areas. The estimated ψ is -1.22%, which suggests that an additional millimeter of precipitation above the municipality mean decreases forced displacement by 1.22% in coca-suitable areas. This coefficient is statistically significant at all levels and economically important, given the high incidence of displacement. The coefficient is very similar and statistically significant when the population control is added[9]. By contrast, in non-coca areas the effect of positive rainfall shocks is approximately ten times smaller and

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municipality-month observations in my dataset that witness presence of guerrilla actions (clashes or attacks) in 1996.

[9] This population measure is a prediction made by DANE, the Statistical office of Colombia in 2005 based on initial population census, so it is not affected by current displacement figures.

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insignificant. Columns (3) and (4) report the results of the negative binomial model for these areas and the

coefficients are -0.138% and -0.07% without and with the population control, respectively.

Table 2.6: Effect of Rainfall on Forced Displacement in Coca and Non-Coca Areas (Negative

Binomial Estimation)

	(1)	(2)	(3)	(4)
Dependent variable	Percentage change in Displacement			
	Coca areas		Non-coca areas	
Rain	-1.22***	-1.18***	-0.137	0.07
	(0.223)	(0.215)	(0.307)	(0.299)
Chi-square test State time trends (p-value)	1542.25	1481.97	5012.32	4720.93
	(0.000)	(0.000)	(0.000)	(0.000)
Chi-square test month*year terms (p-value)	3988.76	4172.55	4558.27	4846.00
	(0.000)	(0.000)	(0.000)	(0.000)
Controls for Population	No	Yes	No	Yes
Municipality fixed effects	Yes	Yes	Yes	Yes
Month*Year fixed effects	Yes	Yes	Yes	Yes
State time trends	Yes	Yes	Yes	Yes
Observations	23,088	23,088	57,642	57,642
Number of municipalities	296	296	739	739

Notes: Each observation represents a municipality-year-month. Variables not shown include municipality fixed effects, month*year fixed effects and linear time trends per State. Coca is a time-invariant variable defined as an indicator (1 or 0) of coca presence during the period 1999-2010. If a municipality shows a least one positive value of coca presence in the municipality during the period 1999-2010, this variable takes a value of 1, and 0 otherwise. The dependent variable is defined as displaced population in the municipality. Rainfall is measured in mm. *** is significant at the 1% level, ** is significant at the 5% level, * is significant at the 10% level.

2.8 Instrumental Variables Estimates

A second way to test for coercion in coca suitable labor markets is to test whether high

productivity months witness lower forced displacement. In therefore match coca leaf yield data with local

violence and employ an Instrumental Variables estimation where changes in forced displacement are

explained by coca leaf yield variations, and I instrument changes in coca leaf yield with rainfall.

Since the seminal work of Miguel, Satyanath and Sergenti (2004) on the impact of unforseeable

weather conditions on economic growth and the outbreak of civil conflict and war in Africa, there has

been an ongoing debate among economists about the use of precipitation as an instrument for economic

variables in studies where the main outcome is conflict. Miguel, Satyanath and Sergenti (2004)'s study measures the effect of changes in income growth on changes in the likelihood of civil conflict, using macroeconomic data from Africa. Since civil conflict may affect economic growth, they isolate the effect of income that comes from variations in rainfall. Miguel and colleagues estimates imply that a five-percentage-point negative growth shock increases the likelihood of a civil war the following year by nearly one-half, at least in African countries.

More recently, other researchers have used rainfall to establish causality when looking at a host of political and economic outcomes. Bruckner and Ciccone (2011), test the theory of political transitions, finding that negative rainfall shocks are followed by significant improvement in democratic institutions. Their instrumental variables estimates indicate that following a transitory negative income shock of 1 percent, democracy scores improve by 0.9 percentage points and the probability of a democratic transition increases by 1.3 percentage points.

Mehlum, Miguel, and Torvik (2006) estimate the impact of poverty on crime in 19th century Bavaria, Germany. Rainfall is used as an instrumental variable for rye prices to address econometric identification problems in the existing literature. The rye price was a major determinant of living standards during this period. The rye price has a positive effect on property crime: a one standard deviation increased property crime by 8%. Higher rye prices lead to significantly less violent crime and the authors claim that higher beer prices, caused by the higher rye prices, are a likely explanation.

Bohlken and Sergenti (2010) focus on the relationship between economic conditions and riots. Specifically, these authors examine the effect of economic growth on the outbreak of Hindu–Muslim riots in 15 Indian states between 1982 and 1995. Similar to Miguel et al (2004), the authors employ instrumental variables (IV) estimation, using percentage change in rainfall as an instrument for growth. The results with IV estimation confirm that an increase in the economic growth rate decreases the expected number of riots and that this effect is significant.

Since rainfall can affect many social phenomena simultaneously (see Dell, Jones and Olken, 2014, for a review), I restrict my sample to a small set of municipalities that are highly dependent on coca

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plantation and transformation into cocaine, and follow cocaleros (coca farmers) during every month for one year from these municipalities, matching their yields to local monthly violence.

I start by expressing displacement in the municipality as a function of municipal and coca farmers' characteristics:

$$(6) \ D_{mt} = \beta_m + \beta_t + \gamma A_{mt} + X_{mt}'\alpha + \mu_{mt}$$

In equation 6, D_{it} represents displacement in municipality m at time t. A_{mt} represents the mean farmer's productivity and X are variables that could affect the farmer's outside option, such as gender, age, migratory status and land ownership. I also include municipality fixed effects (β_m) to capture time invariant geographic characteristics that affect, on the one hand, how costly it is for a group to coerce farmers in municipality m -farmers located in isolation may be easier to coerce- but also may be related to the farmer's outside option, such as closeness to markets. The model includes year dummies to capture common shocks to all farmers, and in particular, the market price of coca leaf or its derivatives as well as the world demand of these products. The term μ_{mt} represents municipality-specific transitory shocks, and are allowed to be correlated across time in all regressions.

The observed effort variable is yield (crop volume sold per unit of land, and I assume that all crop produced is sold). However, yield and productivity are not equivalent since productivity also depends on the use of inputs such as labor and fertilizer. If yield stands for productivity in the next equation:

$$(7) \ D_{mt} = \beta_m + \beta_t + \gamma Y_{mt} + X_{mt}'\alpha + \varepsilon_{mt}$$

and I estimate the above equation by OLS, I will not be able to identify the effect of productivity on the use of violence. Therefore, I use an instrumental variables approach and instrument for yield with rainfall.

The first stage equation relating rainfall and coca leaf yield is:

$$(8) \ Y_{mt} = \delta_m + v_t + \psi Rainfall_{mt} + X_{mt}'\alpha + \varepsilon_{mt}$$

In the equation above, Rainfall is the mean rainfall in municipality m at time t. Rainfall serves as instrument of the endogenous regressor Y_{mt}.

The instrumental variables approach requires the following two assumptions (Angrist, 2009). First, rainfall must be correlated with coca yield. Second, rainfall must be correlated with any other determinants of the violence outcomes of interest. In other words, $corr(\mu, rainfall) = 0$. This condition is called the exclusion restriction, and it words it requires that rainfall affects violence only through its effect on coca leaf yield in coca growing areas, conditional on the municipality fixed effects. In this context, the exclusion restriction is likely to hold given the high dependence of coca production on the particular sample I draw my conclusions from (described below), which suggests that the effect of rainfall on violence is explained solely by changes in coca leaf yield: The coca areas sampled for these surveys rely heavily on coca as currency; physical infrastructure is very poor which impedes that farmers can effectively sell other agricultural goods in the market and therefore their sources of income other than coca are very limited[10].

Given that rainfall is a strong predictor of coca leaf plant (table 2), I proceed to estimate the effect that changes in coca leaf yield due to weather have on forced displacement.

The modified second stage equation that takes into account that plot indicators are included is:

$$\textbf{(9) } D_{mt} = \delta_p + \beta_t + \gamma Y_{pt} + \varepsilon_{mt}$$

where D_{mt} stands for forced displacement in municipality m at time t. Here t is measured in months as before. Y_{pt} is the coca yield obtained from harvesting the coca plants located in plot p at time t. Plot location allows me to match plot information (on productivity) with municipal rainfall and violence data.

δ_p represents a plot indicator as before, β_t represents a linear time trend, and ε_{mt}, municipality-specific monthly shocks. I expect γ to be negative because the coerced sector yields higher returns with better rainfall, and therefore coercion efforts should increase in higher productivity months compared to

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[10] Abadie et al (2015) show that aerial spraying of coca fields and violence are associated; aerial spraying is also negatively correlated with rainfall. Therefore, more rainfall could cause an increase in productivity in partly due to less spraying. Here, I am not separating whether the increase in productivity is due to less spraying but measuring the total impact of increasing yields due to better rainfall.

lower productivity months and less coca farmers should be able to leave the coca contract in higher rainfall months than in lower rainfall periods.

Even though the equations can be expressed in two stages, estimations have been performed using a standard 2SLS estimator and clustering the standard errors at the municipal level.

In fact, results of the econometric estimation present evidence in the direction that when coca productivity is unexpectedly better due to positive rainfall shocks, displacement figures decrease. Table 2.7 presents the estimated γ. Column (3), which controls for a linear time trend and a plot indicator, suggests that one additional arroba of coca leaf per hectare harvested per month is associated with a reduction of forced displacement of 4.77 people on average, and this estimate is significant at all statistical levels. This estimate is economically meaningful, as the displacement mean in coca suitable areas is 35.85 people.

Table 2.7: Effect of Coca Yield on Forced Displacement (Structural Equation)

	(1)	(2)	(3)
	Dep. variable: Forced displacement (2004-2010)		
Yield	-2.136	-6.089	-4.776
	(0.376)***	(1.509)***	(1.165)***
Instrument	Rain	Rain	Rain
Linear time trend	No	No	Yes
Plot indicator	No	Yes	Yes
R-squared	0.0012	0.0012	0.0025
N	11,088	11,088	11,088

Notes: Sample includes only coca municipalities. Each observation is at the plot-municipality-month-year level. Clustered standard errors at municipal level are in parentheses. *** is significant at the 1% level, ** is significant at the 5% level, * is significant at the 10% level.

2.9 Confrontations and Mayor Killings in Coca Areas

In the previous section, I showed evidence that high productivity months relative to months of lower coca production, witness lower forced displacement in coca growing municipalities. According to the conceptual framework outlined in section 2.3, an increase in coca productivity should be associated

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with a decrease in forced displacement and also with expansion efforts by coercive non-State armed groups.

Ideally, I would test an increase in coercion as a result of coca productivity in the IV framework presented below. In absence of coercion data, I rely on coercion expansion efforts by coca-profiting non-State armed groups, measured by two variables: confrontations between these groups and government forces and mayor killings of coca growing municipalities.

I estimate then the effect of coca leaf yield instrumented with rainfall on the two measures of coercion efforts, as in the following equation (which reproduces the second stage estimated below):

$$\text{(10) } \text{Coercion}_{mt} = \delta_p + \beta_t + \gamma Y_{pt} + \varepsilon_{mt}$$

Where Coercion_{mt} stands for either confrontations between non-State armed groups and government forces or killings of coca growing mayors by these groups. As predicted by labor coercion models, increasing coca leaf production generated by good rainfall is associated with an expansion of the coercive sector, and in this case, of confrontations of coca-profiting non-State actors with government armed forces for higher-yielding growing areas. The estimated rise in confrontations is presented in Table 2.8. In Column (3), which presents my preferred specification that includes a linear trend and a plot fixed effect, the coefficient of clashes suggests that means that each additional unit of yield measured in arrobas per hectare of coca leaf is associated with an increase in confrontations of 0.067 on average, controlling for time-invariant characteristics of the coca plots. This estimate is statistically significant at the 1 percent level and is large in magnitude since the mean of clashes is 0.058.

Consistent with the former result, mayors of coca-growing municipalities face a higher risk of being killed by coca-profiting groups: Table 2.9 presents the estimated coefficient of Equation 11 for mayor assassinations due to changes in coca yield, holding constant municipality-specific characteristics that could affect coca productivity and violence. According to Column (3), an additional unit of coca leaf yield due to excess rainfall creates an average rise in the number of coca municipality mayors of 0.001, controlling for a plot fixed effect and a linear time trend. The coefficient is significant at the 5 percent level.

Table 2.8: Effect of Coca Yield on Confrontations (Structural Equation)

	(1)	(2)	(3)
	Dep. variable: Clashes (2004-2010)		
Yield	0.004	0.086	0.067
	(.001)***	(0.018)***	(0.013)***
Instrument	Rain	Rain	Rain
Linear time trend	No	No	Yes
Plot indicator	No	Yes	Yes
R-squared	0.0003	0.0003	0.0011
N	11,088	11,088	11,088

Notes: Sample includes only coca municipalities. Each observation is at the plot-municipality-month-year level. Clustered standard errors at municipal level are in parentheses. *** is significant at the 1% level, ** is significant at the 5% level, * is significant at the 10% level.

Table 2.9: Effect of Coca Yield on Mayor Casualties (Structural Equation)

	(1)	(2)	(3)
	Dep. variable: mayor casualties (2004-2010)		
Yield	0.000	0.001	0.001
	(0.000)**	(0.000)*	(0.000)**
Instrument	Rain	Rain	Rain
Linear time trend	No	No	Yes
Plot indicator	No	Yes	Yes
R-squared	0.0002	0.0002	0.0002
N	11,088	11,088	11,088

Notes: Sample includes only coca municipalities. Each observation is at the plot-municipality-month-year level. Clustered standard errors at municipal level are in parentheses. *** is significant at the 1% level, ** is significant at the 5% level, * is significant at the 10% level.

2.10 Negative Productivity Shocks and Displacement

Another way to test for the relationship between productivity and forced displacement is to look at the effect of a negative productivity shock. According to the economic framework outlined above, I would expect forced displacement to be inversely related to productivity. The reason would be that falling productivity makes a coca growing region less attractive since returns to coercive institutions would decrease as the resources available to expand these institutions. A decrease in coercion would then open the doors for farmers to earning a living off coca plantations, and/or free up non-coca cultivation

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opportunities for farmers. In other words, the fall in coercion would increase the farmer's effective outside option and make it less likely for the participation constraint to hold. This would imply then that more farmers would find it attractive to leave coca growing municipalities in periods of low production rather than in periods of high production.

Empirically, however, testing for this inverse relationship is complicated because in the agricultural sector even extreme amounts of rainfall are not necessarily bad for agriculture (Kaur, 2014). Therefore, I rely on the farmer survey collected by UNODC, which directly asks farmers whether they experienced a negative weather shock that partially or completely destroyed their coca plants. To test whether an inverse relationship holds between weather shocks and displacement using the farmer survey data, I estimate:

$$\textbf{(11) } \text{Displacement}_{my} = \delta_m + v_y + \tau NegativeWeatherShock_{imt} + X'\beta + \varepsilon_{my}$$

where Displacement_{mt} is the number of forcefully displaced population that left municipality m during year of survey y. X is a vector that represents farmer characteristics that affect migration decisions, such as whether farmer is an owner, gender, and previous migratory status. Negative weather shock is a self-reported variable that takes on a value of 1 if farmer reported a negative weather shock that affected the coca leaf yield in survey year y. Consistent with the results presented above and since the weather shock is negative, the estimated τ is positive. In column 1 of Table 2.10, the average difference in displacement in municipalities that experienced a negative weather shock is 331.28 people, controlling for municipality and year of survey effects. The coefficient is significant at the 10 percent level. In column 2, I present results that control for other determinants of migration decisions and correlates to coca productivity, such as land ownership, land area, migrant status, gender and age of coca farmer, and coca leaf specie. The estimated coefficient of the negative weather shock is 316.10, and significant at the 5 percent level.

Table 2.10: Effect of Negative Weather Shock on Forced Displacement, Household Data (OLS)

	(1)	(2)
	Dep. variable: Displaced population	
Self-reported negative weather shock	331.283	316.10
	(194.11)*	(157.77)**
Owner		26.29
		(60.05)
Land area		1.24
		(0.914)
Migrant		114.58
		(97.42)
Male		-0.89
		(22.91)
Age		-0.88
		(1.46)
Coca leaf specie	No	Yes
Municipality fixed effects	Yes	Yes
Year fixed effects	Yes	Yes
R-squared	0.83	0.84
Number of municipalities	57	57
N	1,763	1,763

Notes: Regressors not shown include municipality and year indicators. Each observation is at farmer level. Clustered standard errors at municipal level are in parentheses. *** is significant at the 1% level, ** is significant at the 5% level, * is significant at the 10% level.

2.11 Conclusions

The main goal of this paper is to estimate the effect of productivity shocks on local forced displacement. The context of this study is the Colombian coca farming activity, which is strongly controlled by armed illegal groups that benefit financially from this activity.

I employed an instrumental variables approach together with fixed effects estimators to calculate the effect of exogenous variation in productivity on the dynamics of the conflict. First, the results of the econometric analysis support the hypothesis that positive productivity shocks, generated by larger precipitation than municipality averages, are associated with lower figures of forced displacement in coca suitable municipalities than non-coca municipalities. Shocks to coca productivity have an independent effect on displacement controlling for conditions favorable to insurgent presence.

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To understand the mechanisms behind these results, I turn to a sample of coca municipalities. First, I confirm that better rainfall that increases coca leaf production causes a rise in the demand for labor in coca growing municipalities in the wetter-than-average months. I also confirm that given the coercive nature of the coca trade, an increase in coca production does not change wages.

Instrumenting coca leaf yield with rainfall in coca-growing municipalities, my estimates present evidence in favor of the idea that increased coca production due to positive rainfall generate an expansion effort of the coercive sector measured by an increase in confrontations between coca-profiting groups and mayor killings in these areas. As predicted by a labor coercion economic framework, an increase in coca productivity is associated with a decrease in forced displacement. Finally, relying on farmer self-reported information on negative weather shocks that affect coca plants, my results suggest that when coca output is low, forced displacement increases in coca municipalities. This is in turn consistent with the explanation that in low production states, there is less interest in expanding the coercive (coca) sector by the non-State armed groups, and the effective outside option for the farmer is less restricted. Therefore, displacement is more likely to occur as the participation constraint of the farmer is more difficult to hold in low production periods.

