Coca-Based Local Growth and Its Socio Environmental Impacts in Colombia*

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Abstract

Illegal economies are commonly viewed as barriers to development and sources of violence. This study challenges that view by showing that illegal markets can generate broader economic and social benefits without necessarily increasing violence. We examine the economic and socio-environmental impacts of the 2010s coca cultivation surge in Colombia—the producer of two-thirds of the global coca and cocaine supply—using a difference-in-differences strategy that leverages a policy announcement that created incentives to expand coca cultivation in some municipalities, combined with nighttime lights as a proxy for economic activity. We find that the coca boom increased annual municipal GDP by 2.8% to 10.5%, with an estimated GDP multiplier of 1.45. Despite a 250% rise in coca cultivation, we find no evidence of increased violence. Suggestive evidence indicates improvements in youth educational outcomes. However, the income shock did not lead to higher tax revenues or improvements in public goods provision. Moreover, the economic expansion raised deforestation rates by 77.5%, underscoring the long-term environmental costs of the coca boom.

JEL Classification Codes: O13, O17, Q34, Q56, K42
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"You know that coca moves the entire economy in this region."
Resident of Putumayo, Colombia - June, 2024.

1 Introduction

Do illicit economies hinder local economic and social development? To what extent do their effects spill over into others sectors? Traditionally, illicit markets have been viewed as detrimental to socioeconomic development due to their association with violence and instability (Goldstein 1985; Angrist and Kugler 2008; Castillo, Mejía, and Restrepo 2020; Sviatschi 2022; Vázquez-Cortés 2024). However, in some contexts, they serve as a crucial source of income and social mobility for marginalized communities, particularly where profitable legal alternatives are scarce (Ciro 2020; INCB 2003; Gehring, Langlotz, and Kienberger 2023; Gutiérrez-Sanín 2021; Gutiérrez. 2021; Thomson, Meehan, and Goodhand 2024; Torres-Bustamante 2012). Their economic significance can be substantial: illicit drug production and trafficking accounted for 10% to 15% of GDP in Afghanistan and Myanmar and 2% to 3% in Colombia and Laos (INCB 2003; Montenegro, Llano, and Ibañez 2019). Beyond GDP, illicit economies can reshape legal sectors by injecting financial resources (Thoumi 2003), influence educational and labor market decisions (Angrist and Kugler 2008; Sviatschi 2022), promote social mobility and better living standards (Bautista et al. 2018; Gehring, Langlotz, and Kienberger 2023; Gutiérrez. 2021; Thomson, Meehan, and Goodhand 2024), alter ecosystems (Dávalos et al. 2021; Devine et al. 2021; Murillo-Sandoval et al. 2023; Tellman et al. 2020; Vanegas-Cubillos et al. 2022), and undermine state capacity by fueling competition over territorial control and tax collection (Besley and Persson 2009; Ch et al. 2018; Justino et al. 2024).

This paper examines the local economic impact of Colombia's coca-production boom in the 2010s. Between 2013 and 2017, coca cultivation surged by 256%, rising from 48,189 to 171,494 hectares. This unprecedented expansion resulted from a poorly designed policy announcement in May 2014 regarding an illicit crop substitution program (PNIS by its Spanish acronym), made amid ongoing peace negotiations between the government and the Fuerzas Armadas Revolucionarias de Colombia (FARC)—the country's largest insurgent group—. The announcement lacked concrete implementation details but signaled that the program would prioritize communities engaged in illicit crop cultivation and facing high poverty levels. This fueled expectations that the PNIS would offer economic incentives for voluntary coca substitution, prompting farmers to expand cultivation in anticipation of program benefits (Ladino, Saavedra, and Wiesner 2021; Prem, Vargas, and Mejía 2023; Gelvez and Angarita Serrano 2024).

While previous studies have highlighted the economic significance of illegal economies in marginalized regions, we contribute by quantifying their impact and assessing their magnitude (Britto 2020; Ciro 2020; Espitia and Majbub 2024; Gutiérrez-Sanín 2021; Gutiérrez-Sanín and Machuca 2022; Gutiérrez. 2021; Thomson, Meehan, and Goodhand 2024). In doing so, we provide a more generalizable understanding of how these economies influence economic, social, and environmental dimensions (Duncan 2022).

We employ a difference-in-differences strategy to estimate the impact of the coca production boom on local economic activity, exploiting municipal variation in the ex-ante probability of PNIS selection. This probability—which serves as a proxy for local incentives to expand coca cultivation—is constructed from pre-announcement coca cultivation levels and poverty rates. To measure coca cultivation, we use annual municipal-level data from the United Nations Office on Drugs and Crime's (UNODC) System for Monitoring Illicit Crops (SIMCI), which employs a methodology combining satellite imagery with fieldwork verification. Given the absence of municipal GDP data in Colombia, we measure economic activity through satellite-derived night-time light (NTL) intensity, a widely used alternative in the literature (Henderson, Storeygard, and Weil 2012; Hu and Yao 2022; Martínez 2022). NTL data offer a particular advantage in our context as they capture both formal and informal economic activities, the latter being predominant in coca-growing regions. Our empirical approach compares changes in NTL intensity between municipalities with high versus low PNIS selection probabilities before and after the announcement.

Beyond economic effects, we examine the broader implications of the coca boom on affected regions. We analyze changes in armed conflict dynamics and violence patterns, shifts in land use (including changes in the area allocated to legal agriculture), cattle headcount, and local tax revenues. We also assess environmental impacts through deforestation rates and study effects on school enrollment, migration, labor force participation, and access to utilities. These outcomes are closely linked to the long-term development prospects of predominantly rural communities, providing insights into the potential lasting consequences of the boom.

We first show that municipalities most exposed to the incentives created by the PNIS announcement—those above the 90th percentile of the estimated ex-ante probability of selection—experienced a substantial and rapid increase in coca cultivation. In the year following the announcement, coca cultivation per square kilometer in these municipalities rose by 127% relative to the pre-announcement mean. By 2019, just five years later, coca production had increased fivefold. We find no evidence of differential pretrends and demonstrate that our results are robust to alternative selection-probability thresholds and to using the continuous measure of predicted probability directly.

We find that municipalities with high probability of PNIS selection experienced a substantial 60.3% (s.e. 16.0 pp) increase in NTL intensity post-announcement. The effects exhibit significant spatial heterogeneity, with the largest impacts concentrated in rural areas within municipalities, which experienced an average 77.3% increase in NTL intensity. This pattern aligns with expectations, as coca production predominantly occurs in marginalized regions of the country. Notably, we also observe an 18.3% increase in NTL intensity in urban areas, suggesting substantial multiplier effects in centers of commercial activity. Again, we find no evidence of differential pre-trends across the alternative specifications. Furthermore, when using non-neighboring municipalities with below-median poverty levels as the control group—to account for spatial spillovers and misclassification—the estimated effect increased to 94.3% (s.e. 17.8 pp), indicating that our baseline estimates likely represent lower bounds.

To interpret the economic significance of the observed NTL changes, we estimate the elasticity of GDP to NTL at the departmental level—the highest level of disaggregation for which official GDP statistics are available. Applying the most conservative elasticity estimate of 0.175, corresponding to rural areas, our preferred specification indicates that the coca boom generated a 10.5% increase in municipal GDP between 2014 and 2019, a substantial effect unlikely to be replicated in other legal, non-extractive sectors. Moving beyond these reduced-form estimates, we directly quantify the impact of increased coca cultivation on GDP using an instrumental variables approach, where our instrument interacts the ex-ante probability of PNIS selection with a post-announcement indicator. Our analysis reveals that among pre-announcement coca producers, a one standard deviation increase in coca cultivation per square kilometer (equivalent to 3.1 hectares per Km2) raises municipal GDP by 3.1% in our preferred specification. The differences with the reduced-form estimates emerge because the actual expansion observed in many municipalities was considerably larger, reaching up to four standard deviations.

We show that the increase in revenues from coca cultivation also influences other economic sectors through multiplier effects. To quantify this, we conduct an accounting exercise using UNODC data on regional coca leaf yield per hectare, the price per ton, and observed cultivation changes during the boom years. We find multiplier effects of 1.45 in the agricultural phase and 1.12 in the cocaine base phase, consistent with fiscal multiplier estimates in the literature (Ramey 2011; Delong and Summers 2012; Nakamura and Steinsson 2014). These results, along with rising NTL in urban areas, suggest that coca crop expansion can generate a positive feedback loop, amplifying its overall economic impact.

One key challenge to our identification strategy is the potential confounding effect of FARC's unilateral ceasefire in December 2014, which broadly coincided with the PNIS announcement. However, our results show that FARC's armed presence alone does not significantly affect NTL intensity, suggesting the ceasefire does not drive the observed effects. That said, the largest impact occurs in municipalities with both a high probability of PNIS participation and FARC presence, likely due to former FARC members promoting the substitution program where they had territorial control prior to its implementation (Ladino, Saavedra, and Wiesner 2021; DNP 2023).

We also examine whether the coca boom intensified violence by analyzing multiple conflict indicators, including armed actor presence, victimization rates, and homicides. Contrary to prior literature linking illicit economic booms to rising violence (Goldstein 1985; Angrist and Kugler 2008; Mejia and Restrepo 2013), our findings show no significant increase in these metrics. We do not claim that illegal markets are inherently nonviolent but argue that violence depends on contextual factors such as power equilibria among drug trafficking organizations (DTOs) and state interventions, a perspective supported by recent research (Snyder and Duran-Martinez 2009; Reuter 2009; Durán-Martínez 2017; Ciro 2020; Blattman 2022; Blattman et al. 2025; Gehring, Langlotz, and Kienberger 2023). The FARC's Peace Agreement and the reconfiguration of armed conflict following 2016 could have mitigated the expected increase in violence despite the expansion of coca cultivation.

However, we show that the expansion of coca cultivation significantly increased deforestation rates in affected municipalities, without altering the area dedicated to legal agriculture or the cattle headcount—the primary productive alternatives in these regions. We provide suggestive evidence to interpret the observed deforestation as an indirect effect of the coca economy on environmental degradation, potentially operating through its influence on other economic sectors (Brombacher, Garzón, and Vélez 2021; Ciro 2020; Dávalos et al. 2021; Gutiérrez. 2021; Erazo and Vélez 2020; Murillo-Sandoval et al. 2023; Quiroga-Angel, Pablo, and Wagner 2022). Moreover, the surge in deforestation was concentrated in areas with prior violent FARC presence. However, when exploring heterogeneous effects based on the violent presence of any armed actor, we find that the increase in deforestation driven by coca cultivation was concentrated in municipalities without such presence. These findings suggest that the weakening of FARC's territorial control during the peace negotiations facilitated land grabbing and environmental degradation, whereas in areas with the presence of any armed actor, the coca boom had no effect on deforestation (Prem, Saavedra, and Vargas 2020; Ganzenmüller, Sylvester, and Castro-Nunez 2022; Vanegas-Cubillos et al. 2022).

We find no evidence that increased economic activity translated into higher local tax revenues. Estimates for key municipal taxes—the Industry and Commerce Tax, the Property Tax, and the Fuel Surcharge—show no significant changes, suggesting that much of the economic activity remained informal or operated outside the reach of state taxation. This aligns with broader findings on illicit economies, where parallel governance structures and informal financial circuits limit state fiscal capacity (Besley and Persson 2009; Ch et al. 2018; Justino et al. 2024). The lack of revenue growth underscores the precarious nature of the coca-driven economic boom, as it did not contribute to strengthening local government finances or public investment.