The estimates of the effect of coca yield on coercion efforts and forced displacement are large in magnitude and statistically significant, suggesting that the effect of weather shocks on labor markets is mediated by the quality of the institutions where these markets are embedded.

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Chapter 3: Inside the War on Drugs: Effectiveness and Unintended Consequences of a Large Illicit Crops Eradication Program in Colombia

(Joint with Alberto Abadie, Maurice Kugler and Juan Vargas)

3.1 Introduction

In this article we conduct an econometric evaluation of Plan Colombia (PC): the largest aid package ever received by a country in the western hemisphere. PC was launched in 1999 as a $7.5 billion policy-package co-financed by the American and the Colombian governments, with the stated goal of reducing by 50 percent the cultivation, processing, and distribution of illegal narcotics over a period of six years, starting in 2000. Indeed, with PC the US effectively took the War on Drugs to the country producing 90 percent of the cocaine that reached its border (GAO, 2008a). As a byproduct, by cutting their main source of finance, another important goal of PC was to weaken the illegal armed groups that challenge the Colombian state, and hence to ameliorate the intensity of the country's civil strife. While PC has been the subject of continuous political debate both in Colombia and the US, there are surprisingly very few quantitative evaluations of the program with which to back such debates[1]. Indeed, after over a decade, we know very little on whether PC has been effective or not in achieving its goals, and what elements of PC if any could be improved. Studying the effectiveness of PC is important as most of the cocaine that enters the US comes from Colombia.

We assess both the short run and the long run effects of PC in terms of the two outcomes the program intended to affect: the production of coca bushes and the dynamics of the Colombian armed conflict. We do so by focusing on one particular but well defined policy instrument: the aerial spraying of illegal-crop fields, over the initial period of PC (1999-2005).

Aerial spraying is the most important eradication tool in Colombia, as it allows operating in remote and insecure areas where manual eradication is cost prohibitive or too dangerous. Using satellite images on the location and extension of coca fields, as well as event-based data on the aerial spraying of coca fields and a rich longitudinal dataset on the dynamics of the internal conflict, we investigate the

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[1] One exception is Mejía and Restrepo (2010) who calibrate a general equilibrium model of the wholesale market of cocaine to conclude that PC has been ineffective in reducing the amount of drugs that reach the border of the US in spite if the eradication efforts in Colombia.

long-term effect of the aerial spraying program on coca production and violence[2]. The violence outcomes studied are attacks performed by guerrilla groups, clashes between these groups and government forces, and casualties from the civilian and the combatant population[3].

Our results show that one additional acre of coca eradicated reduces the cultivated area by about 11 percent of an acre on the margin. The mean effect of the eradication effort on coca crops is however plausibly larger, as the same coca field can be sprayed more than once during a given year[4]. However, as our data on aerial spraying is aggregated at the municipal level, it is impossible to know for certain which fields are re-sprayed. Hence, we are only able to report the marginal effect of the eradication program on the size of coca crops. Moreover, while it is also possible that the eradication efforts cause substitution of coca crops to neighboring municipalities, our estimates do not account for this effect, as we focus on within-municipality variation. To the extent that this is plausible our results, which should be interpreted as local effects, would overestimate the true effect of the eradication campaign on coca growing.

In terms of the effect of the aerial spraying program on violence our estimates indicate that guerrilla violent activity increases in sprayed areas. The guerrilla reaction is in turn challenged by the government, which increases two-sided clashes between the government and the guerrilla as well as the killing of combatants and civilians. This result is consistent with the hypothesis that while coca eradication weakens the guerrilla by cutting its main source of finance, localized violence increases as the guerrilla tries to hold on to control of the strategic coca fields.

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[2] While the satellite measures of coca cultivation are available only annually, the rest of the variables have daily frequency. Hence, we can only estimate the long-term effect of the eradication program on the size of illegal cropping. Instead, the effect on violence can be estimated both in the short and the long-term.

[3] We limit our analysis to guerrilla violence for two main reasons. First, guerrilla groups have been associated with the complete chain of drug production and trafficking, even since before the big Colombian drug cartels were dismantled in the first half of the 1990s (Vargas, 2009). Second, the other major illegal group, composed by paramilitary militias under the umbrella organization called AUC, started a peace process and demobilization campaigns since 2003, and hence it is not active for our whole period of analysis.

[4] Once a coca field is sprayed the land takes six to eight months to regenerate to a point in which coca can be grown again there. However if it rains or if growers wash the crops immediately after the spraying the effect of the spraying is mitigated and the land recovers much faster. These plots are likely to be re-sprayed (UNODC, 2007).

We also investigate the short-term effect of the spraying program on violence using daily data on coca spraying and conflict dynamics, disaggregated across over 1,000 municipalities from 1999 to 2005[5]. For this purpose we create two "event" windows: the preparation stage window and the post-eradication window. This allows us to measure by how much high frequency violence outcomes changed around the days that the spraying was carried out in excess to the average behavior observed in the places affected by the spraying program.

Echoing the long-term results, the short-term estimates also suggest that guerrilla activity increases in sprayed areas. However, in contrast to the long-term, in the short term the government does not seem to challenge the guerrilla reaction. This is consistent with the hypothesis that short-term eradication efforts at the dawn of PC were largely unaccompanied by military presence for consolidation purposes, something that the current government (2010-2014) has explicitly addressed.

Our contribution is fourfold. First, in terms of studying the effect of eradication on coca growing, while Mejía et al. (2013) and Rozo (2013) look at local effects by exploiting plausible exogenous variation of spraying at the local level (respectively the border with Ecuador and the areas hosting natural parks), we are the first to look at the average effect over the entire country. This may explain why our estimated substantive effect is about half as large as that of the other two papers, the analysis of which focuses on areas that are not necessarily the average coca-growing region. Still, as mentioned, our estimates may overestimate the true effect of coca eradication on the area cultivated. Second, we focus on the period for which Plan Colombia was originally conceived and hence can compare our estimates with the program's state objectives at the time of its release, prior to any endogenous re-adjustment upon internal evaluations a posteriori. For instance starting in 2006 the aerial spraying eradication component has been scaled down and the manual rooting out of the crops has gained a larger focus[6]. Third, while there is a growing literature of the effects on violence of illicit crops production (in the case of Colombia Angrist and Kugler, 2008 and Mejía and Restrepo, 2013), to the best of our knowledge there little prior of

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[5] The municipality is the smallest administrative unit of Colombia. It is equivalent to the US county.

[6] Personal communication with officials from DIRAN, November, 2013

the costs in terms of violence of large drug eradication programs. This paper concludes that one such program, incidentally the largest ever carried out by the US and with the state objective of reducing violence, may have exacerbated the intensity of Colombia's long standing armed conflict[7].

Fourth, the dataset used for the short-term analysis includes much of the information on coca and conflict the Colombian government observed during the period of study. This is crucial in the setting of this article as the outcomes studied here are most likely taken into account to define the places where policies are targeted as well as their intensities.

Two papers that are contemporaneous to our study have also estimated the effect of coca eradication on the intensity of coca growing. Mejía et al. (2013) use a diplomatic agreement between the governments of Colombia and Ecuador as a natural experiment. In 2008 Colombia conceded to stop any anti-drug aerial spraying within a 10Km band around the border with Ecuador. Using geo-referenced data on the location of coca crops the authors estimate a difference-in differences model to conclude that the eradication of one hectare of coca reduces the areas cultivated by about 20% of a hectare. Consistent with our estimates, the authors acknowledge that their point estimate is likely to be an upper bound of the true effect. Also using geo-referenced data on coca growing, Rozo (2013) exploits the variation given by the prohibition of spraying in protected national parks and indigenous territories. The estimated effect is even larger than Mejía et al. (2013)'s upper bound: aerial eradication reduces the coca cultivated land by 25% of the sprayed area.

The study of the consequences of anti-drug campaigns is not limited to Colombia. Using data for Afghanistan, Clemens (2013) calibrates a theoretical model of enforcement to conclude, in line with the Colombia findings, that drug supply-reduction efforts are ineffective.

The link between coca production and violence in Colombia has also been studied before. Using state-level variation and a difference-in-differences strategy, Angrist and Kugler (2008) assess the consequences on crime rates and labor market outcomes of the shift in coca production from neighboring

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[7] Clemens (2013) studies the effect of the US anti-opium enforcement in Afghanistan but the outcome studied is not violence and his empirical strategy is the calibration of a theoretical model.

countries to Colombia, in the early 1990s. They conclude that income shock derived from coca production, while generating few economic benefits, fueled local violence. In a very similar recent paper Mejía and Restrepo (2013) use a coca suitability index interacted with exogenous demand shocks for Colombian coca to estimate the effect of coca growing on violence outcomes, particularly the homicide rate. The results resonate with those of Angrist and Kugler (2008) in that economic opportunities in illegal markets create violence.

The rest of the paper is organized as follows. Section 2 gives details on the relationship between drugs and violence in Colombia and describes PC, especially its illegal crop spraying component. Section 3 describes the data sources. Section 4 presents the empirical strategy for the long-term analysis and the main results on the effect of aerial spraying on coca cultivation and conflict violence. Section 5 presents the empirical strategy for the short-term analysis and the main results on the effect of spraying events on immediate violent responses. Finally, section 6 concludes.

3.2 Background

3.2.1   Illegal Drugs and Violence in Colombia

Illegal armed groups in Colombia finance their activity with the proceeds of drug trafficking. In fact, the link between illegal drugs and armed conflict in Colombia is well known. For instance, the Revolutionary Armed Forces of Colombia (known by the Spanish acronym, FARC) produce about 60 percent of the cocaine exported from Colombia to the US. FARC is in fact Colombia's largest insurgent organization and in 2001 was designated by the US Department of Justice a terrorist organization (GAO, 2009).

FARC got involved in the cocaine business when the Medellin cartel expanded its operation to southeastern Colombia around the end of the 1970s (Arreaza et al., 2011). At first, FARC's involvement was limited to taxing farmers with 10 percent of coca base production (ICG, 2005). However, during the VII FARC's Conference in 1982, the group exhorted its fronts to get involved in this kind of taxation for financing purposes (Pizarro, 2006; Pecaut, 2008). Later on, at the VIII Conference in 1993, FARC

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decided to get involved in other stages of the cocaine trafficking chain besides taxing production. Different units specialize in different activities, including growing coca bushes, transforming coca base into cocaine in illegal laboratories, controlling traffic routes and exporting the final product to the foreign markets. Indeed, by the late 1990s each local front commander was responsible for financing his own operation (Felbab-Brown, 2010).

FARC devote around fifty percent of its force to drug-trafficking activities (Bibes, 2000). Drug profits have allowed FARC to expand modernize its military equipment. For example, a single airdrop in Russia in October 1999, received by a local mafia, secured the insurgent group a 50-million dollars worth shipment of AK-47s (Berry, et al. 2002).

3.2.2   The aerial spraying of coca fields

The PC strategy against coca crop cultivation includes a number of measures ranging from aerial spraying, to forced or voluntary manual eradication (including "alternative development" and crops' substitution programs), and scaling up the military initiative against drug producers (DNE, 2007).

In this article we study the efficacy of the aerial eradication component of PC, while controlling for the roll out of the other components in the form of crop substitution programs and the expansion of the country's military capacity.

The aerial eradication program is designed to inflict significant economic damage to both the farming and refining segments of the cocaine industry. A damage large enough to produce both a sizable reduction of cocaine production in the medium term, and ultimately bankruptcy in the longer term for producers. The program is carried out by DIRAN with extensive financial and operative support from the US State Department. Detailed aerial recognition of cultivation areas precedes all spray missions. Missions are cancelled if wind speed at the originating airport is greater than 10mph, if relative humidity is below 75 percent, or if temperature is over 32 degrees Celsius (90 Fahrenheit). For efficacy reasons, spraying missions are planned so as to avoid spraying wet coca. The ideal conditions include no rain on the targeted fields from two hours before to four hours after the spraying. Poor atmospheric conditions often are the cause of mission cancellations. For example, in 1998 and 1999, spraying took place on 125

days of the year. During the other 240 days the spray planes were grounded, with the majority of cancellations due to bad weather (U.S. State Department, 2002).

3.3 Data sources

3.3.1 Data on illicit crops

Our dependent variable is the municipal area (measured in hectares) cultivated with coca each year over the period 1999-2005. The source is the Integrated Monitoring System of Illicit Crops (SIMCI by its Spanish acronym) of the United Nations Office on Drugs and Crime (UNODC). SIMCI is a satellite-based monitoring system that estimates the extension of coca crops annually since 1999. It uses satellite imagery of the entire territory of Colombia's mainland (roughly 114 million hectares/ 282 million acres). Based on these satellite pictures, SIMCI experts geo-reference the area that they interpret as coca producing, based on visual inspection. All areas interpreted as coca producing, are confirmed via high definition photographs through helicopter flights.

The estimation date is set arbitrarily by SIMCI on December 31st (UNODC, 2007). However, because the entire satellite imagery used to produce the coca estimate cannot feasibly be purchased, interpreted and tabulated on one day, and in order to have a more accurate estimate, the input is retrieved over a much longer period. About 70 percent of the images are obtained between November of the estimate year and February of the following year. Of the remaining 30 percent, roughly half is obtained from August to November of the estimate year, and half between March and April of the following year. SIMCI purposefully uses satellite images from the first few months of the following year, to allow the coca estimate to include fields that could have not been detected in the current year. This is the case if coca bushes are newly planted, or coca is eradicated and then replanted toward the end of the year, and thus the size of the bushes and the density of the plantation make certain fields undetected by the satellite. In all, efforts are made to have an accurate estimate of the magnitude of coca crops that are productive by December 31st.

Provided by DIRAN, we also have municipal-level data on the number of acres of illicit crops sprayed by Colombian authorities[8]. The dataset lists every eradication event including the date of occurrence, the exact location, and the area sprayed. The data covers over 10,000 spraying events in the period 1999-2005. We observe all this information.

Figure 3.1 shows the aggregate evolution of the amount of land cultivated with coca and the intensity of the spraying campaign during the sample period. After monotonic decline in the cultivated area the figure stabilizes in 2003. Conversely after a sharp increase in the eradication campaign in the first few years of Plan Colombia spraying efforts stabilize in 2002.
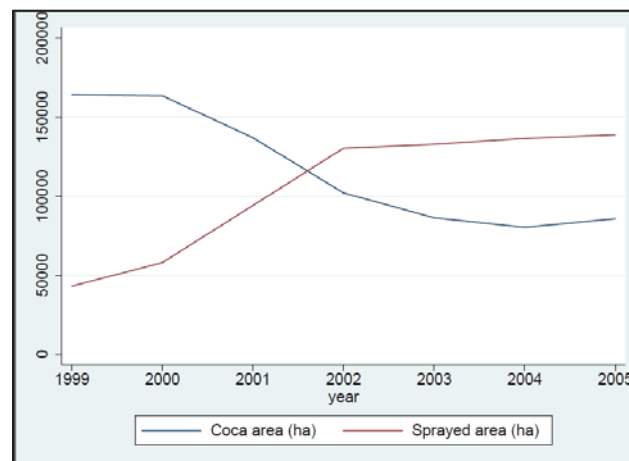

Figure 3.1 Coca Crops and Coca Spraying

3.3.2 Data on conflict

Conflict-related variables come from an event-based conflict dataset on Colombia. For every event the dataset records its type, the date, location, perpetrator, and victims involved in the incident. The dataset is described thoroughly by Restrepo et al. (2004), and has been previously used by Dube and Vargas (2013). Here we provide a succinct account of the data collection process.

The dataset is built on the basis of events published by CINEP, a local NGO that monitors political violence. Most of the event information comes from two primary sources: The Catholic Church,

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[8] Eradication can occur either through aerial spraying or manually, depending on the nature of the economic exploitation of the fields: while large plots are sprayed, smaller plots are rooted out manually. We study aerial spraying here because during our sample period manual eradication figures are negligible compared to aerial spraying. Including manual eradication, however, does not change our basic results.

which has representation in almost every municipality in Colombia--and over 25 newspapers with national and local coverage. The inclusion of reports from Catholic priests, who are often located in rural areas that are unlikely to receive press coverage, greatly broadens the municipality-level representation. Based on these sources, the resulting data includes every municipality that has ever experienced a conflict related action (either a unilateral attack or a clash between two groups).

In our analysis we employ several outcomes related to the dynamics Colombia's armed conflict. These are clashes between insurgent groups and government forces, attacks by left-wing guerrillas, and civilian and combatant casualties resulting from clashes or attacks. Figures 3.2 to 3.5 report the evolution of these outcomes during our sample period.

3.3.3 Other components of Plan Colombia

Recall that the PC strategy against coca crop cultivation includes, in addition to the eradication of illicit crops, initiatives for substituting coca with alternative crops as well as the expansion of the military capacity of the army. A common objective of both these complementary initiatives is to increase what could be called "state presence" in areas previously controlled by drug traffickers or rebel organizations. In order to identify the effect of aerial eradication we control for these additional components of PC.

First, from government's agency Acción Social, we have the municipal-specific area engaged in government-backed projects of illegal-crop substitution. Acción Social channels resources from both Colombia and foreign aid (particularly from USAID) to promote alternative crops among rural farmers known to have been involved in growing illegal crops. The raw data contains information on the number of crop-substitution projects as well as details on the timing of their execution, the plots involved and their size. This allows us to measure municipal-level project intensity (in terms of the area covered as a proportion of the total area of the town) by year[9].