Beyond its direct economic and environmental effects, the coca boom had mixed impacts on broader socioeconomic outcomes. While it did not significantly affect population growth or migration patterns, we find evidence of increased school attendance and literacy rates. These gains were concentrated among individuals under 20, while labor force participation rose among those aged 20 and older. We interpret this finding as evidence that the boom alleviated financial pressure on households, allowing school-age children to remain in school, but simultaneously increased the opportunity cost of higher education as employment opportunities in coca production expanded (Ciro 2020; Gutiérrez-Sanín 2021). Finally, we observe a 6.7 percentage point increase in electricity access, consistent with the rise in NTL, but no significant improvements in access to public water or sewerage services. This indicates that while the coca boom stimulated limited private infrastructure investment, its benefits did not extend to broader public service provision.

Taken together, our findings highlight the complex and uneven consequences of the coca boom. While it generated short-term economic expansion and improved some household outcomes such as educational attainments, its benefits came at the cost of significant environmental degradation. Moreover, the absence of fiscal gains and limited improvements in access to public services could limit the long-term sustainability of the coca boom.

Our paper contributes to three strands of the literature. First, it relates to research quantifying the impact of illegal economies on GDP. Existing studies suggest that drug production can account for a significant share of a country's GDP—up to 15 percent in some cases (INCB 2003; Montenegro, Llano, and Ibañez 2019). However, these estimates rely on accounting exercises based on production, prices, and costs along the supply chain, typically expressed relative to national GDP, even though production is often highly localized. Establishing the causal effects of illicit drug production on local economies remains challenging due to confounding factors that drive both illicit and legal activities, as well as the difficulty of measuring local economic activity. To our knowledge, we provide the first causal estimates of an illegal economy on local GDP, leveraging a plausibly exogenous shift in coca cultivation incentives and using NTL as a proxy for economic activity. Our findings reveal significant short-run effects, aligning with qualitative evidence that coca production is a key income source in regions engaged in early-stage drug production—areas often marked by marginalization, vulnerability, and limited economic opportunities (Bautista et al. 2018; Ciro 2020; Gutiérrez-Sanín 2021; Gutiérrez-Sanín and Machuca 2022; Thomson, Meehan, and Goodhand 2024).

To the best of our knowledge, only two previous studies have examined the economic, social, and violent effects of illegal shocks using quantitative causal methods (Angrist and Kugler 2008; Gehring, Langlotz, and Kienberger 2023). Angrist and Kugler (2008) analyzed the economic impact of Colombia's late-1990s coca boom by comparing coca-producing and non-producing departments, using household survey data. They found that the boom did not significantly increase labor market participation but did raise self-employment income. Additionally, the study identified a positive effect of the coca boom (1990–2000) on an imperfect measure of violence, aggregating homicides, suicides, deaths from military, insurgent activity and non-accident deaths by external causes. Our study contributes to the literature by offering a more granular, regional-level analysis with a comprehensive measure of economic activity. We disentangle the direct and indirect economic effects of the coca boom, employ specific indicators of violence, and adopt a classification approach with lower risks of estimation bias.

A more recent study by Gehring, Langlotz, and Kienberger (2023) examines the effects of opium shocks in Afghanistan on living standards and conflict. Challenging traditional theories that link illegal economies to violence, the authors argue that illegal economic booms can improve socioeconomic conditions and, by raising the opportunity cost of engaging in violence, lead to reductions in conflict-related outcomes. Our findings align more closely with those of Gehring, Langlotz, and Kienberger (2023), as we document significant economic and social effects of the coca boom but no impact on violence indicators. The discussion about the differentiated impacts of illegal economic booms is a central contribution of our paper. We emphasize that our findings are bounded by context-specific conditions—such as conflict configurations and temporal dynamics—and are not intended to be generalized as previous research has done. Nevertheless, they shed light on the developmental potential and economic significance of illegal economies, challenging the prevailing assumption that such activities necessarily constitute barriers to development and drivers of violence.

Second, we contribute to the literature examining the long-run consequences of drug production on the development prospects of affected regions. The prevailing view is that illicit activities hinder development by fostering the presence of non-state armed groups, leading to violence and instability (Goldstein 1985; Angrist and Kugler 2008; Castillo, Mejía, and Restrepo 2020; Sviatschi 2022; Vázquez-Cortés 2024), encouraging corruption, and creating competition with the state over territorial control and tax collection (Besley and Persson 2009; Ch et al. 2018; Justino et al. 2024). We offer a more nuanced perspective. In the short run, we document significant economic gains without an increase in armed group presence or violence. This finding aligns with recent research suggesting that a surge in illicit production does not necessarily lead to violence (Gehring, Langlotz, and Kienberger 2023; Snyder and Duran-Martinez 2009; Reuter 2009; Durán-Martínez 2017; Ciro 2020; Blattman 2022; Blattman et al. 2025), even when the scale is substantial. However, while the economic benefits extend beyond coca growers to other sectors, they remain within the informal economy, failing to improve local tax collection or access to public services beyond those that can be privately sourced. Additionally, increased revenues may ease financial constraints, allowing children to stay in school, but they can also raise labor demand in the sector, increasing the opportunity cost of pursuing higher education.

Finally, we contribute to the literature on the environmental effects of conflict, criminal governance, and illicit economies. Prior research has established a strong link between deforestation and the territorial control of armed groups (Prem, Saavedra, and Vargas 2020; Ganzenmüller, Sylvester, and Castro-Nunez 2022; Vanegas-Cubillos et al. 2022). Studies indicate that conflict-affected areas experienced lower deforestation rates when armed groups maintained control, as they restricted logging and land conversion to reinforce dominance or for ideological reasons. More broadly, armed conflict limited external actors' involvement in large-scale deforestation, whereas its decline created a power vacuum that facilitated environmental degradation by land grabbers, ranchers, and illegal actors. Our findings highlight that deforestation patterns are shaped not only by the presence of armed groups, but also by the economic dynamics driven by illegal economies. While we provide suggestive evidence of the interplay between illicit economies and environmental degradation, further research is needed to deepen our understanding of how illicit and licit economic activities, as well as criminal and rebel governance structures, interact to promote environmental harms.

2 Institutional Context

Colombian Coca Economy. The trajectories and characteristics of the coca economy vary across different regions and have experienced cycles of booms and busts (Torres-Bustamante 2012; Ciro 2020). Although discussing the evolution of this sector and its role in the colonization process in coca-producing areas is beyond the scope of this paper, it is important to highlight some of the reasons that explain its significance for the peasant economy. Like other illicit crops, the coca-based economy has unique characteristics that rupture rural development barriers making it attractive to producers and harvesters, offering benefits that extend beyond those directly involved in production and commercialization of these products.

Coca cultivation, for instance, averages four harvests per year, with low production and transportation costs. Unlike traditional local crops, coca is embedded in a global economy, with a guaranteed international market and long periods of price stability for both leaves and cocaine base. The relatively easy maintenance of coca plants allows farmers to use their free time for other activities. The remaining time is often spent working on other farms, tending to animals, or engaging in other crops (Marín-Jaramillo, Machuca-Pérez, and Acero-Vargas 2020).

As noted by Thomson, Meehan, and Goodhand (2024), economies based on illicit crops generate sufficient income for survival on small plots (including leasing systems), rely on family labor, and offer better-paid temporary employment compared to other activities. These economies also generate income beyond that of the cultivators, which circulates within the local economy. Furthermore, they provide liquidity, access to credit, and even serve as sources to develop public infrastructure. The vibrant markets in coca-growing towns are vividly captured in Gutiérrez. (2021)'s description:

> *"These 'villages', are no small bucolic hamlets – they are buzzing places where motorbikes dart recklessly through the streets non-stop; the sound of the choppers in the coca laboratories is constant; there are busy shops of all kinds and a flourishing commerce; crowded cock-fight pits, nightclubs and bars play music loud (...). People are far from rich but compared to the sluggish pace of rural villages in the central cordillera, you can see that coca does that little bit more in terms of the purchasing power of the local population."* — **(Gutiérrez. 2021)**

The Peace Process with FARC. The 20th century in Colombia was marked by internal conflicts involving left- and right-wing armed groups, as well as drug trafficking cartels. The FARC, founded in the 1960s, emerged as the nation's dominant non-state armed force. In 2012, former President Juan Manuel Santos launched a renewed peace effort with the FARC, publicly announcing negotiations, though secret talks had begun earlier. The negotiation agenda was comprehensive, focusing on six key points: rural reform, political participation, end of the conflict, solution to the problem of illicit drugs, reparation of victims, and implementation, verification, and ratification. A final peace accord with the FARC was reached in 2016, marking a significant milestone in the country's efforts to end the long-running conflict.

The Announcement of the PNIS Program. The cocaine industry has been a significant source of financing for armed groups in Colombia, contributing to the persistence of the conflict (Angrist and Kugler 2008; Cornell 2007; Mejia and Restrepo 2013). Addressing drug trafficking was therefore a crucial part of the peace negotiation agenda. In May 2014, delegates from both parties held a joint press conference in Havana, announcing the creation of the National Comprehensive Program for the Substitution of Illicit Crops (PNIS by its Spanish acronym), to be implemented upon the signing of the peace accord.

The PNIS aimed to transform the socioeconomic conditions in regions affected by illicit crop cultivation as they transitioned into legal economies. Its primary objective, as stated in the press conference, was to create *"material and immaterial conditions of well-being and good living for populations affected by illicit crops, particularly for rural communities in poverty who currently derive their subsistence from these crops."* While the announcement lacked specific details on the benefits or targeted municipalities, it was understood that the program would provide economic support to induce voluntary substitution of illegal crops for legal alternatives.

Even though the Colombian government's objective with this program was to support the transition to legal crops, coca cultivation in Colombia surged dramatically between 2013 and 2017. Figure 1 shows the evolution of the area cultivated with coca during the first two decades of this century, based on information from the UNODC. Between the announcement and the first year of PNIS implementation, the area under coca cultivation increased by 256%, rising from 48,189 to 171,494 hectares.

There is substantial evidence that the announcement of the PNIS program generated expectations of future benefits for coca producers, leading to a coca boom in anticipation of the program's implementation (Ladino, Saavedra, and Wiesner 2021; Prem, Vargas, and Mejía 2023; Gelvez and Angarita Serrano 2024). The boom was partly facilitated by the ease of growing coca, which can yield an initial harvest six months after planting. Surveys among beneficiaries also revealed that households believed participating in the PNIS would yield greater benefits if they had a larger coca cultivation area (Garzón and Llorente 2018). Additionally, families enrolled in the PNIS tended to declare cultivation areas nearly double what they actually possessed (Garzón and Llorente 2018). In a 2019 hearing in the Constitutional Court, former president Santos acknowledged the unintended consequences of the PNIS announcement:

> *"It has been claimed that the increase in coca crops in recent years is due to the cessation of aerial spraying. This is not true. I repeat, this is not true. The majority of the increase can be attributed to several factors: the devaluation of the Colombian Peso (COP), which boosted profits; the decline in gold prices; the realignment of illegal groups in territories previously controlled by the FARC; and, admittedly, the perverse incentives created by the announcement of benefits under the illicit crop substitution program during the negotiations with the FARC."* — **Former President J. M. Santos, Constitutional Court Hearing, Bogota, March 7th, 2019.**

Our empirical strategy, detailed in Section 4, exploits municipal-level variation in the incentives to expand coca production generated by the announcement of the PNIS program. In particular, we exploit differences in the *ex-ante* likelihood of a municipality being assigned to the PNIS and the timing of its announcement to examine the impact of the coca boom on local economic activity. Additionally, we analyze whether other drivers of the boom, such as the ones suggested by former president Santos, may confound the effect of coca production on economic activity.