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[9] When plots covered within a project extend over more than one municipality we impute land shares according to the proportion of the total land of each municipality involved in the aggregate area of all the municipalities included. In addition, since single projects are set to be implemented during several years we assign to the first year the total project-covered area weighted by the inverse of the entire duration of the project, and thereafter the same share year-by-year in a cumulative way.
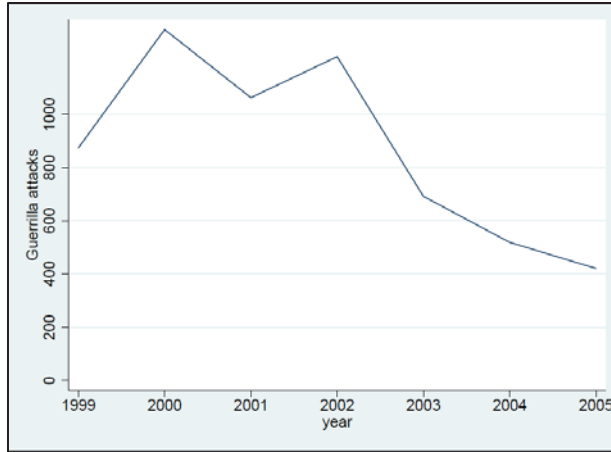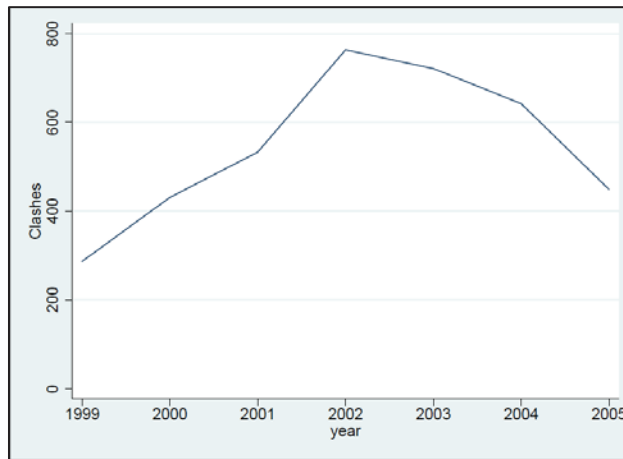
Figure 3.2 Guerrilla Attacks
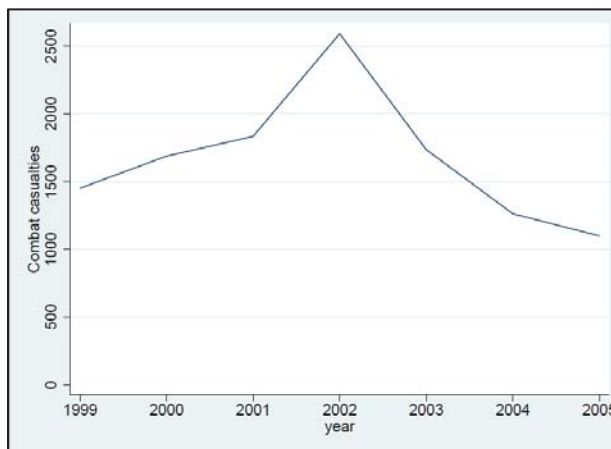

Figure 3.3: Clashes Government-Guerrillas

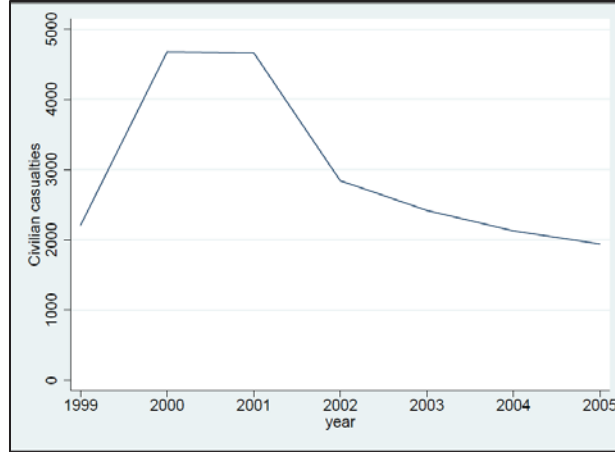**Figure 3.4: Combatant Casualties**

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Figure 3.5: Civilian Casualties

Second, using data compiled from the website of the Colombian army and press archives, we construct an indicator of the presence of army mobile brigades by municipality and year. Then, using GIS techniques, we construct for each municipality the orthodromic distance to the closest brigade on a yearly basis[10]. The inverse of such measure is a proxy of the presence of state security forces.

3.3.4   Rainfall

We control for precipitation levels in all specifications. We use the Tropical Rainfall Measuring Mission (TRMM) database on near-real-time tropical rainfall estimates. The TRMM is a joint project between NASA and the Japan Aerospace Exploration Agency (JAXA). The estimates are provided on a $0.25^\circ \times 0.25^\circ$ grid over the latitude band 50° North-South so we matched the available rainfall estimates with the coordinates of each municipality.

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[10] The orthodromic distance is the shortest distance between any two points on a surface of a sphere measured along a path on the surface of the sphere, as opposed of going through the sphere's interior. Results are however robust to using the latter (Euclidean distance).

3.4 Long-Term Analysis

3.4.1 Empirical Strategy

We use annual data to study the long-term effect of the eradication program on the area cultivated with illegal coca crops and on conflict-specific outcomes. To assess the impact on coca crops we estimate the following model:

$$(1)\ y_{it} = \alpha y_{it-1} + \delta EradicatedArea_{it} + \beta_i + \beta_t + \gamma'X_{it} + \varepsilon_{it}$$

where y_{it} represents the amount of land cultivated with illicit crops in municipality i and year t, and $EradicatedArea_{it}$ is number of hectares (ha) of coca crops eradicated through aerial spraying in municipality i and year t. By including the lagged value of the outcome, y_{it-1}, we take into account the persistence of coca fields. X_{it} is a vector that includes the area involved in crop-substitution programs, the distance to the nearest base of an army's mobile brigade and average rainfall levels.[11] We also include both municipality (β_i), and year (β_t) fixed effects to capture both time-invariant municipal-specific characteristics or aggregate annual shocks that may confound the estimates of interest. The term ε_{it} represents municipality-specific yearly shocks, and are allowed to be correlated across time for the same municipality in all regressions.

We are also interested in the long-term effect of eradication efforts on the dynamics of the local conflict. Given the count nature of the conflict outcomes, and in order to take care of the potential endogeneity of coca eradication, we adopt a nonlinear specification and estimate the next model using the Wooldridge (1997) estimator, that fits an exponential specification that allows for multiplicative fixed effects (Cameron and Trivedi, 2005, pp. 802-808)[12].

$$(2)\ y_{it} = \beta_i exp(\delta EradicatedArea_{it} + \lambda t + \gamma'X_{it} + \varepsilon_{it})$$

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[11] Because new brigades were created throughout our period of analysis, the distance to the closest base is time-varying and so this control is not collinear with the municipal fixed effect.

[12] Because we lack a similarly convincing identification strategy, we do not test the effect of eradication on the country's aggregate level of violence.

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where y_{it} represents either guerrilla attacks, civilian casualties, combatant casualties, or clashes between government forces and left-wing guerrilla groups; X_{it} is the same as in equation (1); λt is a linear time trend and β_i a municipality specific fixed effect[13].

3.4.2 Long-Term Results

3.4.2.1 Impact on Coca Cultivation

Figure 3.6 shows the distribution of coca fields across municipalities in 1999 and 2005 (Figure 3.7), respectively the first and last year of our sample. The grey scale uses the same intensity cutoffs in both years, namely the quartiles of the distribution of coca crops in the initial year (1999). This is done for comparison purposes. It allows us to show the inter-period change in the location and intensity of coca fields[14]. Darker municipalities correspond to a higher coca intensity relative to the municipality area[15]. In the initial sample year (1999) coca was present in 89 municipalities and the mean acreage of coca conditional on having a positive amount was 1,845 ha. In contrast in 2005 coca had doubled its municipal presence reaching 190 towns, albeit with a much lower average field extension (451 ha) which suggests a secular atomization of the production. Indeed, keeping the same intensity quartiles of Figure 3.6, Figure 3.7 shows a much more sparse coca production, but with a lower incidence of dark colors.

When we normalize coca cultivated areas by the total municipality area in hundreds of hectares, we find that, on average, each municipality in Colombia has 0.11 hectares of coca for every hundred hectares of land (Table 3.1)[16].

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[13] To control for potential aggregate shocks overtime we include a linear trend instead of time dummies because when adding time fixed effects the optimization procedure of the Wooldridge encounters a flat region and fails to converge.

[14] This practice is repeated in all the subsequent figures, that map all the variables of interest in the first and the last years of our sample.

[15] In the case of the percentage of the municipal area cultivated with coca, the first (lower intensity) quartile (lightest gray) goes from 0.03 to 1.04 hectares of coca for every thousand hectares of land; the second quartile (somewhat darker gray) goes from 1.04 to 2.73 hectares of coca for every thousand hectares of land; the third quartile (dark gray) from 2.73 to 6.77 and the fourth (highest intensity) quartile (black) from 6.77 to 314.94. This means that in 1999 the municipality with the highest intensity of coca production devoted almost a third of its land to growing coca.

Figures 3.8 and 3.9 presents the geographic distribution of the coca spraying program in 1999 and 2005, with quartiles of spraying intensity measured in 1999 and normalized by the municipal area. Darker municipalities are places more intensively sprayed. 27 municipalities witnessed spraying in 1999. The mean sprayed area conditional on a positive value of spraying was 1,597 ha. In 2005 the program was expanded to 111 municipalities, and the mean eradicated area was 1,250 ha. Figures 3.8 and 3.9 reveal that the intensity of the eradication campaign (share of municipal surface that experienced coca spraying) increased significantly from 1999 to 2005[17]. The mean area sprayed per municipality/year is 0.07 hectares per hundred hectares of land (Table 3.1).

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[16] We computed the total area of the municipalities from the Colombia GIS datasets provided by IGAC, the country's official geography and cartography bureau.

[17] Note that the comparison of Figures 3.6 and 38, and 3.7 and 3.9, implies that in a few instances there appear to be eradication efforts in areas where coca is not present. This is explained by the fact that the satellite images of coca fields are captured at the end of each calendar year, while the spraying figures are the cumulative sprayed areas over each municipality across the entire year.
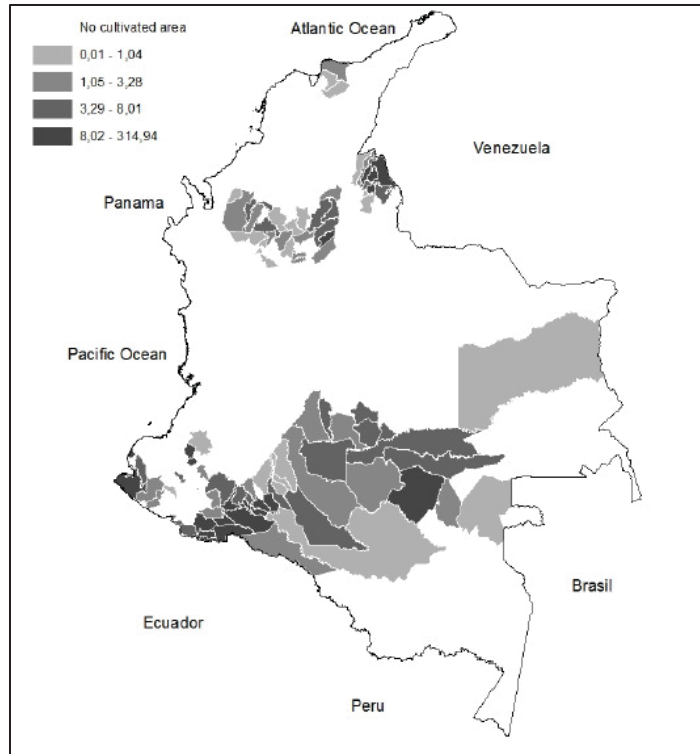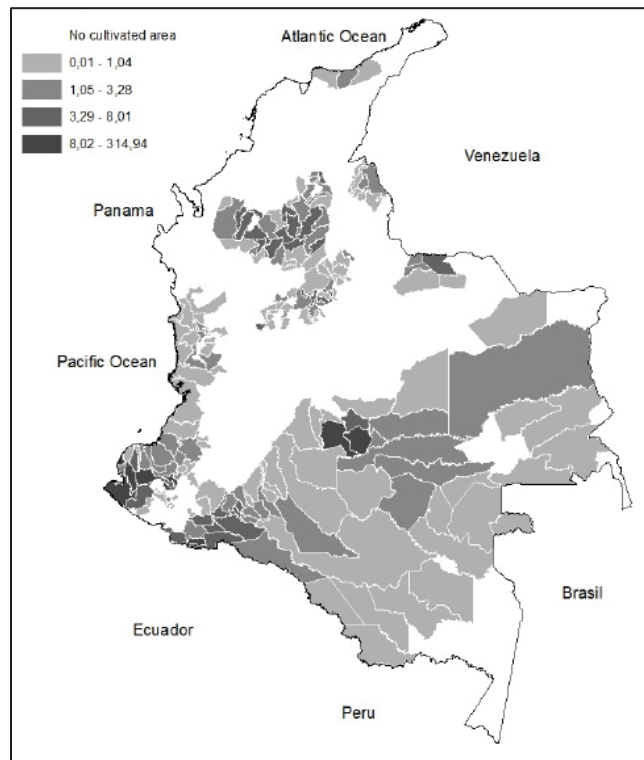
Figure 3.6: Coca Cultivation in 1999
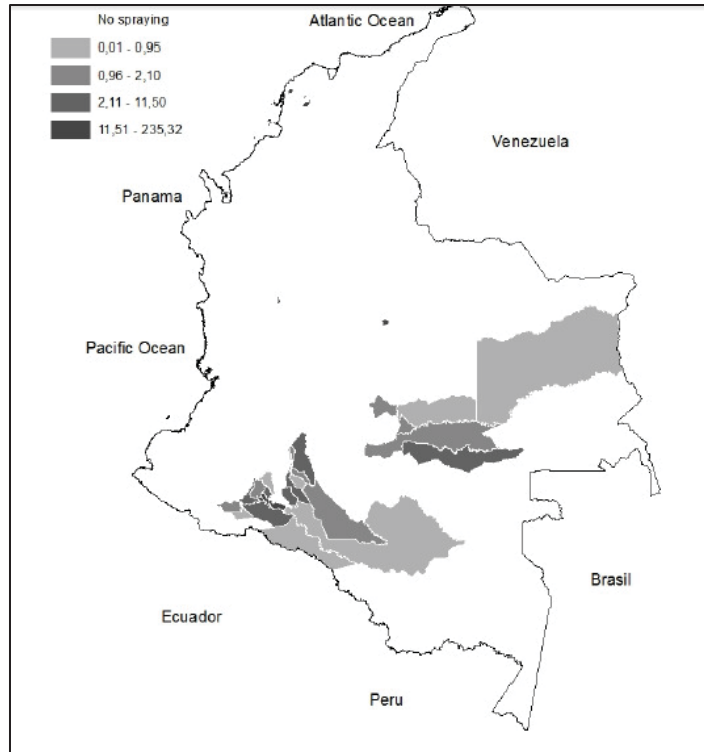

Figure 3.7: Coca Cultivation in 2005

Figure 3.8: Coca Spraying in 1999
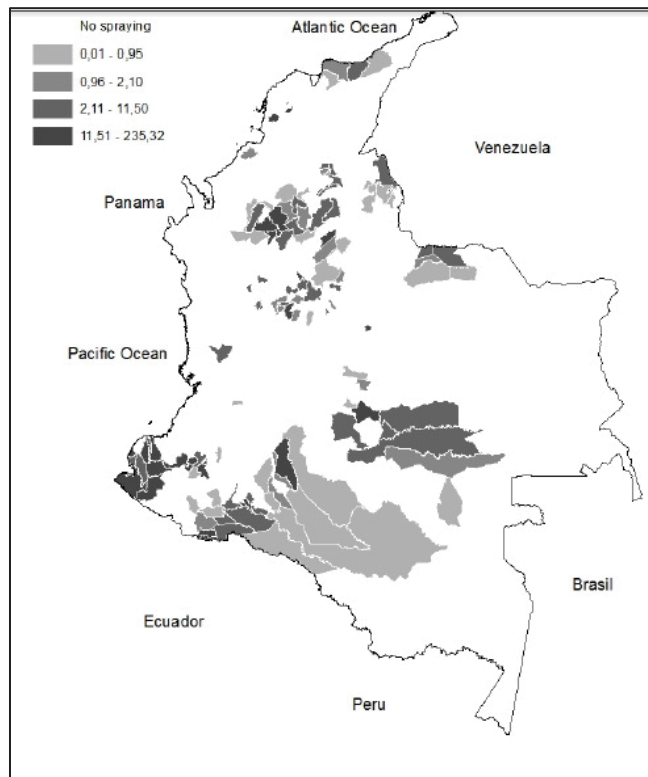
Figure 3.9: Coca Spraying in 2005

Table 3.1: Summary Statistics

	1999		2005		
	Mean	St. Dev.	Mean	St. Dev.	Source
Illicit crops measures					
Coca crops[a]	147.05	973.65	76.66	440.20	SIMCI/UNODC
Coca crops normalized[b]	0.11	1.19	0.04	0.16	SIMCI/UNODC
Sprayed area[a]	38.60	367.61	124.24	1055.69	DIRAN
Sprayed area normalized[b]	0.07	1.00	0.10	0.58	DIRAN
Conflict Measures[c]					
Clashes government-guerrilla	0.26	0.62	0.40	1.16	CERAC/URosario
Guerrilla attacks	0.78	1.89	0.38	1.24	CERAC/URosario
Civilian casualties	1.98	6.12	1.73	5.74	CERAC/URosario
Combatant casualties	1.30	5.59	0.98	3.36	CERAC/URosario
Institutional controls					
Land under crops substitution program[a]	1.45	10.47	146.46	599.75	Acción Social
Land under crops substitution program norm.[b]	0.01	0.08	0.74	3.62	Acción Social
Distance to closest military base[d]	391.44	204.29	160.72	90.93	Army and press
Rainfall					
Rainfall[e]	1,872.92	638.39	1,476.54	591.71	TRMM/NASA

Notes: Number of municipalities 1,117. Number of observations 7,819 (= 1,117 × 7). [a] Number of hectares cultivated/sprayed. [b] Normalized by municipality area and multiplied times 100. [c] Variable not normalized: count of events. [d] Orthodromic distance measured in kilometers. [e] Variable measured in cubic millimeters.