The Implementation of the PNIS Program. The PNIS formally began in 2017, following the signing of the Peace Agreement. However, the program was implemented in only 56 municipalities, representing about 23% of the total municipalities with coca cultivation in 2013. Implementation started with the signing of community agreements, after which the United Nations verified compliance with the program's requirements. Upon verification, the Colombian Government was supposed to transfer 36 million Colombian pesos in cash and in kind (about 9,500 USD at the time) to each household over a two-year period for voluntarily engaging in crop substitution, partially confirming the expectations generated by the program's announcement.

The implementation of the PNIS faced significant challenges, including payment delays, limited coverage, and interference from illegal armed groups. By 2019, only 0.82% of households had received the promised transfers (DNP 2023; Londoño, Marín-Llanes, and Vélez 2024). Given that the program was a key component of the broader objectives outlined in the Peace Agreement, particularly the Comprehensive Rural Reform, these delays also disrupted progress in other areas. According to Kroc (2020), by November 2019, only 4% of the provisions intended to achieve Comprehensive Rural Reform had been completed.

3 Construction of Main Variables and Data Sources

Night-Time Lights. We lack appropriate GDP measures at the municipal level in Colombia.[1] Therefore, we measure economic activity using satellite imagery of *NTL*. Using *NTL* as a proxy for GDP is a widely adopted strategy in the literature, particularly when traditional alternatives are unavailable at the subnational level (Doll, Muller, and Morley 2006; Chen and Nordhaus 2011; Henderson, Storeygard, and Weil 2012; Pinkovskiy and Sala-i-Martin 2014; Pérez-Sindín, Chen, and Prishchepov 2021; Bluhm and McCord 2022; Hu and Yao 2022), or when there are concerns that official statistics might be manipulated (Martínez 2022).

We use two sources for the *NTL* data. First, we employ the Defense Meteorological Satellite Program (DMSP) dataset, which is available annually from 1992 to 2013. Second, we use the Suomi National Polar-Orbiting Partnership (Suomi-NPP) dataset, which is available monthly from April 2012 to the present.[2] To address comparability issues between the two sources, we use the Harmonized Global Night-time Light

1. Municipalities in Colombia are key administrative units within the country's administrative divisions, tasked with local governance and public service delivery. Each municipality is governed by an elected mayor and a municipal council, providing a degree of autonomy to manage resources, set policies, and address community needs. There are 1,120 municipalities in the country. Our analysis is restricted to municipalities with populations of less than 200,000 inhabitants, which comprise 97.6% of all municipalities.

2. Both projects have satellites equipped with sensors capable of collecting the radiation emitted by nightlights on the Earth's surface. However, DMSP employed an Operational Linescan System (OLS) sensor, while Suomi-NPP uses the Visible Infrared Imaging Radiometer Suite (VIIRS) instrument. Additionally, the DMSP data has a resolution of 30 arc seconds (approximately 1 km at the Equator), whereas the Suomi-NPP data has a resolution of 15 arc seconds.

Dataset by Li et al. (2020). In this dataset, VIIRS radiance measures are converted to DMSP-like night-time light values[3] using a sigmoid function trained on the overlapping years of 2012 and 2013, and adjusted for monthly cloudiness. The harmonized dataset provides consistent time-series data from 1992 to 2021.

We aggregate the *NTL* data to the municipal level by taking the average of the annual *NTL* values per pixel within municipalities. To differentiate economic activity in urban and rural areas, we follow a similar procedure but employ the official census cartography of Colombia to construct an *NTL* index for five areas: the entire municipality, the municipality's capital, populated areas[4], urban areas (capital + populated areas), and rural areas (see Figure A.1 for an example).

A natural question is whether *NTL* can serve as a reliable proxy for economic activity at the subnational level in Colombia. To investigate this, we estimate the elasticity of GDP to *NTL* at the departmental level, the highest level of disaggregation for which we have official GDP statistics.[5] Specifically, we regress the logarithm of GDP on the logarithm of *NTL*, controlling for departmental fixed effects and a linear time trend. The results, presented in Table 1, show that the elasticity is between 0.16 and 0.36, depending on the geographic area considered. These values align with previous estimates in the literature (Pérez-Sindín, Chen, and Prishchepov 2021; Henderson, Storeygard, and Weil 2012; Martínez 2022; Hu and Yao 2022).[6]

Extent of Coca Cultivation. We use data on the area cultivated with coca crops at the municipality level from the System for Monitoring Illicit Crops (SIMCI) dataset provided by the United Nations Office on Drugs and Crime (UNODC). SIMCI constructs data on the number of hectares of coca in Colombia through a comprehensive methodology that combines various remote sensing technologies and ground verification. Importantly, given the use of satellite imagery, mismeasurement due to the presence

3. Night-time light values in DMSP are defined in digital numbers (DNs), which are arbitrary units used to quantify the intensity of the light detected by the satellite sensors. The unit of measurement is a result of the 6-bit quantization radiometric resolution used by the DMSP-OLS sensors.

4. Populated areas in Colombia are defined as areas in rural regions with more than 20 houses.

5. Departments in Colombia are the primary administrative divisions, similar to states or provinces in other countries. Colombia is divided into 32 departments, which vary widely in population, economic activity, and geographic characteristics.

6. The elasticities closely match those reported by Pérez-Sindín, Chen, and Prishchepov (2021) for Colombia, also at the departmental level. In cross-country analysis, Henderson, Storeygard, and Weil (2012) and Martínez (2022) estimate elasticities of GDP to *NTL* at 0.30 and 0.28, respectively. Hu and Yao (2022) reports an even larger elasticity of 0.77. The authors attribute their larger estimates to the use of a more flexible statistical model that accounts for measurement errors in both *NTL* and GDP data.

of armed actors in conflict areas is not a mayor concern.[7] We use the average annual hectares of coca cultivation per 1,000 hectares of municipal area.

Armed Groups Presence and Violence. Our primary measures of the presence of FARC and other non-state armed groups rely on recorded violent incidents from the municipal panel produced by the Center for Studies on Economic Development (CEDE), which compiles information on violent acts attributed to different groups until 2014. We define the violent presence of FARC and other armed groups as having at least one recorded violent event attributed to them between 2011 and 2013. Given that CEDE's data has not been updated beyond 2014, we supplement it with data from the Violent Presence of Armed Actors in Colombia (ViPPA) project, which tracks violent events at the municipality level from 1988 to 2019 (Osorio et al. 2019). However, neither measure captures non-violent presence, a key limitation of our approach (Arjona and Otálora 2011).

In some specifications, we use municipality-year homicide data reported by the National Colombian Police. Additionally, we use data from the Unique Victims' Register of the Colombian Government, which records every victim of the internal conflict. Registration in this system is required for victims to be identified and recognized by the Colombian Government, allowing them to initiate a reparation process. The data is categorized by different types of victimization. Finally, as an alternative measure of violence, we use data on the killings of social leaders, obtained from *Somos Defensores*, a nongovernmental organization (NGO) that has monitored these killings since 2005 (Marín-Llanes 2022; Orbegozo-Rodríguez 2021; Prem et al. 2022). All measures of violence were normalized per 100,000 inhabitants.

4 Methods: Empirical Framework

Classification of Municipalities by Probability of Selection into PNIS. We classify municipalities based on their ex-ante probability of being selected for the PNIS. While the announcement did not explicitly identify which municipalities would be chosen to receive benefits, it outlined two primary criteria: high coca crop density and high poverty rates. Consequently, expectations of future gains from the coca substitution program, and the resulting incentives to expand coca production, should be more pronounced in municipalities exhibiting these characteristics. Notably, the announcement did not include the presence of armed groups, including FARC, as a selection criterion,

7. SIMCI uses high-resolution satellite images to detect and monitor coca crops, identifying fields based on specific spectral signatures. Aerial surveys supplement satellite imagery, with aircraft equipped with cameras and sensors validating and providing additional details on coca cultivation. Field teams conduct ground verification missions to cross-check data from satellite and aerial imagery, confirming the presence of coca crops, assessing their conditions, and gathering additional information.

thereby rendering all municipalities eligible for the program.

Following Prem, Vargas, and Mejía (2023), we estimate the *ex-ante* probability of selection using the following Probit model:

$$Pr(PNIS_m = 1) = \Phi\left(\gamma_0 + \gamma_1 \text{CocaCrops}_m + \gamma_2 \text{MPI}_m\right), \quad (1)$$

where $PNIS_m$ equals one if the municipality m was listed by the government as eligible for PNIS in 2017, and 0 otherwise[8]; $CocaCrops_m$ is the average hectares of coca cultivated per 1,000 hectares in municipality m between 2011 and 2013; and MPI_m is the Multidimensional Poverty Index of the municipality as of 2005, the latest pre-announcement measure. With the estimated parameters, reported in Appendix Table A.1, we compute the predicted probabilities.

We use two alternative classifications for municipalities: binary and continuous. In the binary classification, a municipality is considered to have a high probability of selection if its predicted probability exceeds the 90th percentile of the distribution of predicted probabilities across all municipalities. This threshold corresponds to an estimated probability of 11.2%, with an overall mean of 6.9% and a standard deviation of 11.0 percentage points.[9] Our findings remain robust when using thresholds at the median or 75th percentile. To avoid arbitrary cut-points, we also estimate the models using the continuous predicted probability, which is standardized for easier interpretation.

Figure 2 illustrates the spatial distribution of municipalities using the binary classification. High probability municipalities are predominantly situated along the Pacific coast, the Amazonian region in the south, and the Catatumbo region bordering Venezuela. These areas are consolidated coca producing clusters and armed actors are actively present.

Effect of the PNIS Announcement on NTL. For clarity, we outline the methodology using the binary classification of municipalities, though a similar approach is applied for the continuous measure.

The analysis exploits the timing of the May 2014 PNIS announcement in a difference-in-differences (DiD) strategy. We compare NTL—before and after the announcement—between municipalities with a high versus low probability of selection for the PNIS. Specifically, we estimate the equation:

$$\ln(NTL_{m,t}) = \alpha_m + \delta_{d,t} + \beta(Post_t \cdot HighProbPNIS_m) + \phi(X_m \cdot Post_t) + \epsilon_{m,t}, \quad (2)$$

8. The Colombian government defined 77 municipalities as eligible, although the program was implemented in only 56 of them. Our approach follows an intent-to-treat methodology. However, results are unchanged if we use the 56 municipalities where the program has been implemented.

9. The 90th percentile threshold also coincides with the predicted probability of a municipality at the median of the poverty index among all municipalities with a positive average number of hectares of coca crops cultivated before 2014.

where $\ln(NTL_{m,t})$ is the logarithm of the NTL index for municipality m at time t; $HighProbPNIS_m$ is an indicator variable for municipalities classified as high-probability; $Post_t$ is an indicator variable for the years following the announcement, including 2014; α_m represents municipality fixed effects; and $\delta_{d,t}$ represents department-year fixed effects. In some specifications, we include a vector of pre-determined geographic controls, X_m, which includes the municipality's area, altitude, the ratio of rural population over total municipal population in 2013, and distance to the nearest departmental capital, all interacted with the post-announcement indicator. The coefficient β is our parameter of interest. To translate the effect on NTL into economic terms, we approximate the impact on local economic activity by multiplying β by the relevant elasticity of GDP to NTL (see Table 1).