We then estimate the effectiveness of the aerial spraying on coca growing, which is the outcome that should be directly affected by eradication efforts. To this end we estimate equation 1 as a linear dynamic panel, using the Arellano-Bond (1991) estimator. Table 3.2 reports the results of the effect of the aerial spraying of coca fields on the area cultivated with the illicit crop at the municipal level. The benchmark specification, which in addition to the municipality and year fixed effects controls for the lagged coca cultivation, is reported in column 1. Other controls are included additively in the subsequent columns. Column 2 adds rainfall levels to control for climatic conditions that may affect both the incidence of crops and the aerial eradication efforts. Column 3 adds further a variable that measures the distance to the closest base of a mobile military brigade. These military units, the firsts of which were created in the late 1990s, are supposed to perform timely deployments and complicated tactic maneuvers to increase the military control in areas with known presence of illegal armed groups. The bulk of the

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mobile brigades was created during the Uribe administration (2002-2010) when the size of the military increased from 260 thousand to about 450 thousand (Florez, 2011). Because mobile brigades with different jurisdictions where introduced in Colombia at different points in time, this specification can also be estimated including fixed effects. The last column adds the municipal-level area affected by government-led crop substitution program. This is an important potential confounder because the crop-substitution efforts are intended to make the growers of illicit crops to voluntarily substitute these for legal crops, with the technical and financial support from the government.

Table 3.2: Effect of aerial coca spraying on coca area (long term)

Dependent variable: Coca cultivated area				
	(1)	(2)	(3)	(4)
Eradicated area	-.114**	-.115**	-.119**	-.121**
	(.052)	(.052)	(.051)	(.053)
Controls				
Lag. Cultivated area	.698***	.699***	.702***	.705***
	(.057)	(.056)	(.056)	(.059)
Rain		.013	.007	-.002
		(.011)	(.008)	(.006)
Dist. military base			.013	.003
			(0.018)	(0.016)
Crops substitution				-.001
				(0.005)

Notes: Number of municipalities 1,117. Number of observations 5,585. Regressors not shown include municipality and year fixed effects. Robust standard errors are in parentheses. Instruments are lags from 2 on back (until 1999) of the coca cultivated area, lags from 1 on back (until 1999) of the policy variables (eradication, crop substitution and distance to closest military base) and the first difference of rain. *** is significant at the 1% level, ** is significant at the 5% level, * is significant at the 10% level.

The estimated coefficient of the impact of the aerial eradication efforts on the area cultivated with coca is very similar across the four specifications and in all cases it is significant at the 5 percent

level[18].Table 3.2 suggests that on average, during our period of analysis, the marginal acre of illicit coca crops sprayed reduced the cultivated area in 11 to 12 percent of an acre. This figure is however likely to underestimate the mean effect of the spraying campaign since the same coca filed can be eradicated more than once.

Recall that Table 3.2 includes in all specifications year fixed-effects, that control flexibly for any shock that may affect simultaneously all municipalities. Instead, Table 3.3 examines the extent to which the effect of aerial spraying of coca on the area cultivated with the crop is robust to accounting for different type of trends of coca growing. Columns 1 and 2 include a linear aggregate trend. In columns 3 and 4 the linear trend is specific to each department[19].Columns 5 and 6 include a linear trend for each geographic region[20].While the odd columns include no controls beyond the specific trend and municipal fixed effects, the even columns include all the controls as in the last column of Table3.2. Across all columns (i.e. including different type of trends and with and without controls) the estimated coefficient of the effect of eradication of the size of the coca fields is remarkably stable and indistinguishable from the benchmark 11-12 percent reduction of Table3.2.

As a further robustness check, Table 3.4 reports the results coming from a specification similar to the one reported in Table 3.2, but where municipalities are conditioned on having had a positive amount of coca in the 1999 satellite snapshot (the first year of our sample, and the first year in which coca land in Colombia is measured by SIMCI/UNODC). This strategy allows us to investigate the robustness of our estimates of the effect of aerial spraying on coca cultivation using a specification that is much less zero-

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[18] In Table 3.2 neither rainfall (column 2) nor any of the controls of the other components of PC (columns 3 and 4) is significant at conventional statistical levels. This suggests that coca growing does not depend on weather variability and is not affected by the proximity of military brigades. In the case of crop substitution programs the lack of significance is consistent with previous findings for Afghanistan by Clemens (2008). There, efforts to develop alternative livelihoods for local poppy farmers have limited capacity to shift the supply of opium.

[19] The 1,117 Colombian municipalities of our sample are aggregated in 32 departments, equivalent to US states.

[20] The 32 departments are in turn aggregated into six geographical regions, which are clusters of states commonly used in Colombia for public policy and planning objectives.

inflated. As shown in Table 3.5, 89 municipalities were identified as having coca in 1999. By the end of the of the period coca persisted in 81 of those (91 percent).

According to Table3.4, each acre of coca sprayed in the municipalities that presented the illicit crop in 1999 reduced the cultivated area in 15 percent of an acre. Again, the coefficient is robust in magnitude and significant (this time at the 1 percent level) to the additive inclusion of the controls described for the last table.

Table 3.3: Effect of aerial coca spraying on coca area (long term) - Robustness

Dependent variable: Coca cultivated area						
	Agg. lin. trend		Dept. lin. trend		Reg. lin. trend.	
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A: *Baseline*						
Eradicated area	-.115**	-.121**	-.114**	-.115**	-.111**	-.114**
	(.051)	(.050)	(.055)	(.056)	(.051)	(.052)
Panel B: *Normalized cultivated and eradicated area*						
Eradicated area	-.048	-.061	-.053	-.057	-.050	-.052
	(.050)	(.046)	(.042)	(.044)	(.047)	(.047)
Controls						
Lag. Cultivated area		✓		✓		✓
Rain		✓		✓		✓
Dist. military base		✓		✓		✓
Crops substitution		✓		✓		✓

Notes: Number of municipalities 1,117. Number of observations 5,585. Regressors not shown include municipality fixed effects in all columns and municipality fixed effects plus the full set of controls in the even columns. Robust standard errors are in parentheses. Instruments are lags from 2 on back (until 1999) of the coca cultivated area, lags from 1 on back (until 1999) of the policy variables (eradication, crop substitution and distance to closest military base) and the first difference of rain. *** is significant at the 1% level, ** is significant at the 5% level, * is significant at the 10% level.

Table 3.4: Effect of Aerial Coca Spraying on Coca Area for 1999 Coca Municipalities (Long Term)

Dependent variable: Coca cultivated area				
	(1)	(2)	(3)	(4)
Eradicated area	-0.148***	-0.151***	-0.152***	-0.154***
	(0.053)	(0.049)	(0.048)	(0.047)
Controls				
Lag. Cultivated area	0.703***	0.716***	0.705***	0.693***
	(0.065)	(0.065)	(0.067)	(0.070)
Rain		.376	.259	.261
		(.212)	(.226)	(.225)
Dist. military base			- .608	- .608
			(0.918)	(0.889)
Crops substitution				-.564
				(0.527)

Notes: Number of municipalities 89. Number of observations 445. Regressors not shown include municipality and year fixed effects. Robust standard errors are in parentheses. Instruments are lags from 2 on back (until 1999) of the coca cultivated area, lags from 1 on back (until 1999) of the policy variables (eradication, crop substitution and distance to closest military base) and the first difference of rain. *** is significant at the 1% level, ** is significant at the 5% level, * is significant at the 10% level..

Table 3.5: Municipalities With Coca Presence 1999 And 2005

		2005		
		No	Yes	Total
1999	No	920	108	1,028
	Yes	8	81	89
	Total	928	189	1,117

Source: SIMCI/UNODC

It is worth highlighting that due to data availability our estimates should be interpreted as local effects. Indeed, in this paper we do not take into account neither the multiple spraying that mat take place on the same fields, nor potential general equilibrium effects like the fact that the eradication that takes place in one municipality can make coca growers move their illegal crops to neighboring municipalities. Our results are however consistent with accounts that suggest that the illegal crop eradication initiative

has been relatively ineffective, mainly due to the fast recovery of coca fields after eradication efforts. (e.g. GAO, 2008 and Mejía and Restrepo, 2010).

The literature suggests three broad potential explanations for this phenomenon. First, coca is often replanted on sprayed fields, and unless these are repeatedly sprayed, bushes can provide up to four harvests a year depending on the plant variety, its age and the ecological conditions of the field (Mejía and Rico, 2010). In addition, coca farmers prune the plants after spraying, cultivate areas where plants are harder to localize and spray (such as under dense foliage), and intersperse coca plants with legal crops (Felbab-Brown, 2010). Second, eradication campaigns also drive the illicit crops into remoter regions, and induce a shift to smaller-scale plots. Third, the productivity of coca bushes may have increased overtime in terms of the capacity to transform the coca leaf into cocaine base (Mejía and Restrepo, 2010). These three phenomena constitute an obstacle to eradication, especially to aerial spraying by increasing its costs and reducing its effectiveness.

The variety of potential reasons explaining the lack of effectiveness of the eradication efforts imply significantly different policy responses. It is then important to try to assess their relative salience. Table 3.4 provides evidence supporting the first mechanism. Estimated coefficients in this table are interpreted to what extent the regions in which coca was present at the start of PC experienced successful eradication. While the effect is larger than the baseline 11 percent (Table 3.2), it is not so by a high proportion. In addition, Figures 3.6 and 3.7 provides visual evidence in favor of the second mechanism too, as it shows a substantial geographical atomization of coca during our period of analysis. Coca fields doubled from 89 municipalities in 1999 (Figure 3.6) to 190 in 2005 (Figure 3.7), and the average crop size decreased four times from 1,845 hectares in the first year to 451 in the last. Hence, in addition to the crops being replanted on the same municipalities in which eradication takes place (either on the same fields or in more frontier areas of the town), coca fields also witnessed a large atomization. In contrast, using various rounds of a representative survey of coca growers, which among other things asks about coca yields, Rozo (2012) finds no evidence supporting the third mechanism, namely an increase in the productivity of coca leaves in the production of cocaine base.

That coca grows again on sprayed fields or the surrounding areas is consistent with a lack of government-led consolidation efforts to take full control of regions in which illicit crops are eradicated. Indeed, the lack of short-term security and long-term institutional consolidation initiatives in the territories gained to the rebels and where eradication took place is the main objection of the current presidential administration (2010--) to the Democratic Security Policy promoted by president Uribe (2002--2010).We will come back to this hypothesis when discussing the short-term results in the next section.

3.4.2.2   Impact on Conflict Outcomes

Figure 3.10 presents the geographic distribution of guerrilla attacks in 1999 and 2005, normalized by the municipal population. The (un-normalized) mean of guerrilla attacks is 0.78 per municipality/year (Table 3.1).However, the number of municipalities that receive a guerrilla attack decreased from 294 in 1999 to 158 in 2005. Similarly, the maximum number of attacks witnessed by the same town decreased 18 at the beginning of the period to 10 in 2005. Figure 3.10 suggests that the reduction in the intensity of attacks is mainly driven by a significant drop of the guerrilla activity in the north-east of the country.

Figure 3.11 maps the incidence of (population-normalized) clashes between government forces and guerrilla groups. The total number of clashes decreased from 211 in 1999 to 160 in 2005. In addition to more geographically concentrated, clashes became more intense during this period: The maximum number of clashes per municipality/year rose from 6 in 1999 to 10 in 2005. According to Figure 3.11, the hot spot of clashes that appears in the north-east of the country in 1999 disappeared by 2005. Instead, spots of intense clashing emerged in the center and south of the country. However other areas persisted in terms of clashes between government forces and guerrillas, specifically the north-west of the country.
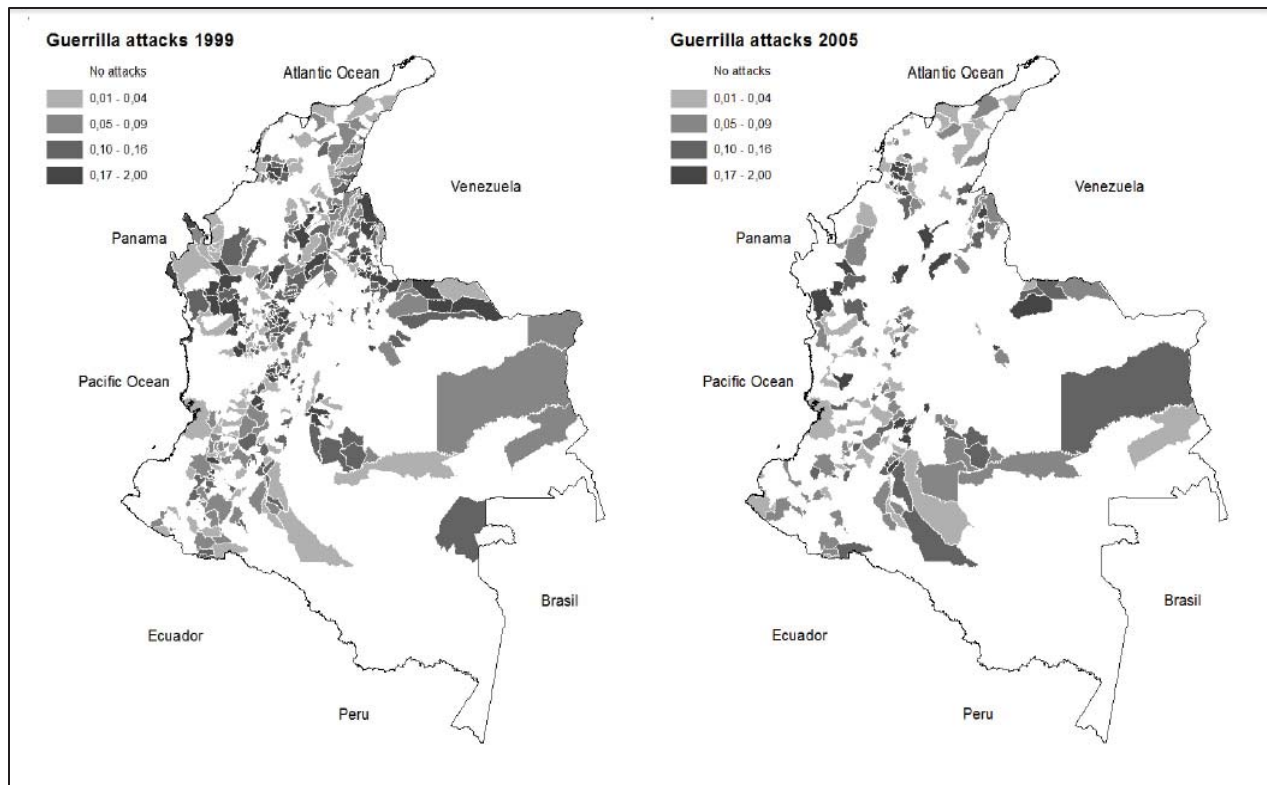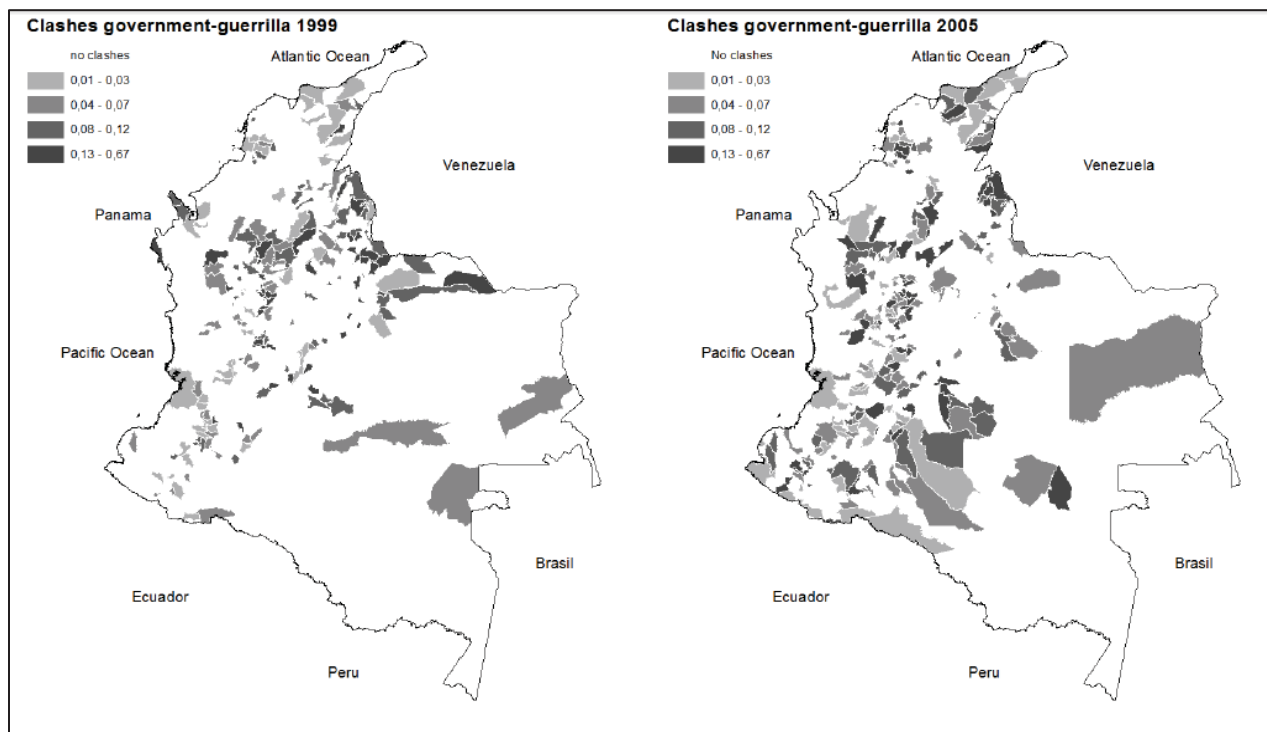
Figure 3.10: Guerrilla Attacks

Figure 3.11: Clashes Government-Guerrilla

More civilians than combatants died as a direct result of the conflict during the period of analysis. The mean total number of civilian casualties is 1.98 and that of combatants is 1.30 per municipality/year (Table 3.1). Figures 3.12 and 3.13 show respectively the spatial distribution of incidence of combatant and civilian casualties in conflict events involving the guerrillas (i.e. guerrilla attacks or clashes with the guerrillas) across Colombian municipalities in 1999 and 2005. The figures show that both combatants and civilians experienced a large improvement in their security over this period.