Identification relies on the standard common trends assumption. To assess its validity and analyze the temporal dynamics of the announcement's impact, we estimate a dynamic version of Equation (2):

$$\ln(NTL_{m,t}) = \alpha'_m + \delta'_{d,t} + \sum_{j \neq -1} \tau_j (\mathbf{1}\{j = t - 2014\} \cdot HighProbPNIS_m) + \phi'(X_m \cdot Post_t) + e_{m,t}. \tag{3}$$

Threats to Identification. The primary threat to identification stems from potential confounding factors that coincided with the PNIS announcement and could have differentially impacted economic activity across municipalities with varying probabilities of PNIS selection. A notable concern is the shifting local conflict dynamics resulting from the advancing peace process and the unilateral ceasefire by FARC in December 2014. The presence of FARC and other armed groups in a municipality is positively correlated with coca crop cultivation, a key predictor of PNIS targeting. If local conflict dynamics changed in response to the announcement and simultaneously influenced economic activity, we might erroneously attribute these effects to the coca boom. More broadly, the announcement marked a significant milestone in the peace process and could have been interpreted as a signal of de-escalating conflict with FARC. This perception alone might have led to improved local economic conditions, particularly in areas with a strong FARC presence.

We examine this possibility in three ways. First, we estimate a modified version of Equation (2) where $HighProbPNIS_m$ is substituted with $FARC_m$, an indicator of FARC violent presence in the municipality during the years preceding the announcement. Second, we investigate the heterogeneous effects of the announcement by FARC presence in a triple-difference approach. Finally, we assess the announcement effects on local violence metrics.

Effect of the Coca-Production Boom. The estimates from Equations (2) and (3) represent the reduced-form (RF) effects of the PNIS announcement on NTL. However, our primary interest lies in quantifying the effect of the coca production boom itself. To this end, we extend our difference-in-differences strategy to an instrumental variables (IV) framework. Specifically, we estimate the following equation:

$$\ln(NTL_{m,t}) = \alpha''_m + \delta''_{d,t} + \gamma CocaCrops_{m,t} + \phi''(X_m \cdot Post_t) + \eta_{m,t}, \tag{4}$$

where $CocaCrops_{m,t}$ is the hectares of coca cultivated per square kilometer in the municipality. In this specification, we instrument $CocaCrops_{m,t}$ with the interaction $Post_t \cdot HighProbPNIS_m$.

Beyond the identification threats discussed above, this instrumental variables approach relies on two key assumptions. First, the PNIS announcement incentivized increased coca cultivation in municipalities with a high probability of selection. Second, the PNIS announcement affected NTL only through its impact on coca cultivation. We assess the validity of these assumptions below.

5 Effect of the Coca Boom on Municipal NTL and GDP

Differential Pre-Trends and Instrument Relevance. We begin by presenting two pieces of evidence supporting our identification strategy: no differential pre-trends in NTL and a strong positive effect of the PNIS announcement on coca production.

Figure 3 presents estimates of the τ coefficients in equation (3). Panel (a) uses the binary classification of municipalities, while Panel (b) employs the standardized probability of selection. The results show no evidence of differential pre-trends: the patterns of NTL from 2005 to 2013 are similar across municipalities with varying probabilities of selection for the PNIS. The F-test for the joint null hypothesis that all pre-announcement coefficients are zero cannot be rejected, with values of 1.18 and 0.76, respectively. This supports the assumption that parallel trends would likely hold in the absence of the announcement.

Figure 4 shows estimates from a similar model specification, but using $CocaCrops_{m,t}$ as the dependent variable instead of $\ln(NTL_{m,t})$. This corresponds to a dynamic version of the first-stage regression in the IV model. In the year of the announcement, hectares of coca cultivated per square kilometer in high-probability municipalities increased by 5.97 (s.e. 1.71) on average, representing a 127% increase relative to the pre-announcement mean. By 2019, only five years later, coca production in these municipalities had increased by a factor of five, a massive change over a short period.

Estimates using the continuous measure of PNIS probability reveal smaller but still significant effects: a one-standard-deviation increase in the likelihood of receiving PNIS is associated with an increase in coca production of 1.2 hectares per square kilometer in 2014, escalating to 4.5 hectares per square kilometer by 2019. Both the binary and continuous measures provide compelling evidence that the PNIS announcement triggered a significant expansion of coca cultivation in Colombia.

Effect on Night-Time Lights and Economic Activity. Table 2 presents the effects of the PNIS announcement and the subsequent coca boom on *NTL* intensity and municipal GDP. Panel (a) reports the reduced-form estimates; while panel (b) presents the instrumental variables (IV) estimates. All specifications report clustered standard errors by municipality and department-year in parentheses.

Our analysis reveals a robust and statistically significant positive effect of the PNIS announcement on *NTL* intensity. In our preferred specification with geographic controls, high-probability municipalities experienced a 60.3% increase in *NTL* post-announcement (s.e. 16.0 pp) relative to the control group. Using the continuous classification, a one-standard-deviation increase in the assignment probability corresponds to a 15.8% increase in *NTL* (s.e. 4.3 pp).

Applying the estimated overall elasticity of GDP to *NTL* from Table 1, which is 0.358, our results imply a significant expansion in municipal GDP, ranging from 5.5% (continuous classification) to 21.1% (binary classification). However, estimates of the effects by geographic area, discussed below, show that the impacts on *NTL* are predominantly concentrated in rural areas and populated centers. Given this, a more conservative elasticity of 0.175, specific to rural areas, is more appropriate. Using this rural-specific elasticity, we estimate a more modest, yet still notable, economic expansion ranging from 2.8% (continuous classification) to 10.5% (binary classification).

The timing of the effects is particularly noteworthy and provides insights into the causal mechanisms at play. Figure 3 reveals that the increase in *NTL* intensity in high-probability municipalities began immediately following the PNIS announcement, with the effect peaking in 2018. Notably, by 2016, when the peace agreement was signed and before the actual implementation of PNIS began, the majority of the observed effect had already materialized. This temporal pattern is inconsistent with the hypothesis that either the signing of the peace agreement or the implementation of PNIS explain the results. Instead, it suggests that the anticipation of the program through the increase in coca crops was the primary catalyst for the observed changes in economic activity.

Panel (b) of Table 2 presents the IV estimates of equation (4). To interpret the magnitude of the effects under our preferred specification, we consider a one standard deviation increase in coca cultivation per square kilometer among pre-announcement coca producers, equivalent to 3.1 hectares. Notably, the actual increase was significantly larger, reaching up to four standard deviations. We estimate a rise in *NTL* intensity between 14.6% (continuous probability) and 17.6% (binary classification). Applying our more conservative elasticity of GDP to *NTL* for rural areas, this translates to an increase in municipal GDP between 2.5% (continuous classification) and 3.1% (binary classification).

These results extend the predominantly qualitative literature on the economic impact of coca cultivation in Colombia. They align with extensive qualitative studies highlighting the coca economy's central role in regional economic dynamics (Ciro 2020; Gutiérrez. 2021; Thomson, Meehan, and Goodhand 2024). While previous quantitative analyses have linked illicit crop cultivation to labor market conditions, household food consumption, and asset acquisition (Angrist and Kugler 2008; Gehring, Langlotz, and Kienberger 2023), our study advances this understanding by measuring its impact on local economic activity, including both formal and informal sectors.

Heterogeneity by Geographic Area. We exploit the detailed granularity of our data by aggregating NTL across the four geographic areas within municipalities. For each area, we estimate separately equation (3) using the binary classification and the full set of geographic controls. Patterns are unchanged when using the continuous classification.

Results from this exercise are shown in Figure 5. The coca boom has a positive and statistically significant impact on economic activity in all areas except for the municipal capital. The largest effects are observed in rural areas, where NTL increased by 77.3% on average (static specification), followed by a 29.2% increase in populated areas. This heterogeneity is expected, as coca production is concentrated in marginalized rural areas. However, we observe an 18.3% increase in NTL in urban areas, which is consistent with a sizeable multiplier effect in areas were commercial activities takes place.

Direct and Indirect Effects on GDP. Coca production can boost local economic activity through two main channels: directly by increasing revenues from coca cultivation and indirectly by stimulating demand for goods and services in other sectors. If these multiplier effects are large, even small changes in coca production can have a significant impact on local GDP. To quantify the contributions of these channels, we conduct a simple accounting exercise.

We begin by estimating the direct effect, denote by $\Delta D_{m,t}$, using three variables: the number of hectares under cultivation in each municipality ($CocaCrops_{m,t}$), the average coca leaf yield per hectare (in tons) ($Yield_{m,t}$), and the price per ton of coca leaves ($P_{m,t}$).[10] In particular,

$$D_{m,t} = CocaCrops_{m,t} \cdot Yield_{m,t} \cdot P_{m,t}, \tag{5}$$

10. Yield and price information are taken from UNODC. The data is available for seven regions spanning 2005–2021.

and $\Delta D_{m,t} = D_{m,t} - D_{m,t-1}$. However, revenues from coca leaf sales capture only the initial stage of the cocaine production chain.[11] While most coca growers are involved only in the agricultural phase, a significant portion also engages in the transformation of coca leaves into coca paste or cocaine base.[12] To account for the second stage in the cocaine value chain, we also estimate revenues using the conversion rate from coca leaf to cocaine base—an output with higher added value than coca paste and for which data is available—adjusting for the corresponding market price of cocaine base (UNODC 2023). This value-added measure incorporates the cost of coca leaves, offering a more accurate assessment of the economic gains generated along the production chain.

Second, building on our findings from panel (b) of Table 2, we estimate the total (monetary) effect of the production boom on local GDP, denoted by $\Delta Y_{m,t}$. We do this by first multiplying the estimated response of NTL to coca cultivation ($\hat{\gamma}$) by the actual change in municipal coca hectares ($\Delta CocaCrops_{m,t} = CocaCrops_{m,t} - CocaCrops_{m,t-1}$). Then, we apply the elasticity of GDP to NTL, using the rural-specific elasticity of 0.175. In particular,

$$\Delta\% G\hat{D}P_{m,t} = \Delta CocaCrops_{m,t} \cdot \hat{\gamma} \cdot 0.175 \tag{6}$$

A key challenge is comparability, as the total effect is expressed as a percentage change of municipal GDP, while we are interested in the change in values. Since municipal GDP data are unavailable, we approximate them by assuming that a municipality's share of departmental luminosity reflects its share of departmental GDP, that is, $GDP_{m,t} \approx \frac{NTL_{m,t}}{\sum_{m \in R} NTL_{m,t}} \cdot GDP_{R,t}$, where R indexes departments. While this assumption may introduce some imprecision, it provides a reasonable first approximation. Finally, we define $\Delta Y_{m,t} = \Delta\% G\hat{D}P_{m,t} \cdot GDP_{m,t-1}$.

Total and direct effects are related by

$$\Delta Y_{m,t} = (1 + m) \cdot \Delta X_{m,t}, \tag{7}$$

where $(1 + m)$ is a measure of the multiplier effect, which we compute using $\Delta Y_{m,t}$ and $\Delta X_{m,t}$.

Table 3 reports the estimated average of two multipliers, distinguishing between income generated from the sale of coca leaves and that from the sale of cocaine base. These estimates are based on the sample of municipalities with coca production prior

11. Coca cultivation, the agricultural input for cocaine production, contributes 8.2% of the total value added within national production and distribution (Zuleta 2024). Its share drops to 1.1% when accounting for international commercialization.

12. According to UNODC (2020), 45% of coca growers between 2015 and 2019 participate in this transformation process, though there are substantial regional differences: in the Pacific and Caribbean regions, only 8% and 9%, respectively, are involved, whereas in *Orinoquía* and *Meta-Guaviare*, the rates are 100% and 87%.

to the announcement. During the boom period, the multiplier $(1+m)$ for coca leaves is 1.446 (s.e. 0.089). For cocaine base, the multiplier is 1.119 (s.e. 0.067). These results suggest a significant indirect effect that extends beyond the direct revenues from coca production. The coca boom benefits other sectors of the economy as well, creating a positive feedback loop that amplifies the overall economic impact.