Our second set of results then estimate the impact of aerial spraying on the incidence of conflict-specific violence, as measured by the outcomes already described. Table 3.6 reports the long term impact of coca eradication efforts on measures of conflict-specific outcomes. There is one column for each outcome and all specifications include as controls municipality fixed effects, linear time trends, and the distance to the closest mobile military brigade[21].

We report the marginal effects. These are obtained by multiplying the estimated coefficient times 100 and should be interpreted as the impact of one additional unit of the independent variable of interest on the percentage change of the dependent variable. Since, to account for the heterogeneity in municipal areas, coca eradication is measured as the percentage of hectares that are sprayed relative to the extension of the municipality, the reported coefficients can be interpreted as the percentage change in each of the violence outcomes for an additional 1 percent of the municipality area sprayed. Hence, according to column 1 of Table 3.6, an additional 1 percent of the municipality area witnessing coca eradication leads to 22 percent more guerrilla attacks and this is significant at the 1 percent level. Note that the average is 0.11.

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[21] In this specification, contemporaneous and lagged rainfall levels are used to instrument municipal eradication. The presence of the alternative crops program is not included due to endogeneity.
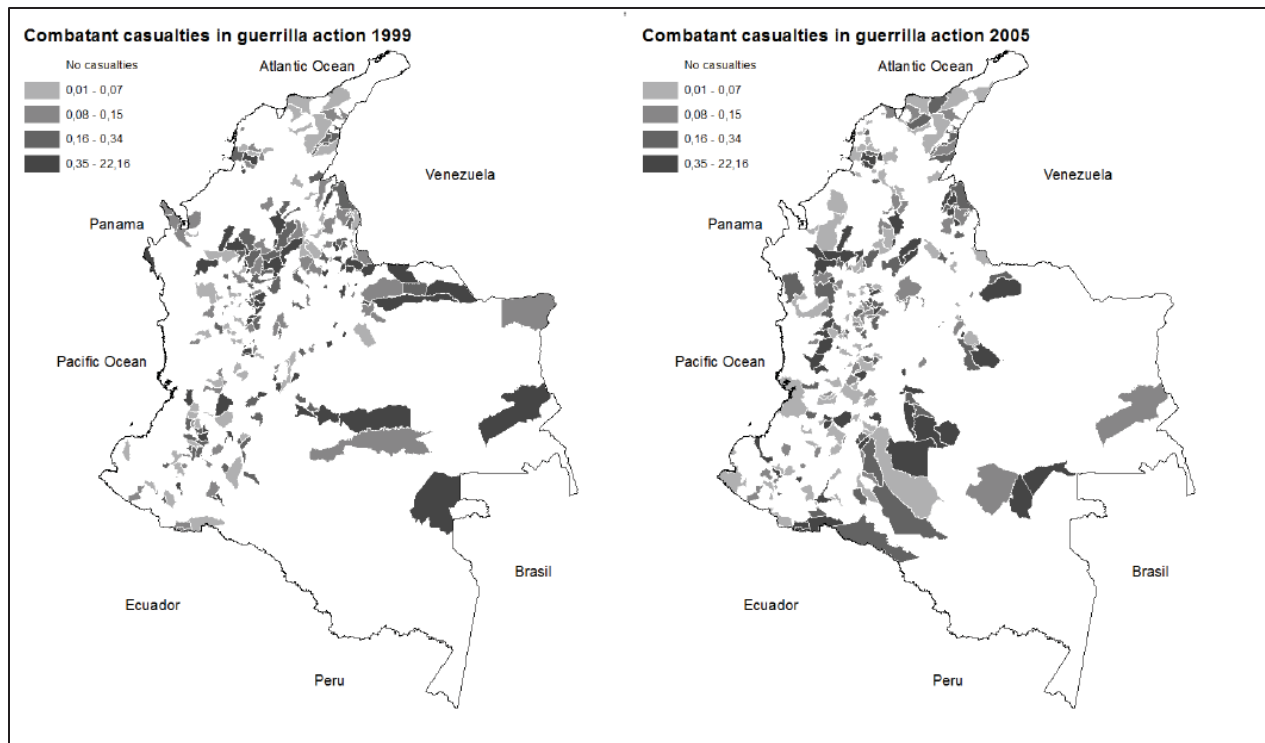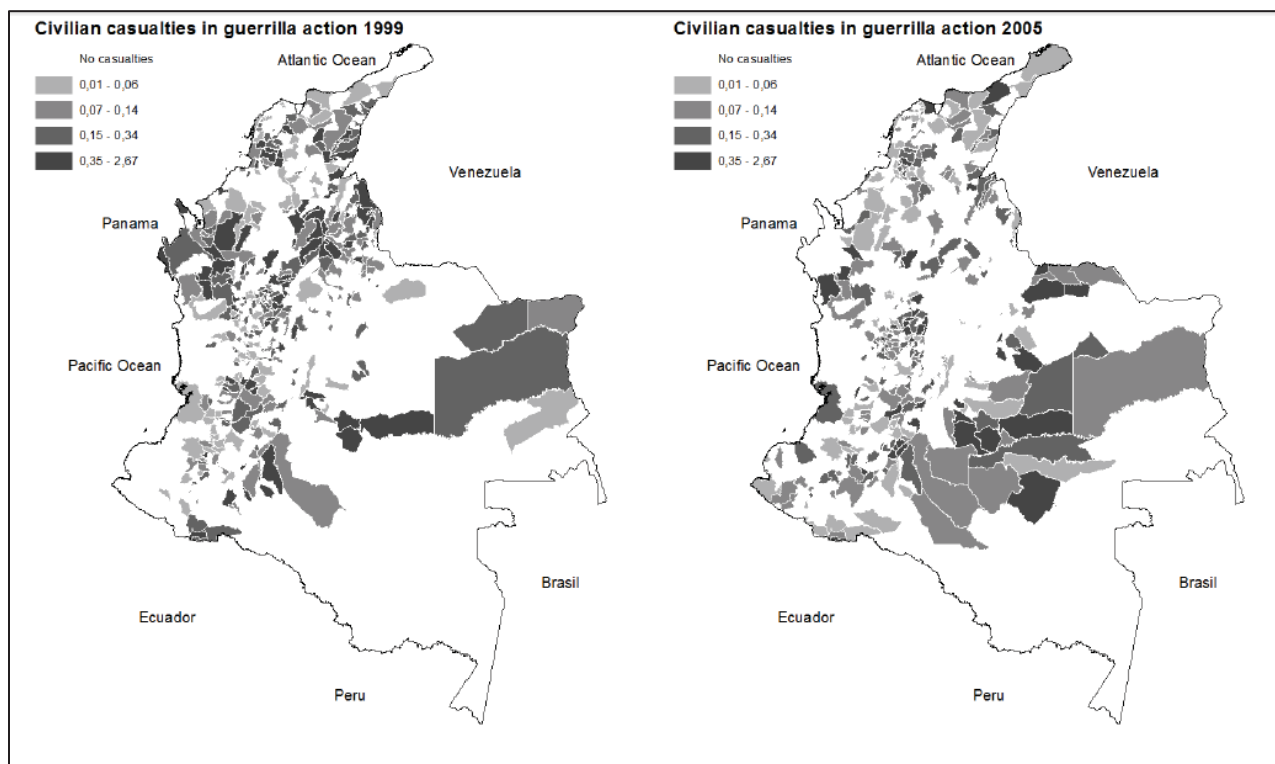
Figure 3.12: Combatant Casualties in Guerrilla Actions

Figure 3.13: Civilian Casualties in Guerrilla Actions

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Table 3.6: Effect of Aerial Coca Spraying on Conflict Violence – Marginal Effects (Long Term)

Dep variable:	Guerrilla attacks	Clashes gov.-guer.	Combatant casualt.	Civilian casualt.
	(1)	(2)	(3)	(4)
Eradicated area	22.413***	24.476***	22.087***	15.578**
	(5.319)	(9.458)	(7.258)	(7.819)

Notes: Number of municipalities 1,117. Number of observations 5,585. Regressors not shown include a linear trend, the distance to the closest base of a military mobile brigade, and municipality fixed effects. Instruments for Eradicated area are rain and lagged rain. We report marginal effects, obtained by multiplying the estimated coefficient times 100 and which should be interpreted as the impact of one additional acre of coca sprayed on the percentage change of the dependent variable. Clustered standard errors by municipality are in parentheses. *** is significant at the 1% level, ** is significant at the 5% level, * is significant at the 10% level.

The armed initiative of the guerrilla in Colombia is not uncontested. As reported in column 2 of Table 3.6, an additional 1 percent of the municipality area witnessing coca eradication is associated with 24 percent more clashes between the guerrilla and the government (also significant at the 1 percent level). This is consistent with the contestation story summarized in the conceptual framework at the beginning of this subsection, and further suggested by the positive and significant result on unilateral guerrilla attacks reported in column 1: When the guerrilla tries to recover the coca-growing areas they face the government forces, which try to hold the upsurge of guerrilla attacks. The result that coca eradication has increased guerrilla attacks in municipalities where eradication took place instead of weakening their military power via a reduction in coca income is consistent with the idea that instead of running away to non-coca-growing (and therefore not exposed to spraying) municipalities, guerrillas do not easily cede the control of coca-growing municipalities. According to Felbab-Brown (2010, Chapter 4), fighting eradications efforts helps the guerrilla gain the support and allegiance of local coca farmers[22].

One way of fighting eradication is by shooting spraying aircrafts. Up to the year 2007, 1,116 spraying aircraft had been impacted by gun fire (Semana, 2007). A likely consequence of these shootings

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[22] Although the results is also consistent with anecdotal evidence linking guerillas' adaptation to eradication by switching to kidnapping and extortion in their areas of influence.

and the clashes mentioned above, is surely the death of combatants from both the government forces and the rebels. In column 3 of Table 3.6 we look specifically at this outcome and estimate a positive and significant effect of 22 percent.

Unfortunately, civilians in this context also get their share of victimization. An additional 1 percent of the municipality area witnessing coca eradication leads to 16 percent more civilians killed. This is consistent with the short-term findings that we describe in the next section.

Overall, we show that eradication efforts in the context of PC have led to higher violence outcomes in the municipalities where aerial spraying of coca fields took place. The stated intention of the eradication campaign, besides the reduction of drug supply, has been the abatement of violence inflicted by illegal armed groups by crunching their main financial source pushing them to retract and slow down their violent activities. However the eradication of illegal coca crops may also increase violence perpetrated by the parties who benefit from the drug trade. As we argue, this is because armed groups are not willing to give up the control of coca regions to the government without disputing them violently.

These findings are in line with recent scholarship that has found a positive relationship between drug enforcement policies and the level of violence. Jeffrey Miron has argued that the traditional anti-drugs approach of prohibition create black markets and that these type of markets often resort to violence to resolve disputes. Controlling for the traditional determinants of the homicide rate he finds that increases in enforcement of prohibition of illegal substances has been associated with higher homicide rates in the US (Miron, 1999) and that differences in the enforcement of drug prohibition can predict differences in violence across countries (Miron, 2001). Also, Dell (2015) shows causal evidence that the PAN-led campaign against drug cartels in Mexico under the Calderón administration had the unintended consequence of increasing violence. She argues that after successful defeats of incumbent cartel leaders rival traffickers dispute violently the territories that remain leaderless.

In a similar vein, Clemens (2013) argues that the effect of US efforts to reduce the Afghan opium trade have backfired because as demand is inelastic, when supply shrinks the rents of the remainder

producers surge. A similar argument is used by Mejía and Restrepo (2010) to explain the relatively little success of PC in eliminating coca production.

The hit to the finance of terrorists and their violent reaction to dispute their rents' root are two opposing forces that are consistent with a stylized fact documented in this paper. While violence increased in the sprayed areas, it shrank in the country as a whole (see Table 3.6 and Figures 3.2-3.5 respectively). This is because armed groups have both a national political agenda but localized financial sources. If the mechanism explaining the observed escalation of violence was instead similar to the one proposed by Clemens (2013) for the ineffectiveness of the anti-opium enforcement in Afghanistan, namely that the eradication-led supply shrinkage increases the rents of the remainder traffickers feeding their bellicose capacity, then we would expect violence to surge in the rest of the country and less so in sprayed regions. Not only is this the opposite from what we find, but also, as discussed in section 3.4.2.1, eradication has been rather ineffective in reducing coca supply.

By providing evidence that eradication efforts lead to an increase of violence at the local level, in this section we highlight an unintended negative consequence of PC in terms of on of the program's main objectives, namely the reduction of violence in Colombia.

5 Short-term analysis

5.1 Empirical strategy

In this section we focus primarily on the effect of illicit crops eradication efforts on short term violence outcomes, using daily frequency data at the municipal level. The events of interest in our study are each of the aerial fumigations of coca fields that are carried out in Colombia during our sample period, 1999-2005. We define the "event window" as the period over which the violence outcomes are observed around each spraying event. Using daily data, in order to capture the short-term violence dynamics both pre and post each event, our benchmark event window spans for a month (30 days) both before and after every event. The pre-event window is meant to capture previous conflict dynamics, which are of interest because military forces are generally scheduled to arrive to the areas to be sprayed several

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days in advance in order to secure the places[23]. The post-event window, instead, will capture the short-term violent reaction to the spaying events.

We estimate the model:

$$(3) \ y_{it} = \beta_i \exp(\gamma PRE_t + \alpha POST_t + \delta_{rt} + \varepsilon_{it})$$

where y_{it} represents each of the violence variables in municipality i recorded on day t. PRE_t is a time indicator that captures the window spanning for 30 days before the eradication event. That is, γ captures the effect of the eradication on the incidence of violent outcomes prior to it taking place. We include this term in order to control for previous conflict dynamics that may affect where and when current fumigation efforts are going to be implemented. We include the time indicator $POST_t$, spanning for 30 days after the eradication event. That is, α is our main coefficient of interest as it captures the violent reaction of the eradication event. We include municipality fixed effects (β_i) to capture time invariant municipal-specific characteristics that may be related to conflict and eradication variables, such as geographic variables (Abadie, 2006). We also include 6 regions $\times$ 84 months $=$ 504 region $\times$ month dummy variables, represented by δ_{rt}, that capture the effect of time shocks that are common to all the municipalities located within the same geographical region.

Because of the count nature of the outcome, in equation (1) we adopt an exponential model (Cameron and Trivedi, 2005, pp. 802-808).

5.2   Short Term Results

Table 3.7 reports the marginal effects in percentage terms of the estimated coefficients. We only find significant changes in the month before the spraying events in the number of combatant casualties. In contrast, shortly after the occurrence of the events civilian casualties present a significant 22.8 percent increase (column 4). We do not find significant effects of the coca spraying events on guerrilla attacks, or clashes between the government forces and the guerrillas (columns 1 and 2). Consistent with this, in column 3 we do not find a significant increase in combatant casualties.

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[23] Ministry of Defense, 2009 (interview with Eradication Policy Advisor).

Table 3.7: Effect of Aerial Coca Spraying on Conflict Violence, Percentage Change (Short Term)

Dep variable:	Guerrilla attacks (1)	Clashes gov.-guer. (2)	Combatant casualt. (3)	Civilian casualt. (4)
Pre-event window	6.038	0.399	22.486**	4.201
	(11.046)	(10.965)	(10.573)	(8.867)
Post-event window	7.929	-3.854	-3.112	22.820***
	(10.978)	(11.002)	(11.028)	(8.482)
Observations	1,795,014	1,590,454	1,633,923	2,089,069
N. of municip.	702	622	639	817

Notes: Number of observations per municipality 2,557. Regressors not shown include municipality fixed effects and region-level linear trends, where region is a cluster of neighboring departments. We report marginal effects, obtained by multiplying the estimated coefficient times 100 and which should be interpreted as the impact of one additional acre of coca sprayed on the percentage change of the dependent variable. Standard errors are in parentheses. *** is significant at the 1% level, ** is significant at the 5% level, * is significant at the 10% level.

Our short-term results are consistent both with the functioning of the spraying program, and with recent theoretical accounts of civilian victimization in civil conflict. Take on the one hand our finding that there is an increase in combatant casualties prior to the spraying events. As explained in our empirical strategy, government forces are sent to 'clear' territories to be sprayed. Spraying aircraft have to fly low for the herbicides to hit the target and minimize the chance they are blown to near coca-free spots by the wind. If a guerrilla squad with anti-aerial artillery or ranged weapons is present, spraying airplanes are at risk of being hit. In fact, according to a local magazine, up to year 2007 1,116 spraying aircraft had been impacted by gun fire (Semana, 2007). Thus, military platoons sent for advanced territorial clearing often find local armed resistance.

On the other hand, we show that civilian casualties increase after eradication. Kalyvas (2006)'s theory on selective violence argues that the extent to which violence against civilians is used in civil conflicts depends on the degree of control that armed groups have over valuable territories. In cases of territorial contestation among more than one group, non-state actors rely on selective violence to deter defection or active collaboration with the rival actor. Rather, in cases in which actors exercise territorial

hegemony violence is seldom used as it hampers the group's legitimacy. We argue that pre-eradication deployment of troops, as well as the eradication events per se, increase contestation in rebel controlled coca-producing areas, and hence primes non-state actors to exert violence. Moreover, because the process of pre-eradication preparation exposes them to interacting with the government, (coca) farmers in sprayed areas are more likely to be seen as collaborating with the enemy. In all, once the spraying takes place, coca-profiting armed actors conduct selective killings to punish alleged collaboration with the government. This is consistent with vast anecdotal evidence that guerrilla groups punish farmers thought to have collaborated with government forces. More systematically, Vargas (2009) shows that territorial contestation increases civilian targeting by illegal armed groups in Colombia.

However, in contrast with the long-term results, the short-term guerrilla punishment upsurge following eradication efforts is not contested by the government as clashes are not significantly different from zero (column 2). This is consistent with the hypothesis that short-term eradication efforts at the dawn of PC were largely unaccompanied by military presence for consolidation purposes, something that the current government (2010-2014) has explicitly addressed.

In short, we show that the eradication efforts in the context of PC have had the unintended consequence of making sprayed territories more violent. This finding is consistent with recent claims of the existence of a positive association between drug enforcement policies and violence in different contexts: drug and alcohol prohibition efforts in the US (Miron, 1999), the war against drug cartels in Mexico (Dell, 2015) and the war against opium production in Afghanistan (Clemens, 2013).

3.6 Conclusions

In this paper we conduct for the first time a rigorous econometric evaluation of Plan Colombia, the largest aid package ever received by a country in the western hemisphere. While Plan Colombia has been the subject of continuous debate, criticism and praise has come mostly from NGOs and journalistic accounts, while evidence-based arguments are usually absent. Indeed, after over a decade of its existence, surprisingly there has been very little academic research on whether PC has been effective or not in achieving its goals, or what elements of it could be improved.

We assess both the short- and the long-term effect of PC in terms of the two outcomes the package intended to affect: The production of coca and the dynamics of the Colombian armed conflict. We do so by focusing on one particular and well defined policy instrument: the eradication of illegal-crop fields. We investigate the long-term effect of eradication on coca production and a large set of conflict-related violence outcomes controlling for various state presence measures as well as climate conditions, municipality and time fixed effects and linear time-trends.

Our preferred estimate suggests that one additional acre of coca eradicated reduces the cultivated area by about 11 percent of an acre on the margin. The mean effect of the eradication effort on coca crops is however plausibly larger since, as explained, as the same coca fields can be re-sprayed. However, as the available data on aerial spraying is aggregated at the municipal level, it is impossible to know for certain which fields are re-sprayed. Hence, we are only able to report the marginal effect which is most likely a lower bound of the mean effect of the eradication program on the size of coca crops.

In terms of the effect of the aerial spraying program on violence our estimates indicate that both in the short and the long run, guerrilla activity increases in sprayed areas. In addition, while in the short run this results in significantly higher numbers of civilian casualties, in the long run guerrilla attacks are challenged by government forces which increases two-sided clashes and the killing of combatants. These results are consistent with the hypothesis that while coca eradication weakens the guerrilla by cutting one of its main source of finance, it is not enough to decrease localized violence as the guerrilla tries to hold on to control of the coca fields.

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Chapter 4: The Effect of Extreme Hydro-Meteorological Events on Labor Market Outcomes: Evidence from the Colombian Caribbean

4.1 Introduction

Individuals try to protect themselves from the costly effects of random extreme events described by a probability distribution that we call climate. The adaptation measures that individuals undertake can be ex-ante actions (such as investing in defensive measures) or ex-post changes in behavior, conditional on available information and technology. This study explores a fundamental and related question: to what extent is labor supply a consumption smoothing mechanism in response to extreme weather events?

This study is at the intersection of different strands of the literature. On the one hand, this project contributes to the new so called "Climate-Economy Literature" (Dell, Jones and Olken, 2013). The Climate-Economy Literature in this area has focused on estimations of labor supply outcomes responses to weather fluctuations in developed countries. Graff Zivin and Neidell (forthcoming) show using a panel of US daily temperature and individual data from the 2003-06 National Time Use Surveys that weather fluctuations lead to substantial changes in labor supply. They find a moderate aggregate response of time allocated to labor during hot temperatures, but when examining exposure to climatic elements by different industries they conclude that at daily maximum temperatures over 85 degrees F, workers in industries with high exposure to climate reduce daily time allocated to labor by as much as one hour.

Connolly (2008) measures the extent to which US workers respond to daily fluctuations in weather by substituting future leisure with present leisure. Her study shows that rainfall decreases enjoyment of leisure and therefore increasing hours at work and an increase in wages. In Conolly's study, men work 30 minutes more and have an average of 25 minutes less of leisure during a daily rain. There are heterogeneous regional effects, with men in drier regions working more than men in less dry regions. Conolly also concludes that precipitation, unlike snow, and temperature has an unambiguous effect on the labor/leisure decision.

This study adds up to the literature that controls for space and time-fixed effects (e.g. Auffhammer, Ramanathan and Vincent 2006; Deschenes and Greenstone 2007; Schelnker and Roberts 2009). This approach overcomes one important limitation of the initial cross-sectional approach to

estimate response functions of economic variables due to climate and climate change: that there may be unobservable variables that vary across the municipalities, which are likely correlated with the climate/weather variables (e.g Kelly, Kolstad and Mitchell 2005; Mendelsohn, Nordhaus and Shaw 1994).

In this study, fixed-effects estimators rely on variation across time (2001-2010) within Caribbean municipalities in Colombia as the source of identifying variation rather than variation across these municipalities. This means that the underlying identification relates time series deviations from the municipality-specific mean in the climate indicators to deviations in the outcome variable of interest (Auffhammer, Hsiang, Schlenker and Sobel, 2013).

This project also contributes to the literature on the effects of shocks on income and labor market outcomes in the developing world. Shocks have proven to be detrimental to the lives of the poor (Rosenzweig and Wolpin 1993; Dreze 1995; Jacoby and Skoufias 1997; Jensen 2000; Jayachandran, 2006). Besides, shocks affect differentially poorer than richer households. Shocks may even worsen inequality through its effect on the labor market. For example, Jayachandran (2006) found that for the Indian case, productivity shocks cause larger changes in the wage when workers are poorer, less able to migrate, and more credit-constrained because of such workers' inelastic labor supply. This equilibrium wage effect hurts workers. In contrast, it acts as insurance for landowners. Most of these studies, however, rely on rural samples and are context dependent with some studies pointing to non-negative effects of floods in wages (Kaur, 2014) and other studies finding negative effects.

The Colombian Caribbean is a good context for studying the labor market effects of extreme rainfall. The annual average of natural disasters in Colombia reaches 600 events, greater than the combined number of shocks of these nature in Peru, Mexico and Argentina. The Caribbean region of Colombia is large and diverse: more than 10 million people live in this region that includes 8 Departamentos (equivalent to States), including indigenous groups. However, since the Colombian Caribbean has experienced more extreme weather events than its neighbors, individuals may have learned

to adapt over time, which suggests that ther marginal cost of new events is lower in the Colombian Caribbean than in its Andean neighbors (Hsiang and Narita, 2012).

On the other hand, impacts of climate change by 2050 will include flooding in the Caribbean coasts, increases in the vulnerabilities of non-technically developed smallholders (Ramirez-Villegas, 2012) and changes in the variability and thus availability of water resources.

Finally, with more than half of the working adult population employed in the informal sector and therefore uninsured, a large proportion of the economically active population is increasingly vulnerable to the rising damages of extreme rainfall and climate change.

This project focuses its attention on labor supply in the developing world – the primary source of household income throughout the world. Household allocation of adult labor in response to precipitation represents an avenue for exploring potential adaptations that may minimize or worsen the welfare effects from climate change. Finally, commercially mechanisms such as insurance can play a role in providing protection against losses due to climate change (National Climate Assessment Report, 2014; Shiller, 2014). The first necessary step for insurance to be commercially available and protect workers against extreme weather events is to quantify damages in different places and different groups of the population. In the remain sections of the paper, I describe rainfall patterns in the Caribbean, present the key variables used to measure rainfall shocks, introduce the empirical strategy, describe the data, the results of the econometric estimations and finally, conclude.

4. 2 Institutional context

4. 2.1 Background on floods in the Colombian Caribbean in 2001-2010

Rainfall exhibits a uni-modal annual cycle (May– October) at the northern Caribbean coast of Colombia. The El Niño/Southern Oscillation (ENSO) is the main forcing mechanism of inter-annual climate variability from hours to seasons to decades. In general, the warm phase of ENSO (El Niño) begins during the boreal spring, exhibiting a strong phase locking with the annual cycle, and

encompassing two calendar years characterized by increasing sea surface temperature anomalies during the boreal spring and fall of the onset year, peaking in winter of the following year.

Anomalies then decline in spring and summer of the ensuing year (Alvarez, Poveda and Rueda, 2011). Originating in the tropical Pacific, ENSO influences virtually the entire tropics by radiating waves through the atmosphere, linking climates around the globe through so-called teleconnections. (Ropelewski, C. F. & Halpert, M. S., 1987 and Chiang, J. C. H. & Sobel, A. H., 2002). ENSO oscillates between its two extremes: El Niño (warm event) and La Niña (cold event).This study focuses on the cold phase of ENSO (La Niña events). In the Caribbean region of Colombia, La Niña increases the amounts of precipitation (IDEAM, 2010).

Generally, during a period of La Niña, the sea surface temperature across the equatorial Eastern Central Pacific Ocean will be lower than normal, reaching its peak at the end of the calendar year and tends to dissipate during the mid-year of the following year. In a typical Niña year in the Colombian Caribbean, rainfall starts increasing mid-year progressing to strong precipitation, river flooding and increases in the likelihood of hurricanes in the Atlantic Ocean (IDEAM, 2010).

During the period of study (2001-2010), the strongest Niña event occurred in 2010. In fact, it was the strongest Niña event since 1949 in Colombia (IDEAM, 2010). The States of La Guajira, Magdalena, Cesar, Sucre, Atlántico and Bolívar experienced rainfall greater than 70% of its monthly mean (IDEAM, 2010). Consistent with the high levels of precipitation of 2010, the Colombian government reported several river flooding in the Caribbean, as well as sudden and large increases in river volume (IDEAM, 2010). In Cartagena, the capital of the State of Bolivar, newspapers reported in November of 2010 shocking pictures of a completely flooded city, yielding millionaire material loses. Among the most affected, there were 700 families lost their dwellings after 12 hours of very strong rainfall in the city (El Espectador, November 3, 2010).

4. 2.2 Labor Market in the Colombian Caribbean

The economically active population in the labor market in the Colombian Caribbean is largely made up of self-employed adults (DANE, 2012).

60% of working adults are self-employed, and some segments of the urban poor are mostly self-employed.

In qualitative studies working adults report relying heavily on weather, and in particular, on rainfall patterns to be able to generate labor income. For example, setting up small shops and operating them in the streets, information transportation (moto-taxismo), fruit and other food sales in the beach or in other public spaces depend on rainfall. Individuals report also that produce get spoiled due to excess rainfall and that this hampers their ability to generate income.

4. 3 Conceptual Framework

In absence of insurance, and with all households in one market, individuals "self-insure". This means that instead of redistributing rainfall shock across states, individuals redistribute across time. The consequence of this time redistribution of rainfall shocks is that whereas in the presence of perfect insurance, marginal utility of consumption would be constant, individuals smooth consumption.

In the first case, marginal consumption equals:

$$U'(C_t) = \lambda = U'(C_{t+\tau})[(1 + \delta)/(1 + r)]^t$$

Instead, smoothing implies:

$$U'(C_t) = [(1 + r)/(1 + \delta)]^t E_t[U'(C_{t+\tau})]$$

Labor supply has the following features that make it a good consumption smoothing mechanism: 1) Labor supply can be partitioned into small pieces: small changes in marginal utility are possible, 2) The covariate between marginal utility and wages could be positive for certain occupations: when the rainfall shock hits and consumption decreases (and therefore marginal utility increases), some types of wages could increase, for example, construction workers. Finally, the depreciation of human capital is low.

4.4. Measurement of key variables

The main outcome variables of this study are two: 1) labor income and 2) labor supply.

4.4.1 Outcome variables

Labor income

The measure of labor income in this research is the logarithm of the real wage per hour. To obtain this variable, I took the self-reported weekly nominal labor earnings from DANE's Great Integrated Household Survey in pesos, deflated all the series to constant Colombian pesos, and divided by weekly hours worked. Finally, I calculated the log of the real wage per hour. Those who reported being unemployed were assigned a zero log wage per hour.

Labor supply

The measure of labor supply in this research is logarithm of the number of hours worked last week, as reported by each surveyed adult in the sample. As in the case with wages, the distribution of hours worked is highly skewed and truncated at zero, so the benefits of using the logarithm apply here as well. Those who reported being unemployed were assigned a zero hours worked, and zero log of worked hours.

4.4.2 Extreme rainfall shocks

This study relies on a flood indicator called "Days of heavy precipitation". It was calculated by counting the number of days in the municipality that witness rainfall larger than 10 mm per month (Aguilar et al, 2005).

4.4.3 Sample

The sample of this research consists on individuals who were surveyed by DANE and reported being either employed, self-employed or unemployed and who are older than 18 years old.

4.5 Empirical strategy

This research tests the hypothesis that individuals react to weather anomalies by changing their individual labor decisions in order to smooth consumption, in absence of unemployment insurance and the communal nature of the shock, which prevents communal insurance.

I estimate the log-linear model with Ordinary Least Squares in the model

$$(1) \ \mathrm{Log}(Y_{ijt}) = \delta_j + v_t + X_{ijt}'\beta + E_{jt}'\alpha + \varepsilon_{ijt}$$

where i indexes individuals, j indexes municipalities, t indexes survey year. In Equation 1, Y_{ijt} represents both labor supply outcomes including hours worked and labor income. X_{ijt} is a vector of observed measures of productivity and outside options. These measures include gender, educational attainment, age, age squared, married status and urban/rural location.

v_t are year fixed effects and δ_j are municipality fixed effects. The Vector E includes the number of hydro-climatic events happening from January to December of last year (shock month), measured by the "days of heavy precipitation" indicator.

This methodology will compare outcomes in the municipality j when a weather anomaly has occurred with outcomes in the same municipality in absence of the event. Since weather anomalies, as studied in this research, vary plausibly over time as random draws from the distribution in a given spatial area (i.e. "weather" draws from the "climate" distribution), this weather-shock approach has strong identification properties (Dell, Jones and Olken, 2013). Standard errors are clustered at the municipal level to allow for correlation across individuals within a municipality and within the same municipality over time.

According to the conceptual framework outlined below, I test that $\alpha \neq 0$ in Equation 1.

4.6 Data

4.6.1 Data sources

I match individual labor market outcomes collected by the Departamento Administrativo Nacional de Estadistica (DANE) during the rounds of 2001-2010 with NASA's rainfall data at the municipal level during the same period.

Labor outcomes

DANE collects individual information on its "Great Integrated Household Survey". The great integrated household survey is a survey that gathers information about the employment conditions of persons (whether they work, what they work in, how much they earn, if they have social security for health care, or if they are looking for a job), as well as about the general characteristics of the population, such as gender, age, marital status, and educational level, sources of income and expenses (what they buy, how often they buy, and where they buy). The GEIH provides information at the national, urban-rural, regional, and departmental levels, as well as for each one of the department capitals. Currently, the survey specializes in the measurement of the labor market structure and household incomes; it has an annual total sample of approximately 240,000 households, which makes it the largest survey in coverage in the country. This data is rich in both temporal and spatial dimension, allowing for fine-grained analysis of how the extreme precipitation event associated with La Ni a that occurred in 2010 impacted individuals' labor decisions across different municipalities through the year (IDEAM, 2010).

The particular questions that I employ in the context of this study are the following: Employment status: employed, self-employed, unemployed; Labor income last week; Hours worked last week; Demographic characteristics: gender, age, marital status, and educational attainment

Rainfall

This project uses NASA's TRMM Multi-satellite Precipitation Analysis (TMPA), which is available at 0.25 degree resolution (Huffman et al 2007). The work is being carried out as part of the Tropical Rainfall Measuring Mission, an international project of NASA and JAXA designed to provide improved estimates of precipitation in the Tropics, where the bulk of the Earth's rainfall occurs. The main advantages of this dataset include that it is routinely produced, publicly available, fine-scale in space and time, quasi-global and near-real-time produced.

4.6.2 Summary Statistics

Tables 4.1 and 4.2 provide summary statistics for the key variables used in this paper. The average worker in the Colombian Caribbean generates income in the order of 2 dollars per hour (the mean of the log wage is 3.36, which is equivalent to 3,700 pesos per hour, or roughly 2 dollars). The average log hours is 6.84, or 41.5 hours per week. Workers in this region have 9 years of education on average, are 37 years old and live mostly in urban areas (92%). Finally, 56% of the sample reports being married. There are, on average, 41 days of heavy rains in the Caribbean municipalities per year.

Figure 4.1 presents the average number of Hydro-Climatological Events by month, measured by the "Number of Heavy Rains" Indicator. Columns in orange represent the wet season of the Colombian Caribbean while the blue columns represent the dry season.

Table 4.1: Summary Statistics, Rainfall Shocks

	Mean	Standard deviation	Min.	Max.	Observations[3]	Source
Rainfall shocks						
Days of heavy rain (rainfall >10 mm)	41.09	17.18	3	111	1,690	NASA
95th percentile shocks[4]	18.01	34	2	48	1,690	NASA
99th percentile shocks[5]	3.85	2.45	0	13	1,690	NASA

Notes:

1. This table presents summary statistics for the rainfall shock variables used in the analysis. Mean and standard deviations are presented for each variable.

2. Includes States (Departamentos) in the Caribbean region: Atlantico, Bolivar, Magdalena, Cordoba, La Guajira, Cesar and Sucre.

3. Rainfall shock observations are at the level of municipality-year.

4. A 95th percentile shock is defined as whether rainfall in the municipality-month-day falls above the 95th percentile of the usual municipality rainfall distribution in that month (eg, January).