Lastly, we use the estimated total effect by municipality to assess the impact of the coca boom on national GDP. To do this, we sum the total effect across all municipalities for each year and then divide the resulting value by the corresponding national GDP. Our findings indicate that, on average, the coca boom contributed 0.4% to national GDP. Although this value may seem modest given the substantial effects on local economies, it is important to note that coca-producing municipalities account for only 1.93% of national production on average. Therefore, significant local impacts do not necessarily translate into large aggregate effects. We also emphasize that this calculation does not capture the broader impacts of cocaine production at later stages of the supply chain, likely resulting in an underestimation of the overall economic impact.

Spillover Effects. A key concern is that the effects of increased coca production likely extend beyond the municipalities where cultivation occurs. These spillover effects could reach neighboring areas, potentially causing an underestimation of the economic impact when nearby municipalities are classified as part of the control group.

To test for spillover effects, we modify our empirical strategy by defining three groups: (i) municipalities with a high probability of being included in the PNIS (defined as before), (ii) municipalities neighboring those with a high probability of PNIS selection, and (iii) all other municipalities. Using this classification, we estimate equation (2), treating the third group as the control. The results, presented in Table A.2, indicate that the effects remain concentrated in high PNIS probability municipalities and are statistically indistinguishable from those in the original specification. However, we find some evidence of spillover effects on neighboring municipalities, where *NTL* increases by 16.6% relative to the controls. This pattern could also reflect a misclassification of treated municipalities due to the selected cutoff.

To further examine this issue, we estimate the dynamic model in equation (3), comparing high PNIS probability municipalities with two alternative control groups: (i) municipalities with no coca production at baseline and (ii) municipalities with no coca production at baseline and multidimensional poverty rates below the median. The rationale behind this approach is that these municipalities are less likely to be targeted by PNIS, reducing the risk of misclassification. Moreover, spillover effects on these control municipalities would occur mostly through cross-municipality multiplier effects, which, while potentially relevant, are significantly smaller in magnitude. The results of this exercise are shown in Panels (a) and (b) of Figure 6. In both cases, we find no evidence of differential pre-trends. The estimated effects remain economically significant: 61.4% (s.e. 16.9 pp) in the first specification and 94.3% (s.e. 17.8 pp) in the second. The latter result suggests that, if anything, the baseline estimates should be considered lower bounds.

Gold Mining and Cannabis. Coca-producing regions often engage in other illegal activities, which could confound the effects of the coca boom on local GDP. Colombia is also a major producer of cannabis, especially in the Northern Cauca region (Espitia and Majbub 2024). Some cannabis is grown indoors with artificial lighting to maintain production levels during the night. Therefore, some of our findings might be influenced by the overlap between regions cultivating coca and those involved in cannabis production. Additionally, as pointed out by President Santos, declining gold prices during the analysis period might have affected gold mining activities, particularly unregulated ones. Since this shock occurred at broadly the same time as the PNIS announcement, it is important to disentangle its effects.

To address these concerns, we conducted two robustness exercises. First, we excluded the Cauca department from our estimation sample. As shown in Table A.3, the results remain consistent with our baseline findings. Second, we examined whether the coca boom had differential effects on economic activity in municipalities with active gold mining. The results in Table A.4 indicate no significant difference in economic performance between municipalities with and without gold mining activities following the PNIS announcement.

Local Violence Dynamics. One of the main threats to our identification strategy is that the PNIS announcement coincided with FARC's unilateral ceasefire in December 2014, potentially confounding the effect of the coca boom on local economic activity.

The results in columns (1) and (2) of Table 4 show that FARC presence alone has no significant impact on *NTL*, suggesting the ceasefire does not explain the observed effects. However, column (3) shows the largest impact occurs in municipalities with both a high probability of PNIS participation *and* FARC's violent presence. Former FARC members promoted the substitution program in these areas (Ladino, Saavedra, and Wiesner 2021; DNP 2023), likely raising expectations of future benefits in regions previously affected by FARC-related violence. Notably, prior to PNIS implementation, the program included socialization meetings, 62% of which took place in municipalities with a pre-announcement FARC presence (Ladino, Saavedra, and Wiesner 2021).

This does not mean that municipalities with a high probability of PNIS participation but no FARC presence experienced no effect. Comparing these municipalities to those with low PNIS probability and no FARC presence reveals a 36.9% increase in *NTL* (column 3). Although the estimates are imprecise and not statistically significant due to the small sample of municipalities with these characteristics, the data show a consistent pattern. A similar result emerges when using an indicator for the presence of any armed group.

In a second exercise, we assess whether the coca boom intensified the conflict using a comprehensive set of violence metrics. These include measures of violent presence of non-state armed actors, victimization rates, and homicide rates. In practice, we estimate equation (2) with each metric as the dependent variable.

Table 5 presents the results, showing that, apart from the killings of social leaders (discussed below), the coca boom did not intensify the violent presence of armed actors, internal conflict victimization rates, or homicides. These findings contrast with the literature suggesting that rising returns from illegal economic activities often fuel violence by increasing competition among groups vying for market control (Angrist and Kugler 2008; Goldstein 1985; Mejia and Restrepo 2013). However, we do not interpret our results as evidence that illegal activities never lead to violence. Rather, our study takes place during a period of reconfiguration of armed conflict due to the Peace Agreement with one of the main non-state actors involved. What the evidence suggests is that violence is not an inevitable consequence of illegal booms, even one of this magnitude.

An alternative explanation is that spillover effects result in an increase in violence in both treated and control groups, leading to attenuation bias. We argue this is unlikely. First, national trends, presented in Figure A.2, show that key violence indicators—including violent disputes among armed actors, the presence of armed groups, homicide rates, and victimization rates—were either stable or declining over the period of analysis, particularly before 2018, when the effect on economic activity had already materialized. A similar pattern is observed in coca-producing regions. Even if spillover effects where present, the broader evidence suggests that violence was not rising during the boom period. Second, we estimate the same two-arm treatment model using violence indicators as dependent variables. Table A.5 presents these results, showing that the coca boom did not differentially affect eight out of nine violence metrics in high-PNIS-probability municipalities or their neighbors relative to the non-neighboring control group.

Regarding the killings of social leaders, the implementation of the PNIS program began with collective agreements led by social leaders, who played a crucial role in encouraging households to voluntarily substitute coca crops. In a previous study, Marín-Llanes (2022) found that the signing of these agreements led to a 481% increase in the rate of killings of social leaders. However, this surge in violence occurred after the PNIS was implemented. Figure A.3 presents the estimates from the dynamic model for this variable, showing that, consistent with Marín-Llanes (2022), statistically significant effects emerged only from 2017 onward, coinciding with the signing of community agreements.

This paper does not aim to identify the mechanisms behind these results or analyze non-state armed actors and DTOs dynamics during this period. However, several studies suggest that illegal markets do not necessarily lead to higher levels of violence, as the extent of violence depends on factors such as power equilibria between DTOs and state interventions (Britto 2020; Ciro 2020; Durán-Martínez 2015b; Durán-Martínez 2015a, 2017; Grisaffi 2022; Osorio 2015; Reuter 2009; Snyder and Duran-Martinez 2009). These groups often act strategically, and in many contexts, violence is not economically profitable (Durán-Martínez 2015b; Durán-Martínez 2017; Blattman 2022; Blattman et al. 2025). Thus, while prior studies link coca cultivation to rising violence, the specific context of 2014–2019—shaped by the peace negotiations and peace agreement with the FARC— may have mitigated violence despite shifts in coca production.

6 Effect of the Coca Boom on Land Use, Local Taxes and Other Socioeconomic Outcomes

Land Use and Deforestation. While many local economies targeted by the PNIS rely heavily on coca cultivation, this sector coexists with legal agriculture, livestock farming, and other commercial activities. A survey of PNIS beneficiaries found that 21% identified coca cultivation as their primary income source, while 16% relied on cattle ranching, and 14% worked as wage laborers (FIP and UNODC 2018). Moreover, as shown by the multiplier analysis, the coca economy not only generates income for individuals directly involved in its production, but also stimulates other sectors of the local economy. Building on this insight, we evaluate whether the coca boom influenced agricultural production, increased the cattle headcount, and altered land use patterns associated with deforestation.

Table 6 and Figure A.4 present the estimated effects on these variables. Details on data sources and variable definitions can be found in the data appendix (see Section A.1). We find no evidence that the municipal share of land allocated to legal agriculture declined following the expansion of coca production, suggesting that households engaged in the coca economy did not systematically replace legal crops with illicit ones.[13] Additionally, we observe no significant increase in cattle headcount registered with the Colombian Agricultural Institute (ICA, by its Spanish acronym), where registration is mandatory for vaccination. This is noteworthy given livestock's multiple role as a savings mechanism, an economic asset for households, and, in some cases, an asset to formalize resources from an illegal economy (Balboni et al. 2022; DNP 2023;

13. Robustness tests using alternative measures—such as planted area, harvested area, and total agricultural production reported by the Colombian government—yield consistent results. These additional findings are available upon request.

Reyes-Posada 2009).

However, we find a substantial increase in deforestation.[14] Our estimates indicate that annual deforestation rates increased by 77.5% in high-PNIS-probability municipalities compared to the pre-announcement mean (0.44%). Using the IV specification, we estimate that a one standard deviation increase in coca cultivation raises the deforestation rate by 18.3% to 22.5%.

These findings can be interpreted through two competing mechanisms. The first relates to the expansion of coca crops directly driving deforestation—what Dávalos et al. (2021) refers to as direct deforestation. This mechanism does not refer simply to correlated variation in coca cultivation and deforestation at the municipal level, but rather to actual forest clearing for coca cultivation. The second mechanism involves an indirect pathway, in which the economic activities and productive sectors catalyzed by the coca boom contribute to higher levels of deforestation. While this mechanism also relates to variation in coca cultivation and deforestation within the same municipality, it differs from the direct mechanism in that forest loss is not caused by coca cultivation *per se*, but by the expansion of other economic activities fostered by the coca economy.

Although we do not provide causal identification of these mechanisms, we present suggestive evidence that supports the interpretation that our estimated effects are more consistent with the latter, indirect channel.

First, for the direct deforestation mechanism to hold, a substantial share of coca cultivation would need to occur in previously forested areas. Using pixel-level data on coca cultivation from 2014 to 2019, we calculate the share of coca crops planted in areas that had forest cover in the previous year. During this period, only between 3.08% and 5.59% of total coca crop hectares were located in regions that had forest cover the year before. Additionally, we examine the share of coca crops planted in pixels that did not have coca cultivation in previous years. Between 2014 and 2019, between 0.01% and 3.9% of coca crops were located in new pixels, of which only 3.79% to 7.13% were in areas with forest cover. Taken together, these results suggest that most of coca cultivation occurred in areas that were already deforested, providing evidence against the direct deforestation mechanism.

Second, one mechanism previously identified in the literature as a driver of the indirect deforestation is the expansion of pastures for cattle ranching. On the one hand, livestock presents attractive economic returns compared to other assets in these regions (Balboni et al. 2022; DNP 2023). On the other hand, the conversion of land

14. We define deforestation as the area where tree canopy cover was completely removed within a given year, expressed as a share of the total number of pixels with more than 30% tree canopy cover in the municipality in 2000 (Hansen et al. 2013; Sexton et al. 2016; Prem, Saavedra, and Vargas 2020). As a robustness check, we normalize the deforested area by the total rural area of each municipality, and the results remain consistent across both definitions.

to pastures in the context of illegal economies has been documented as a source of land-grabbing and money laundering (Devine et al. 2020; Devine et al. 2021; Ibañez 2009; Reyes-Posada 2009; Tellman et al. 2020; Uribe-Kaffure 2014). To examine this mechanism, we employ data for 79 municipalities located in the Colombian Amazon, a region where deforestation pressures are especially acute. As detailed in Section A.1, we use municipality-level data on the area converted from coca crops to cattle pasture and assess differential changes in this variable between municipalities affected by the coca boom and those that were not.