5. A 99th percentile shock is defined as whether rainfall in the municipality-month-day falls above the 99th percentile of the usual municipality rainfall distribution in that month (eg, January).

Table 4.2: Summary Statistics (Outcome and Explanatory Variables)

	Mean	Sd	Min.	Max.	Observations	Source
Outcomes						
Hours (log)[3]	3.3662	1.2501	0	5.123964	804,686	DANE
Real wage per hour (log)[3]	6.8458	2.6851	-5	15.2716	721,584	DANE
Unemployed[3]	0.1315	0.3380	0	1	830,903	DANE
Self-employed[3]	0.5664	0.4955	0	1	721,594	DANE
Worker is between 12-18 years[4]	0.0332	0.1793	0	1	563,272	DANE
Child works[5]	0.0971	0.2961	0	1	192,949	DANE
Demographic characteristics						
Age	36.8867	13.3400	10	99	830,902	DANE
Years of education	9.0799	4.8022	0	26	799,808	DANE
Urban	0.9236	0.2656	0	1	830,903	DANE
Married	0.5663	0.4955	0	1	830,903	DANE
Male	0.5706	0.4949	0	1	830,903	DANE

Notes:

1. Includes States (Departamentos) in the Caribbean region: Atlantico, Bolivar, Magdalena, Cordoba, La Guajira, Cesar and Sucre.

2. Observations are at the individual level.

3. Sample includes employed, self-employed, workers who work for free and unemployed older than 18 years old.

4. Sample includes all workers (employed, self-employed, workers who work for free) older than 12 years old.

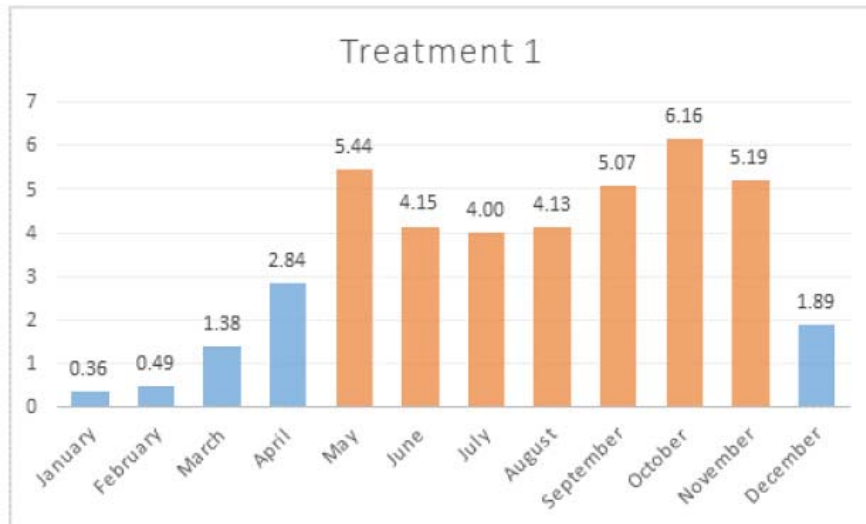5. Sample includes all survyed children between 10-17 years old, regardless of employment status.

Figure 4.1: Average Number of Heavy Rain Days By Month

7 Results

7.1 Monthly results on labor supply and income

Figure 4.2 presents the log real wage per hour by hydro-climatological events. When I split the sample between those economically active adults who were hit by at least one rainfall shock last month and those who did not, there is a striking difference in the (log) wage distribution of these two samples. In particular, there is a lot of mass around zero wages for the sample of adults hit by at least an extreme rainfall event (measured here by days of heavy rainfall) compared to the sample of economically active adults who were not.
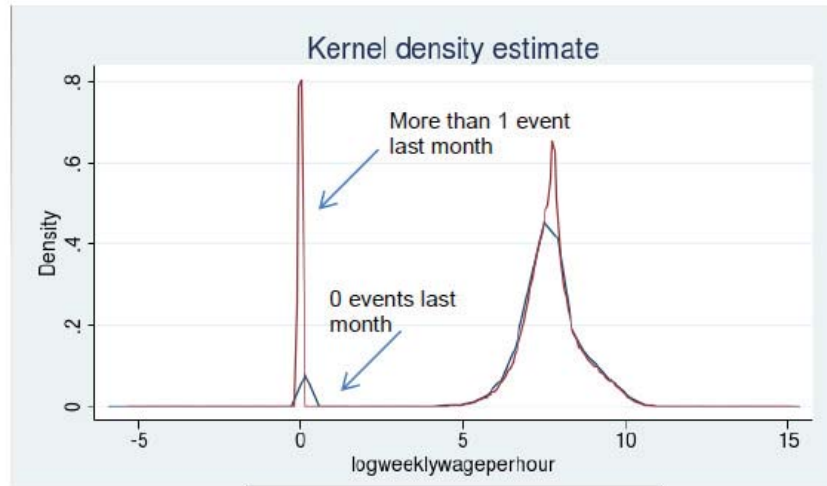
Note: Sample includes adults (older than 18), who are employed, unemployed or self-employed. Unemployed are assigned zero wages and hours worked. Events measured by rainfall > 10 mm/day

Figure 4.2: Log real wage per hour by hydro-climatological events

I then first estimate by how much the probability of unemployment increased due to at least one rainfall shock, for individual i located in municipality j surveyed at time t:

$$(2)\ Y_{ijt} = \delta_j + v_t + X_{ijt}'\beta + \alpha F_{jt} + \varepsilon_{ijt}$$

Where Y_{ijt} stands for the probability of unemployment, X_{ijt} is a vector of observed measures of productivity and outside options and α measures the causal effect of experiencing at least one flood during the previous month.

According to Table 4.3, the probability of unemployment due to living in a municipality that experienced at least one flood increases by 0.054 percentage points controlling for observable determinants of productivity and outside options, as well as for municipality and year fixed effects. This estimate is statistically significant at the 1% level (Column 1) and its magnitude is important as the mean of unemployment is 0.13.

Table 4.3: Short Term Labor Market Effects of at Least One Negative Shock Last Month:

Unemployment and Self-Employment

VARIABLES	(1) Unemployment	(2) Self-Employment
Flood	0.0544***	0.0588***
	(0.00819)	(0.00785)
Male	-0.0476***	0.147***
	(0.00459)	(0.00666)
Educational attainment	0.00634***	-0.0244***
	(0.000398)	(0.00104)
Age	-0.00124*	0.0203***
	(0.000646)	(0.000818)
Age squared	-0.00000*	-0.000172***
	(0.00000)	(0.00000)
Married	-0.0672***	-0.00156
	(0.00325)	(0.00515)
Urban	0.0416***	-0.00404
	(0.00934)	(0.0139)
Observations	803,436	698,721
R-squared	0.167	0.681

Notes:
Standard errors clustered at the municipal level are shown in parentheses. Variables not shown include municipality fixed effects and year fixed effects. Flood is a binary variable that takes on a value of 1 if the number of days of heavy rains in the municipality is positive the month previous to the survey month. *** is significant at the 1% level, ** is significant at the 5% level, * is significant at the 10% level.

Not all individuals in the labor market who report positive wages are employees, but also self-employed. It is important to understand the extent to which adult individuals try to smooth shocks by becoming "forced entrepreneurs". I therefore estimate by how much self-employment increases in response to floods measured as before, and estimate Equation 2again. The probability of self-employment also increases by 0.0588 percentage points on average, controlling for observed predictors of productivity and outside options, municipality indicators and year fixed effects. This coefficient is also significant at all statistical levels (Column 2).

Figure 4.2 presents suggestive evidence that average wages largely decrease as a consequence of extreme rainfall. I then estimate econometrically what the magnitude of this loss is per shock month on next year's labor outcomes. With this goal in mind, I estimate Equation (3) for each survey month (eg, January through December):

$$\textbf{(3)} \operatorname{Log}(Y_{ijt}) = \delta_j + v_t + X_{ijt}'\beta + \sum_{m=1}^{12} E_{m,t-1}'\Delta + \varepsilon_{ijt}$$

In Equation (3), the main interest resides in the estimation of Δ. Δ is the vector of coefficients of lagged extreme rainfall shocks, by month of occurring during t-1, where t is the survey year. Therefore, Equation (3) estimates the labor outcomes effects surveyed for individual i who lives in municipality j, surveyed in month m of year y, as a function of characteristics that affect his or her labor supply and earnings, as well as a set of lagged shocks. Equation (2) also includes municipality fixed effects and year effects.

Estimated coefficients measure by how much one additional extreme event during each month last year change log wages and log hours in the survey month, holding constant additional covariates. However, the main interest resides in measuring by how much events happening in each month of last year (eg Dec t-1) affect labor outcomes the following year. For example, by how much December events affect labor outcomes in January, in February,…. December. I therefore transposed the results matrix.

Figure 4.3 and 4.6 plots the transposed matrix coefficients, which can be then interpreted as by how much extreme events happening each month of last year affect the following year labor outcomes. Figure 4.3 plots the coefficients for log(hours) and Figure 4.4 for log(wages), respectively. Some patterns emerge from Figures 4.3 and 4.4. Focusing on the 2 months that are closest to each survey month (December and November), and are therefore more precisely estimated than coefficients from earlier months, it's possible to see that all coefficients lie under zero, meaning that one additional extreme hydroclymatic event, measured by rainfall larger than 10 mm, decreases hours worked throughout the following year. December has the most precised estimated coefficients because it's the closest lag to all months of next year.

(Log) Wages and (Log) Hours coefficients follow similar patterns as a result of extreme rainfall. That means that the graphs of both outcome variables together. However, the effect of negative hydro-climatic event is larger in magnitude for labor income than hours worked (more negative). The results from Figure 4.3 indicate that 1 additional extreme rainfall event in December of last year causes a

decrease in 3% in hours worked in January of the following year. The effect is statistically significant at 10 percent level; however, the mean effect is larger, as the mean number of extreme rainfall events in December mean is 1.89. This effect is statistically significant at 10 percent level. Likewise, 1 additional extreme rainfall event in December of last year causes a decrease in 7% in real labor income in January of the following year. The effect is statistically significant at all statistical levels. The effects still persist in July (important vacation season), when effect is a decrease in 9%, and significant at 1% level.

Figures 4.6 and 4.7 show the smoothing patterns after a rainfall shock has occurred in December of last year. There is an upward response trend to the effect of extreme precipitation. After one year, effects are zero for hours worked and still small negative for wages.

I now turn to examine the effects of extreme rainfall during the rainy season. For this purpose I focus on the November results, which is the second closest month to all survey months. The effect of a marginal day with heavy rains is -2% in hours and -8% in wages, significant at 5% and 1% level respectively. Starting in February, an additional day of heavy rainfall happening in November has a lower effect on log hours than December. However, the mean effect of extreme rainfall shocks is five times larger than December, given that November is still part of the rainy season whereas December is not. Finally, it's possible to see from Figures 4.3 and 4.4 that after 13 months of the extreme event, hours and wages have recovered their initial levels in real terms.
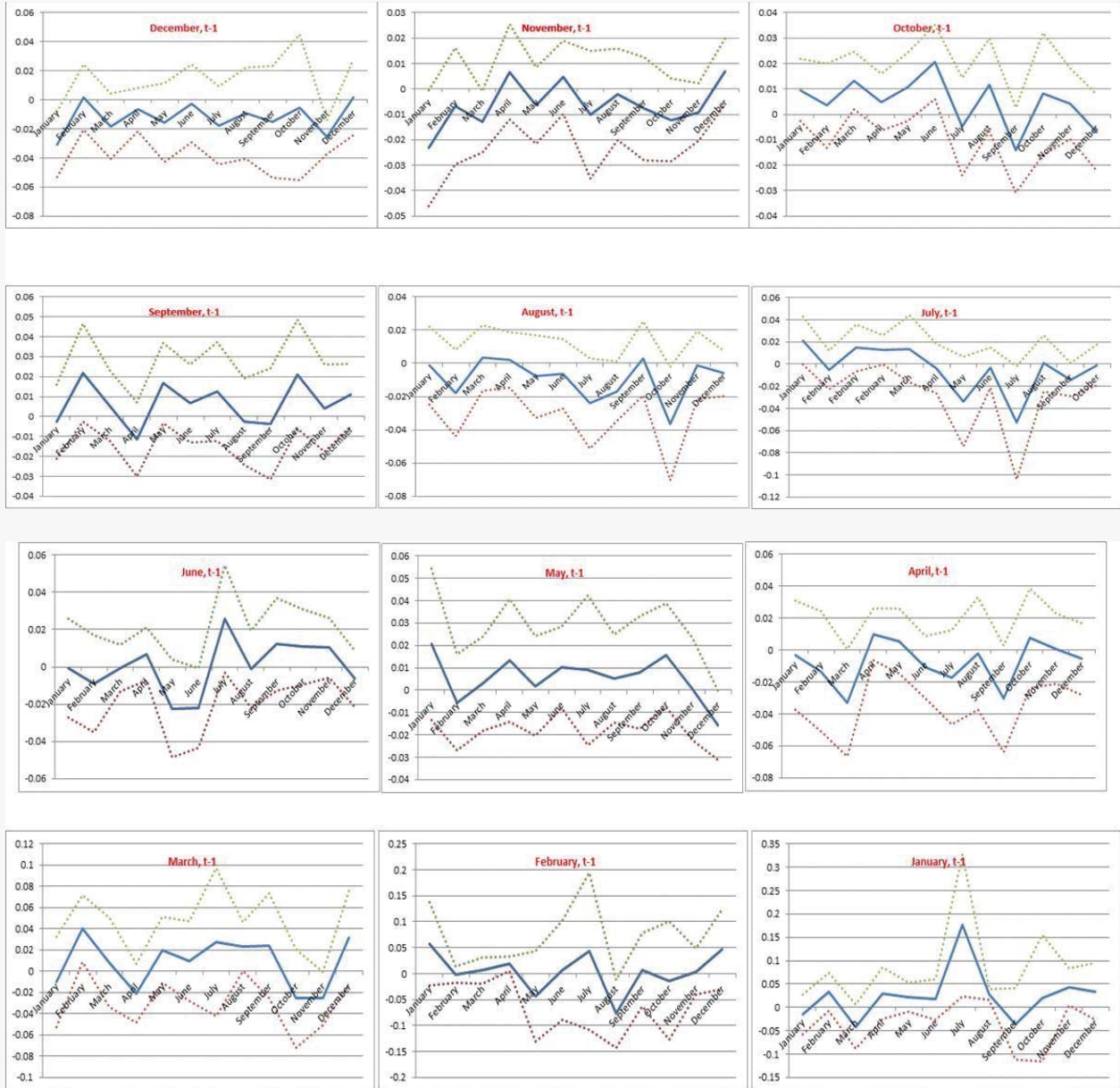
Figure 4.3: By How Much Extreme Events Happening Each Month of Last Year Affect This Year's Log (Hours Worked)
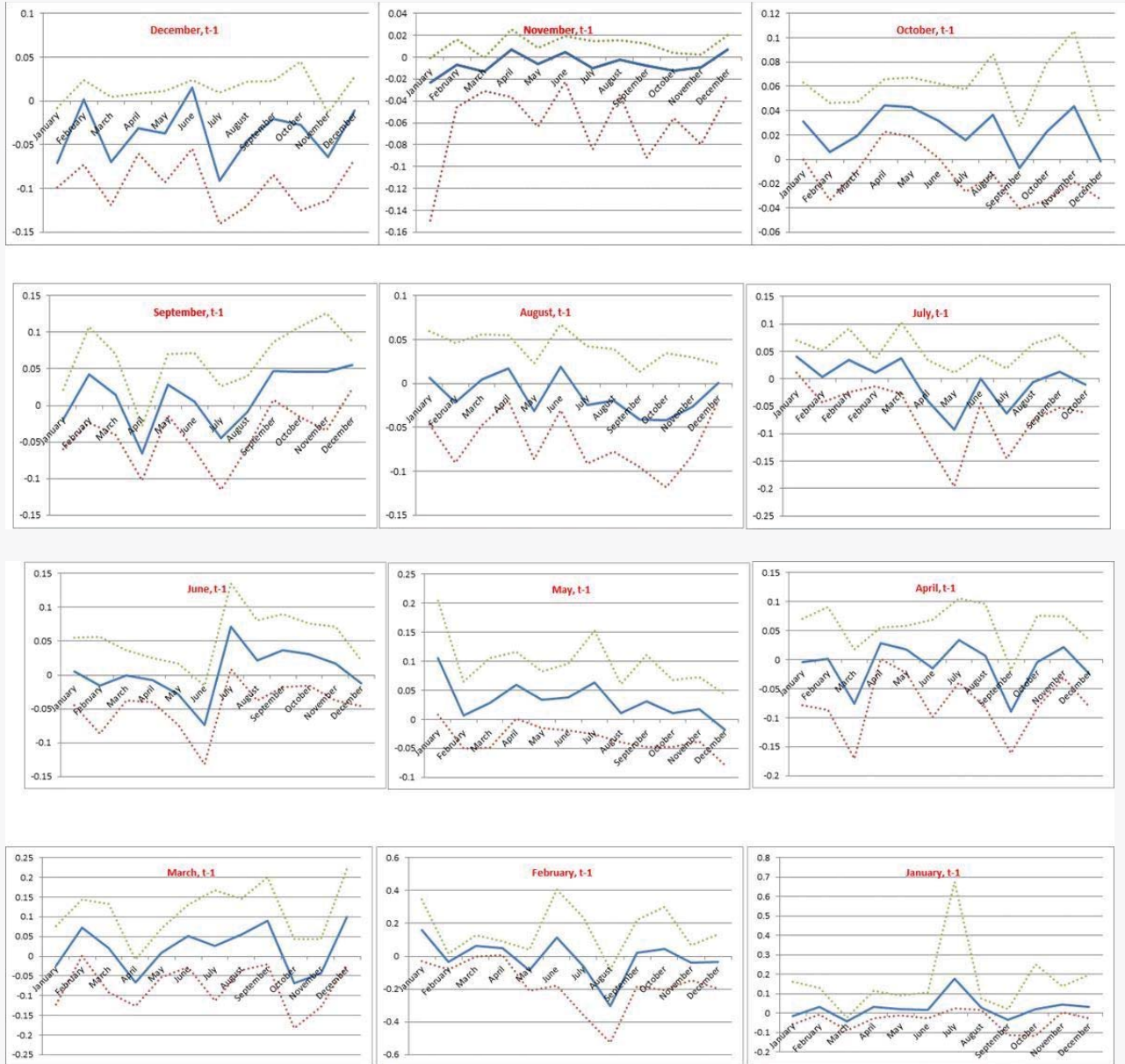
Figure 4.4: By How Much Extreme Events Happening Each Month of Last Year Affect This Year's Log (Wages)
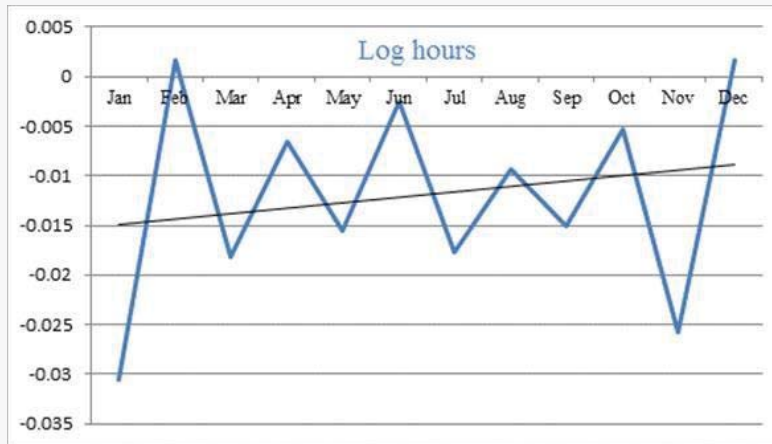
Figure 4.5: Smoothing Patterns (Log Hours) After a Rainfall Shock has Occurred in December of Last Year