Figure A.5 presents these results. We find that, for this subsample of Colombian municipalities, the coca boom increased the area converted from coca to cattle pasture by 302%, and we do not observe evidence of pre-existing trends. While these results are limited by the geographic scope of the data and are not generalizable to the entire country, they provide suggestive evidence in support of the indirect deforestation mechanism. They indicate that one of the primary drivers of deforestation in the Colombian Amazon—pastures for cattle ranching—has been disproportionately affected by changes in coca cultivation.

This interpretation, emphasizing the indirect relationship between coca crops and deforestation, is consistent with prior research. In addition to systematically showing that coca cultivation is not the main driver of deforestation, previous studies have argued that the broader economic system associated with the coca sector can produce significant environmental consequences (Brombacher, Garzón, and Vélez 2021; Ciro 2020; Dávalos et al. 2021; Gutiérrez. 2021; Erazo and Vélez 2020; Murillo-Sandoval et al. 2023; Quiroga-Angel, Pablo, and Wagner 2022).

Research has also established a strong link between deforestation and the territorial control exerted by armed groups (Prem, Saavedra, and Vargas 2020; Ganzenmüller, Sylvester, and Castro-Nunez 2022; Vanegas-Cubillos et al. 2022). For instance, several studies show that conflict-affected areas experienced lower deforestation rates during periods of armed group control, as these groups imposed restrictions on logging and land conversion to maintain territorial dominance or for ideological reasons. More broadly, armed conflict restricted external actors from engaging in large-scale deforestation, but its decline created a power vacuum that allowed land grabbers, ranchers, and illegal actors to accelerate environmental degradation.

We examine the heterogeneous effects of armed group presence on deforestation in Table 7. The results indicate a positive, though not statistically significant, effect of FARC presence on deforestation following the PNIS announcement (column 1). In contrast, even after accounting for the presence of FARC or any armed group, we find consistent evidence of the coca boom's impact on deforestation rates (columns 2 and 4). This effect is larger in municipalities with FARC presence (column 3), suggesting that deforestation was driven by the interaction between FARC's pre-announcement violent presence and the expansion of coca crops, rather than by either factor alone. When considering the presence of any armed group, the effects appear concentrated in municipalities without such presence. A full analysis of criminal and rebel governance dynamics lies beyond the scope of this work, but these findings provide a preliminary contribution to understanding the complex interactions among illegal economies, governance structures, and environmental degradation.

Local Taxes. If the economic gains from coca production spill over into the formal economy through multiplier effects, they can boost local government revenues via tax collection, potentially strengthening fiscal capacity and improving the provision of public goods—both essential for long-term development (Besley and Persson 2010, 2013). However, preliminary descriptive evidence suggests that fiscal revenues may be lower in municipalities where coca crops are present(Justino et al. 2024). In regions where the economy is heavily reliant on informal transactions, local governments face significant challenges in enforcing tax collection, while criminal organizations often impose their own levies, further discouraging state taxation (Besley and Persson 2009; Ch et al. 2018; Acemoglu, García-Jimeno, and Robinson 2015).

Table 8 presents the results on the effects of the coca boom on local tax revenues, focusing on three taxes that are managed and collected at the municipal level: the Industry and Commerce Tax[15], the Property Tax[16], and the Fuel Surcharge[17]. We find no statistically significant effects of the coca boom on revenues from these taxes, suggesting that the expansion of coca production did not lead to measurable changes in formal local tax collection. Instead, the substantial effects on economic activity were primarily concentrated in the informal sector or, at the very least, did not translate into taxable economic activity. This has important implications, as the benefits of the boom may not sustain long-term economic growth driven by public investment.

Other Socioeconomic Outcomes. The effects of illegal economies may extend beyond other productive sectors, contributing to improving social conditions and human capital accumulation (Dammert 2008; Gehring, Langlotz, and Kienberger 2023; Rodriguez 2020), increasing labor supply in illicit or informal activities (Angrist and Kugler 2008; Sviatschi 2022), and driving migration due to economic opportunities in booming local economies. We explore the effects on these socioeconomic outcomes using census data from 2005 and 2018. Although the data capture only two points in

15. Paid by businesses, professionals, and industries operating within a municipality, with tax rates varying by locality.

16. Paid by owners of urban and rural real estate properties, based on the cadastral value assessed by local authorities.

17. Paid by consumers purchasing gasoline and diesel, with revenue distributed between municipalities and departments.

time—one before the boom and the other four years later—they can still be exploited in a long-difference estimation approach.

Results, reported in Table 9, indicate that the coca boom did not lead to a differential increase in the municipality's total population, the share of non-natives residing in the municipality, or labor force participation. However, school attendance increased by 9.6% relative to the mean, and the literacy rate rose by 1.6 percentage points from a baseline average of 89.7%. When conditioning on age-specific rates (see Figure 7), an interesting pattern emerges: school attendance grows among children and teenagers below 19 but declines for individuals aged 20 or older. Conversely, labor force participation increases by 10 percentage points among individuals in their early twenties and by 8.8 percentage points for those 25 or older, with no significant change among teenagers.

Our findings mirror previous studies showing that eradication efforts aimed at *reducing* coca crops negatively impact the educational outcomes of young children and school attendance (Ciro 2020; CEV 2022; Gutiérrez-Sanín 2021; Rodriguez 2020; Dammert 2008). However, they also suggest that beyond the typical age of secondary school completion, there is a disincentive to continue studying as opportunities to work in coca production increase. That said, this conclusion remains suggestive, as we lack data on the specific sectors in which individuals are employed, and opportunities for jobs requiring higher education are minimal in these municipalities.

Finally, we examine the impact on access to utilities (see Table 9). Our findings indicate a positive and statistically significant impact on electricity access, with a 6.7 percentage point increase, translating to a 7.7% rise relative to the baseline average. This aligns with our main result that *NTL* is increasing. However, we do not observe significant changes in access to aqueduct and sewerage services. Unlike aqueduct and sewerage infrastructure, which require substantial public investment, electricity access is more responsive to individual decisions and financial constraints. Given the lack of significant variations in tax revenues, it is no surprise to find null effects on public utilities that rely heavily on government investment.

7 Discussion

The results of this paper suggest a positive effect of the coca boom on economic activity, as measured by *NTL*. We find that the incentives provided by the crop substitution program increased *NTL* by 60.3% in average each year. This translates to a 2.5% to 3.1% increase in municipal GDP for a one standard deviation increase in coca crops. Our results are consistent across several robustness tests and occur in every area within municipalities. However, these results are mainly driven by rural areas, where *NTL* increased by 77.3% due to the coca boom. The magnitude of these effects could be explained both by the proximity to coca crops and by the low initial levels of economic activity in these areas. These findings quantify systematic qualitative research in illegal economies highlighting the pivotal role of illegal economies (Andreas 2014; Britto 2020; Ciro 2020; Gutiérrez-Sanín 2021; Gutiérrez-Sanín and Machuca 2022; Gutiérrez. 2021; Thomson, Meehan, and Goodhand 2024).

We estimate the indirect effect of increases in this economy on total economic output by computing the local GDP multiplier. In average, each dollar of coca leaf value during the 2014-2019 period results in an increase of $1.45 in total output. For the cocaine base value, which excludes the cost of coca leaves, the multiplier is equivalent to 1.12. These findings show that total output does not merely increase due to growth in this economic sector; rather, this activity generates substantial indirect effects on aggregate economic activity. This result reveals the importance of the coca economy beyond coca cultivation itself, as it stimulates the entire local economy with significant social consequences (CEV 2022; Duncan 2022).

We report suggestive evidence on the impacts of the coca boom on educational outcomes, labor market participation, and access to electricity. Although the econometric approach is not as robust as the ones previously presented due to data availability, we find significant increases in school attendance and literacy rates among children aged 5 to 19. Further, we find negative consequences of the coca boom on educational attendance for individuals above 20 years old and positive effects on labor market participation within this same cohort. These findings suggest that additional resources from the coca economy enable households to increase children's participation in the educational system while raising the opportunity cost for those above 20 years old, thereby increasing the workforce (Gutiérrez-Sanín 2021; Dammert 2008; Rodriguez 2020).

Regarding the relationship between the coca boom and violence, we find null effects of the FARC ceasefire on economic activity. While the crop substitution program would not have been announced without the peace process, and is therefore institutionally linked to it—as well as to the former guerrilla's role in the territories they controlled—the actual withdrawal of the FARC from areas under their violent presence did not lead to a differential increase in economic activity.

Moreover, in both scholarly literature and public discourse, drug production and trafficking have often been inherently associated with violence. However, we find no significant effects of the 2010s Colombian coca boom on the presence of armed actors, disputes among them, internal conflict victimization, homicide rates, or the killing of social leaders. These findings challenge classical assumptions that posit a direct relationship between the coca or cocaine economy and heightened levels of violence. Instead, they suggest a more nuanced understanding of these dynamics— potentially shaped by factors such as territorial control, market regulation by organized criminal groups, and the evolving interaction between state institutions and criminal governance (Arjona 2016; Britto 2020; Ciro 2020; Durán-Martínez 2015b; Durán-Martínez 2015a, 2017; Gehring, Langlotz, and Kienberger 2023; Grisaffi 2022; Snyder and Duran-Martinez 2009).

Regarding other productive sectors, we do not find statistically significant effects on the area of municipalities dedicated to agricultural production nor on livestock headcount. For the provision of public goods, this economic boom did not impact taxable economic activities, as we find no statistically significant effects on revenues from sales, property, or fuel surcharge taxes. Further research should explore and identify the formal sectors fostered by illicit economic booms to have a broader understanding of the interplay between these economies and licit activities.

Yet, we identify significant effects of the coca boom on deforestation. We provide suggestive evidence that this impact is an indirect consequence of the economic dynamism generated by the coca sector in other areas of the local economy. In the Amazon region, we observe a 302% increase in land use transformation from coca cultivation to pastures for cattle ranching. These findings may point to land-grabbing patterns associated with the coca economy, aligning with previous studies from Central America that have documented processes of *narcodeforestation*—where the primary objective is not agricultural expansion per se, but rather the laundering of illicit funds and the consolidation of territorial control by drug trafficking organizations (DTOs) (Devine et al. 2020; Devine et al. 2021; Tellman et al. 2020).

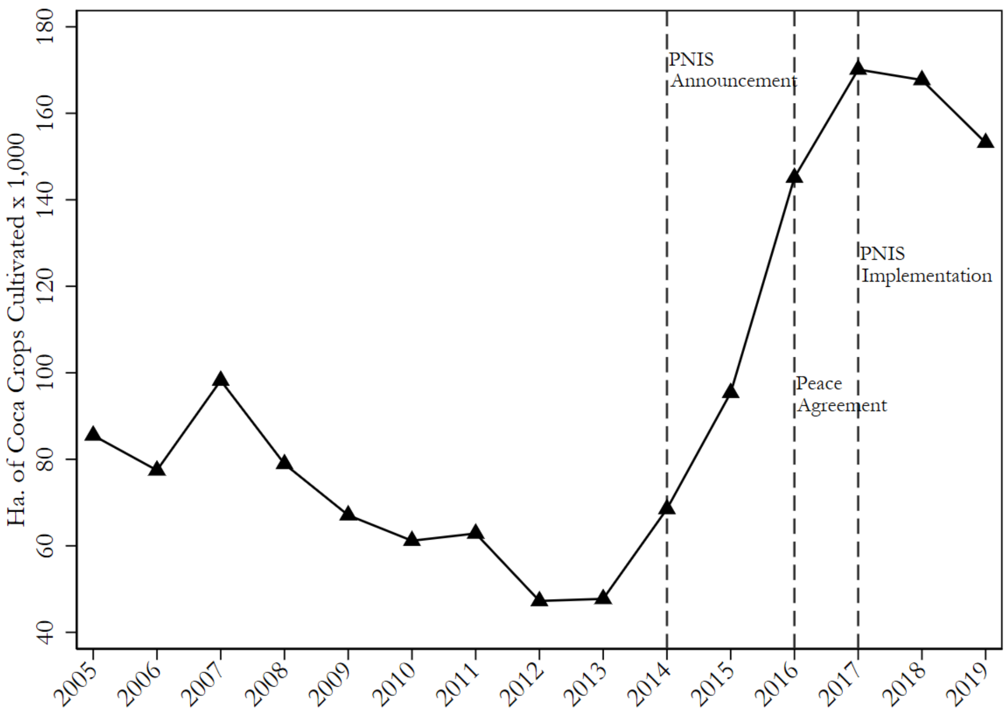
Overall, our findings suggest that while coca-based local growth may generate short-term economic and social benefits beyond those directly involved in this economy, its long-term economic development are uncertain. While educational outcomes might improve communities well-being in the long run, the economic boom does not result in increased state revenue needed to fund public goods at the local level. Three years after the period of our study, during which we identified yearly average GDP increases of 10.5% in municipalities where the coca boom occurred, these regions faced the most prolonged humanitarian and nutritional crisis in recent decades due to reduced levels of commercialization and prices of coca paste. This suggests that the potential role of social mobility of the coca economy does not translate to the current generation but could lead to structural changes in future ones (Ciro 2020; Gutiérrez-Sanín 2021). Further, it leads to harmful land-use changes that could undermine sustainable development in the region.

These results have policy and research implications. Given the magnitude of the estimated effects and the significant barriers to rural development in countries like Colombia, it is unlikely, at least in the short term, that other agricultural or forest-based sectors could replace the economic and social benefits generated by illegal economies at the regional level.

Our paper aligns with the literature that identifies trade-offs in contexts where illicit activities occur. Illicit economies shape economic relations, market outcomes, and social dynamics (Ciro 2020; Gutiérrez-Sanín 2021; Gutiérrez-Sanín and Machuca 2022; Thomson, Meehan, and Goodhand 2024). Given our results suggesting null effects of a massive illicit economic boom on violent dynamics while significantly altering social and economic interactions, the study of the role of illicit economies should move beyond a purely violence-centric perspective. Instead, related studies should consider these economies as sectors capable of providing economic and social development and forming state institutions (Andreas 2014; Torres-Bustamante 2012). However, they remain unable to structurally change conditions of vulnerability and marginality, and exacerbate environmental damages.

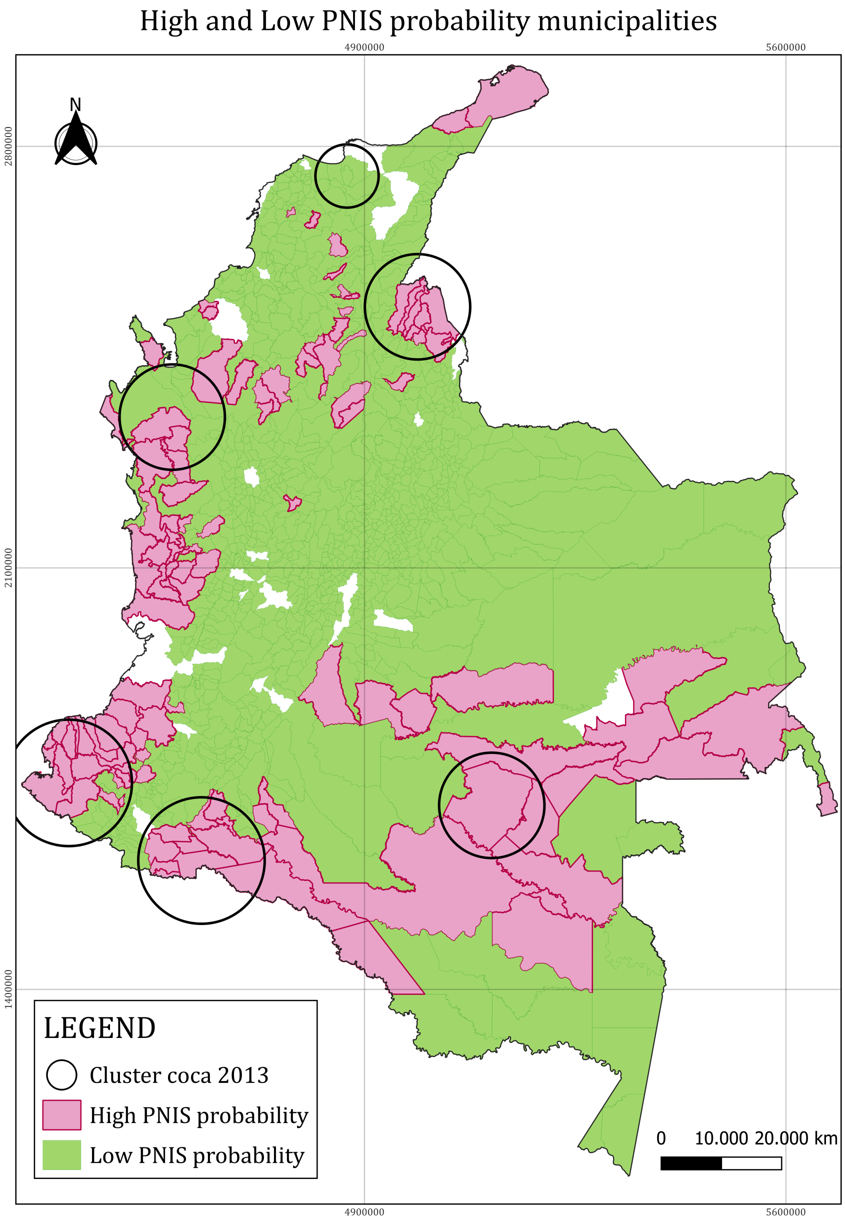
Figures and Tables

Figure 1: Hectares of Coca Cultivated per 1,000, 2005-2019



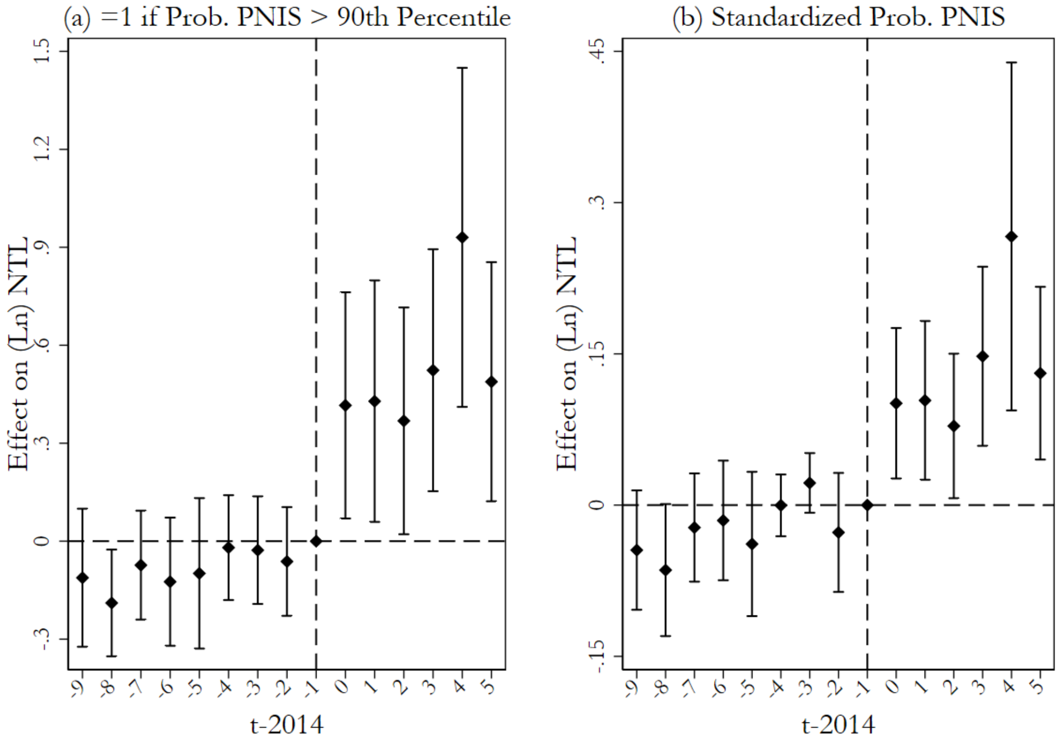
Notes: This figure shows the trend in coca cultivation area in Colombia over time, using data from the United Nations Office on Drugs and Crime (UNODC). See Section 3 for more details.

Figure 2: Geographic Distribution of Municipalities by PNIS Classification



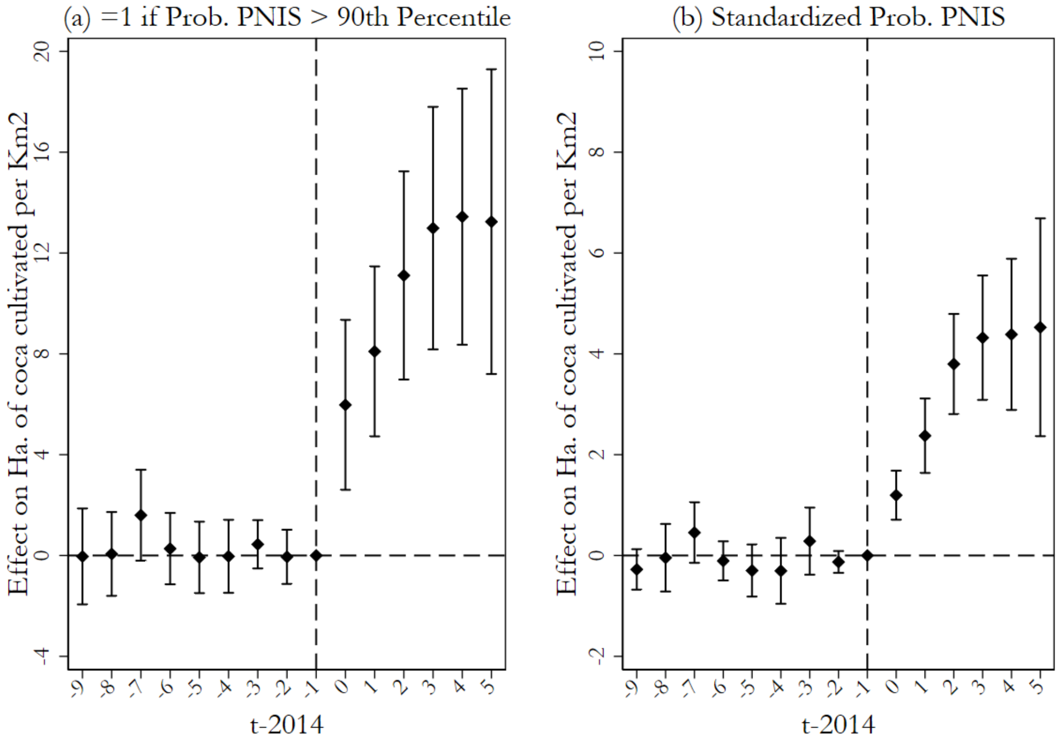
Notes: The figure shows the geographic distribution of municipalities classified by high and low probabilities of PNIS eligibility. For details on the methodology and data sources, see Section 3.