Figure 4.6: Smoothing Patterns (Log Wages) After a Rainfall Shock has Occurred in December of Last Year

4.7.2 Heterogeneous effects, Non-linearities and Composition of the Labor Market

To measure the extent of heterogeneous effects in the impact of rainfall shocks on the labor markets and its composition, I estimate the linear model for individual i located in municipality j surveyed in year y:

$$(4) \ Y_{ijt} = \delta_j + \nu_t + X_{ijt}'\beta + E_{jt}'\alpha + \varepsilon_{ijt}$$

Where Y_{ijt} stands for either the probability of unemployment, probability of self-employment, probability of being a minor (younger than 18) given that the person is on the labor force, or the probability of being a worker (in exchange for a salary or for free) given that the surveyed person is a child. The Vector E includes, besides the number of "days of heavy precipitation" during the survey year, two additional indicators that help to gauge the existence of non-linear effects. The two additional indicators are a " 95th percentile shock" and a " 99th percentile shock" in the municipality j at time t[1].

α measures the causal effect of one additional extreme event during the survey year.

Tables 4.4-4.7 present the estimated regression coefficients of equation 3 for the different studied outcomes (Table 4.4: probability of unemployment, Table 4.5: probability of self-employment, Table 4.6: probability of being a minor -younger than 18- given that the person is on the labor force, Table 4.7: probability of being a worker -in exchange for a salary or for free- given that the surveyed person is a child).

All Tables present results for all the sample in column 1; column 2 presents results for men; results for women are shown in column 3, and finally, columns 4 and 5 present the estimated coefficients for urban and rural individuals, respectively. In turn, each Table presents results for the three rainfall shocks calculated in this section. Panel A shows results for the " Days of heavy rains" measure; Panel B provides coefficients for the "95th percentile" indicator, and lastly, Panel C shows estimated coefficients for the " 99th percentile".

---

[1] To construct the "95th percentile indicator", a distribution of rainfall for each municipality-month pair was constructed for the period of available rainfall data (January 1st, 1999 to December 31st, 2010). For example, for the month of January and the municipality of Cartagena, the rainfall distribution has 372 observations (31 days* 12 years). From this distribution, I calculated the 95th percentile. Then, I performed daily comparison of rainfall in that municipality-month with the calculated 95th percentile threshold. If the observed precipitation exceeded the threshold, I labeled it as a 95th percentile shock. I then proceeded to do the same with the following municipality-month pair (eg, Cartagena, February). Finally, I added up the number of 95th percentile shocks for that municipality-year, simply summing up the number of shocks for the municipality m in each of the months of that year.

Table 4.4: Yearly Adult Labor Market Outcomes: Unemployment

VARIABLES	(1) All	(2) Men	(3) Women	(4) Urban	(5) Rural
Panel A: Days of Heavy Rains					
Days of heavy rains	0.00314***	0.00201***	0.00415***	0.00352***	0.00232***
	(0.000343)	(0.000222)	(0.000507)	(0.000354)	(0.000492)
Observations	604,410	341,110	263,300	549,750	54,660
R-squared	0.160	0.124	0.211	0.166	0.147
Panel B: 95th percentile shocks					
95th percentile indicator	0.00264***	0.00165***	0.00344***	0.00295***	0.00186***
	(0.000489)	(0.000312)	(0.000788)	(0.000541)	(0.000529)
Observations	604,410	341,110	263,300	549,750	54,660
R-squared	0.157	0.122	0.207	0.162	0.144
Panel C: 99th percentile shocks					
99th percentile indicator	0.00494***	0.00305***	0.00633***	0.00537***	0.00435***
	(0.00101)	(0.000670)	(0.00174)	(0.00126)	(0.00150)
Observations	604,410	341,110	263,300	549,750	54,660
R-squared	0.156	0.121	0.206	0.161	0.144

Notes:
Standard errors clustered at the municipal level are shown in parentheses. Variables not shown include municipality fixed effects and year fixed effects, and controls for education, age, age squared, marital status and indicators of gender (columns 1, 4 and 5) and urban/rural status (columns 1, 2 and 3). Days of heavy rains is defined as the annual count of days per municipality when rainfall exceeded 10 mm. A 95th percentile shock is defined as whether rainfall in the municipality-month-day falls above the 95th percentile of the usual municipality rainfall distribution in that month (eg, January). A 99th percentile shock is defined as whether rainfall in the municipality-month-day falls above the 99th percentile of the usual municipality rainfall distribution in that month (eg, January).*** is significant at the 1% level, ** is significant at the 5% level, * is significant at the 10% level.

Too much rainfall in a municipality compared to its usual seasonal rainfall raises unemployment for all population groups, and the more extreme the shock, the larger the increase in the probability of unemployment given being in the labor force (Table 4.4, Columns 1 to 5, Panels A, B and C). Column 1 of Table 4.3 shows that, having socio-economic characteristics, municipality indicators and year effects fixed, an additional day of heavy rains in the municipality increases the probability of unemployment by 0. 0031.

This means that 10 more days of heavy rains imply an increase in unemployment of 0.031, which is a large effect given that the mean of unemployment in the sample is 0.13.

The sign of the coefficients are also positive and their magnitudes larger as the floods worsen. Interestingly, going from one additional 95th percentile shock to an additional 99th percentile shock doubles the impact of the flood on unemployment, for the overall sample as well as for each of the subgroups of the population: men (column 2), women (column 3), urban (column 4) and rural (column 5), suggesting non-linearities in the relationship between extreme weather and labor market outcomes. For example, one more 95th percentile shock raises the probability of unemployment by 0.0026, whereas one additional 99th percentile shock increases this probability by 0.05. This finding is consistent with previous results for typhoon impacts on income and deaths (Hsiang and Narita, 2012).

On the other hand, the most negatively affected by the floods are the females: the largest coefficients in each of the Panels are those that correspond to female workers, suggesting that women witness the largest increase in unemployment as a result of rainfall shocks of different magnitudes even holding constant years of education, age, municipality indicators and year fixed effects.

Another important indicator of employment quality is self-employment. Qualitatively, the effect of floods on self-employment is very similar to that of unemployment, that is, floods increase self-employment in a non-linear way. However, unlike unemployment, the magnitude of the effect is relatively small. The coefficient presented in Panel A, column 1 of Table 4.4 indicate that too much rainfall measured by one additional day of heavy rain in the municipality increases on average the probability of being self-employed by 0.0032, and this effect is statistically significant. If a municipality experiences 10 additional days of heavy rains, the probability of self-employment increases by 0.032 percentage points, which constitutes 5% of the self-employment mean. The robust but small effect is consistent through all the subgroups of adult population studied (columns 2-5 of Table 4.5).

Consistent with the worsening of labor market conditions, the probability that a worker is a minor is also larger in the years with very heavy rains (Table 4.6), and results are significant for the pooled sample, women and men separately and urban individuals. The coefficient of Panel A, column 1 of Table 6 is 0.00586: having socio-economic characteristics, municipality indicators and year effects fixed, an additional day of heavy rains in the municipality increases the probability that a worker is a minor

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(younger than 18 years old) by 0. 00586. This effect is very large given that the mean probability that a worker is a minor is 0.03. Interestingly, the magnitude of the effect of floods on the probability that the worker is a minor also doubles when one goes from a 95th percentile shock to a 99th percentile shock.

Table 4.5: Yearly Adult Labor Market Outcomes: Self-employment

VARIABLES	(1) All	(2) Men	(3) Women	(4) Urban	(5) Rural
Panel A: Days of Heavy Rains					
Days of heavy rains	0.00328***	0.00504***	0.00186***	0.00231***	0.00389***
	(0.000301)	(0.000439)	(0.000357)	(0.000217)	(0.000976)
Observations	526,668	309,620	217,048	475,759	50,909
R-squared	0.708	0.748	0.606	0.667	0.789
Panel B: 95th percentile shocks					
95th percentile indicator	0.00373***	0.00549***	0.00211***	0.00243***	0.00485***
	(0.000458)	(0.000690)	(0.000450)	(0.000410)	(0.00113)
Observations	526,668	309,620	217,048	475,759	50,909
R-squared	0.708	0.747	0.605	0.667	0.789
Panel C: 99th percentile shocks					
99th percentile indicator	0.00696***	0.0105***	0.00362**	0.00428***	0.00852***
	(0.00112)	(0.00146)	(0.00163)	(0.00128)	(0.00230)
Observations	526,668	309,620	217,048	475,759	50,909
R-squared	0.708	0.747	0.605	0.666	0.788

Notes:
Standard errors clustered at the municipal level are shown in parentheses. Variables not shown include municipality fixed effects and year fixed effects, and controls for education, age, age squared, marital status and indicators of gender (columns 1, 4 and 5) and urban/rural status (columns 1, 2 and 3). Days of heavy rains is defined as the annual count of days per municipality when rainfall exceeded 10 mm. A 95th percentile shock is defined as whether rainfall in the municipality-month-day falls above the 95th percentile of the usual municipality rainfall distribution in that month (eg, January). A 99th percentile shock is defined as whether rainfall in the municipality-month-day falls above the 99th percentile of the usual municipality rainfall distribution in that month (eg, January).*** is significant at the 1% level, ** is significant at the 5% level, * is significant at the 10% level.

Finally, I cannot find robust evidence of a change in the probability that a child works (Table 4.7). From Panel B, Columns 2 and 5 suggest that there is a modest but significant increase in the probability that rural boys work as a consequence of an additional 95th percentile shock in the municipality, holding constant socioeconomic characteristics of the worker, municipality indicators and year effects fixed. The estimated coefficient from equation 3 for men is 0.001, which represents 1% of the

mean of child labor, and the coefficient for the rural sample is 0.006, which is 6% of the mean of this variable. All other coefficients are very close to zero and not significant (Columns 1-5, Panels A and C). The finding that the probability that a worker is a minor is accompanied by a very modest increase in the probability of child labor may seem puzzling. However, these two facts are reconciled by considering that less adults are working as suggested by the large increase of adult unemployment whereas the evidence points to a relatively constant number of children entering the labor market.

Table 4.6: Yearly Adult Labor Market Outcomes: Probability that Worker is a Minor

VARIABLES	(1) All	(2) Men	(3) Women	(4) Urban	(5) Rural
Panel A: Days of Heavy Rains					
Days of heavy rains	0.00586***	0.00660***	0.00506***	0.00430***	0.00756***
	(0.000527)	(0.000495)	(0.000683)	(0.000532)	(0.00162)
Observations	545,198	321,831	223,367	490,606	54,592
R-squared	0.220	0.230	0.180	0.157	0.339
Panel B: 95th percentile shocks					
95th percentile indicator	0.00543***	0.00620***	0.00461***	0.00374***	0.00735***
	(0.000857)	(0.000854)	(0.000986)	(0.000812)	(0.00175)
Observations	545,198	321,831	223,367	490,606	54,592
R-squared	0.197	0.204	0.157	0.137	0.322
Panel C: 99th percentile shocks					
99th percentile indicator	0.0114***	0.0129***	0.00996***	0.00779***	0.0147***
	(0.00176)	(0.00182)	(0.00200)	(0.00154)	(0.00390)
Observations	545,198	321,831	223,367	490,606	54,592
R-squared	0.187	0.193	0.148	0.130	0.313

Notes:
Standard errors clustered at the municipal level are shown in parentheses. Variables not shown include municipality fixed effects and year fixed effects, and controls for education, age, age squared, marital status and indicators of gender (columns 1, 4 and 5) and urban/rural status (columns 1, 2 and 3). Days of heavy rains is defined as the annual count of days per municipality when rainfall exceeded 10 mm. A 95th percentile shock is defined as whether rainfall in the municipality-month-day falls above the 95th percentile of the usual municipality rainfall distribution in that month (eg, January). A 99th percentile shock is defined as whether rainfall in the municipality-month-day falls above the 99th percentile of the usual municipality rainfall distribution in that month (eg, January).*** is significant at the 1% level, ** is significant at the 5% level, * is significant at the 10% level.

Table 4.7: Yearly Adult Labor Market Outcomes: Probability that Child Works

VARIABLES	(1) All	(2) Men	(3) Women	(4) Urban	(5) Rural
Panel A: Days of Heavy Rains					
Days of heavy rains	0.000174	0.000695	-0.000342	2.80e-05	0.000274
	(0.000342)	(0.000619)	(0.000262)	(0.000311)	(0.000560)
Observations	190,595	96,050	94,545	161,889	28,706
R-squared	0.222	0.300	0.122	0.180	0.285
Panel B: 95th percentile shocks					
95th percentile indicator	0.000956**	0.00153***	0.000411	0.000364	0.00163**
	(0.000374)	(0.000572)	(0.000396)	(0.000326)	(0.000701)
Observations	190,595	96,050	94,545	161,889	28,706
R-squared	0.222	0.300	0.122	0.180	0.286
Panel C: 99th percentile shocks					
99th percentile indicator	0.000105	0.00158	-0.000569	-0.00131	0.000640
	(0.00106)	(0.00156)	(0.000911)	(0.00102)	(0.00172)
Observations	190,595	96,050	94,545	161,889	28,706
R-squared	0.221	0.300	0.122	0.180	0.285

Notes:
Standard errors clustered at the municipal level are shown in parentheses. Variables not shown include municipality fixed effects and year fixed effects, and controls for education, age, age squared, marital status and indicators of gender (columns 1, 4 and 5) and urban/rural status (columns 1, 2 and 3). Days of heavy rains is defined as the annual count of days per municipality when rainfall exceeded 10 mm. A 95th percentile shock is defined as whether rainfall in the municipality-month-day falls above the 95th percentile of the usual municipality rainfall distribution in that month (eg, January). A 99th percentile shock is defined as whether rainfall in the municipality-month-day falls above the 99th percentile of the usual municipality rainfall distribution in that month (eg, January).*** is significant at the 1% level, ** is significant at the 5% level, * is significant at the 10% level.

4.8   Conclusions

This study used a large sample of workers from the period 2001-2010 and matched their labor market information as well as socioeconomic characteristics that explain these outcomes with daily rainfall information in the municipality where these workers live. The main objective of this research project was to calculate the effect of floods on labor market outcomes, as well as their heterogeneous effects on different sub-samples of the population and test for possible non-linearities. Econometric estimation of labor market equations was performed to study this question, controlling for municipality

indicators that absorb time-invariant characteristics of the municipalities where workers live and year indicators that control for common shocks to all municipalities in the same year.

I find evidence that urban labor market adjustments in response to negative shocks occur partly through increases in adult unemployment and "forced entrepreneurship". This suggests that at least a fraction of the population is unable to rely on their labor supply to smooth extreme rainfall shocks.

The marginal effect of one additional extreme hydro-climatic event on hours worked and labor income is negative in the short term, and the largest estimated marginal effect on real wage is -8%. This estimate is most likely an under-estimation of the upper bound (worst or most negative) of the effect of floods on real wages per hour, as people adapt to extreme events (Hsiang et al, 2012) and surveyors collecting labor market data could not visit the most affected municipalities during the floods of 2010. This estimate is statistically significant and economically meaningful. On the other hand, the mean effect is larger, as there are more than 1 extreme rainfall events on average during the rainy season in the Caribbean. The effect of negative hydro-climatic events is larger for labor income than hours worked. This has an important implication for welfare: if people wanted to smooth income and obtain the same earnings they did before the extreme rainfall shock, they would have to work more hours at a lower rate. Finally, hours worked and labor income fully recover after 13 months of the extreme rainfall event.

My econometric results show that floods measured by extreme rainfall events compared to usual seasonal rainfall have important heterogeneous effects on the labor market of the Colombian Caribbean. Unemployment raises across all population groups: men, women, urban and rural samples, and this effect is statistically significant and economically meaningful. My evidence points to a larger probability of minor workers as a consequence of extreme rainfall shocks, even though this seems to be a compositional effect rather than an absolute increase in child labor. That is, the proportion of children in the total pool of workers increases even though there is no evidence of an increase in the likelihood that a child works. This may seem puzzling but is mainly the consequence of a raise in adult unemployment, and therefore a decrease in the proportion of adults in the total pool of workers.

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