Figure 3: Dynamic Effects of the PNIS Announcement on Nigh-Time Lights



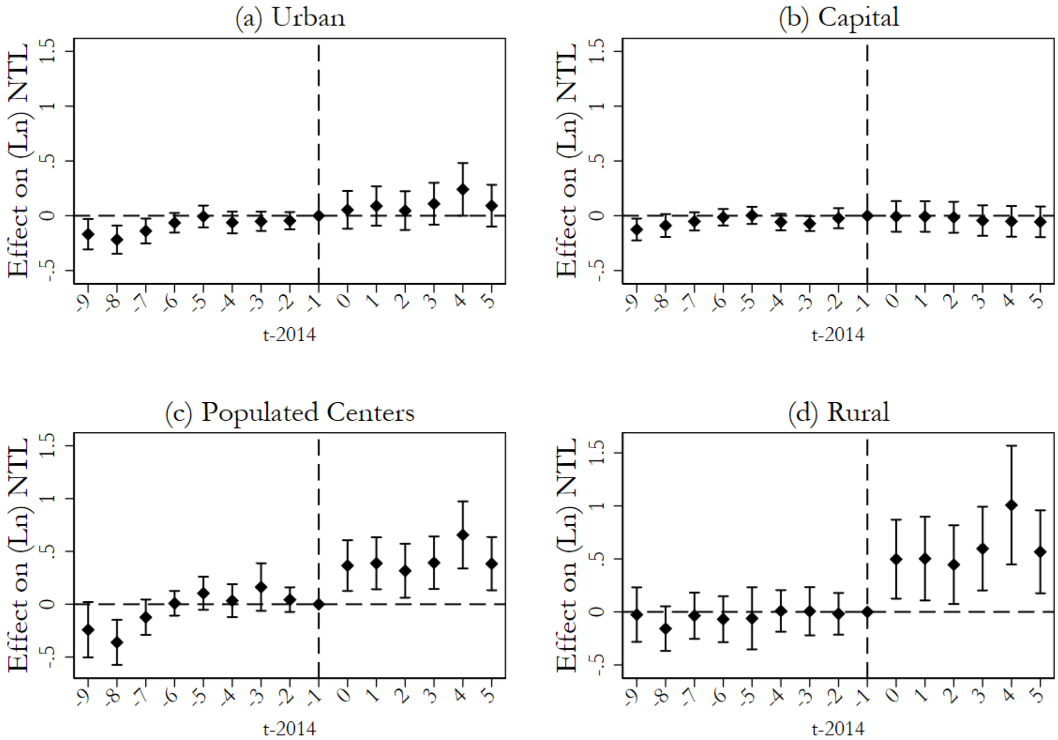
Notes: The figure presents estimates of the τ coefficients from the dynamic specification in equation (3). Panel (a) uses the binary classification of municipalities, while Panel (b) relies on the standardized *ex-ante* probability of selection. The models include municipal and department-year fixed effects, as well as geographic controls interacted with the post-announcement indicator. Standard errors are clustered at the municipality and department-year levels.

Figure 4: Dynamic Effects of the PNIS Announcement on Coca Production



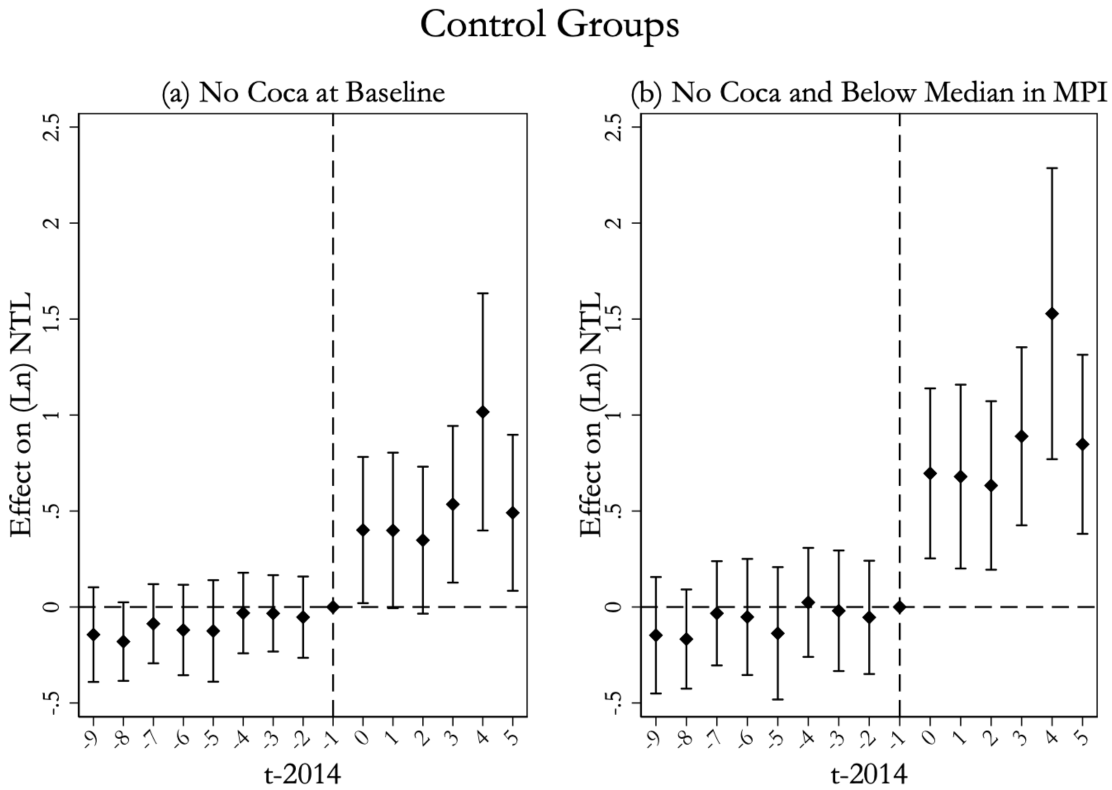
Notes: The figure presents estimates of the τ coefficients from the dynamic specification in equation (3), replacing $\ln(NTL_{m,t})$ with $CocaCrops_{m,t}$ as the dependent variable. Panel (a) uses the binary classification of municipalities, while Panel (b) relies on the standardized *ex-ante* probability of selection. The models include municipal and department-year fixed effects, as well as geographic controls interacted with the post-announcement indicator. Standard errors are clustered at the municipality and department-year levels.

Figure 5: Dynamic Effects of the PNIS Announcement on Nigh-Time Lights by Geographic Area



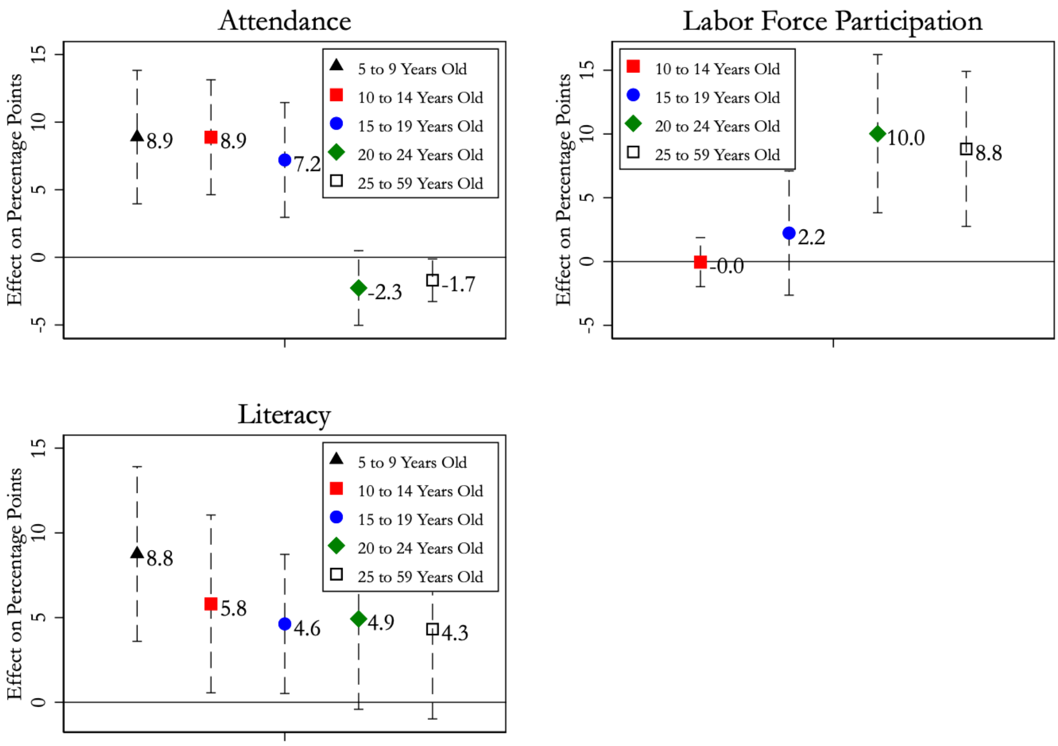
Notes: The figure presents estimates of the τ coefficients from the dynamic specification in equation (3), using the binary classification of municipalities. Panel (a) corresponds to urban areas (municipal capital + populated centers), Panel (b) to the municipal capital, Panel (c) to populated centers, and Panel (d) to rural areas within each municipality. The models include municipal and department-year fixed effects, as well as geographic controls interacted with the post-announcement indicator. Standard errors are clustered at the municipality and department-year levels.

Figure 6: Dynamic Effects of the PNIS Announcement on Night-Time Lights: Alternative Control Groups



Notes: The figure presents estimates of the τ coefficients from the dynamic specification in equation (3), using a binary classification of municipalities while varying the control group. The left panel considers as controls municipalities with no coca production at baseline, while the right panel further restricts the control group to municipalities with multidimensional poverty rates below the median. All models incorporate municipal and department-year fixed effects, along with geographic controls interacted with the post-announcement indicator. Standard errors are clustered at the municipality and department-year levels.

Figure 7: Effects of the PNIS Announcement on Schooling, Labor Force Participation, and Literacy by Age



Notes: The figure presents estimates of the impact of the PNIS announcement and the subsequent coca cultivation boom on schooling, literacy, and labor force participation by age. The models include municipal and department-year fixed effects, along with geographic controls. Standard errors are clustered at the municipality and department-year levels.

Table 1: Elasticity of Economic Activity to Nigh-Time Lights: Estimates using Departmental GDP

	Dep. Var.: (Ln) Departmental GDP				
	Total	Urban	Capital	Populated Centers	Rural
(Ln) NTL	0.358***	0.203***	0.162**	0.177***	0.175***
	(0.038)	(0.059)	(0.059)	(0.025)	(0.023)
Linear Trend	0.030***	0.037***	0.038***	0.037***	0.036***
	(0.002)	(0.003)	(0.003)	(0.002)	(0.002)
Observations	279	279	279	279	279
Department FE	✓	✓	✓	✓	✓

*** 1 percent ** 5 percent * 10 percent.

Notes: The table presents estimates of the elasticity of GDP to changes in night-time light (NTL) intensity across Colombian departments for five geographical areas. Data sources include satellite imagery for NTL, and official GDP estimates from the Colombian Statistical Agency (DANE). For a detailed description of the data sources and methodology, see Section 3.

Table 2: Effect of the PNIS Announcement and the Coca Boom on Nigh-Time Lights Intensity and Municipal GDP

	Dep. Var.: (Ln) Night-Time Lights Index (NTL)			
	(1)	(2)	(3)	(4)
Panel (a): Reduced-form estimates				
High Prob. PNIS × Post Announcement	0.722***	0.603***		
	(0.117)	(0.160)		
(Std.) Prob. PNIS × Post Announcement			0.260***	0.158***
			(0.048)	(0.043)
Panel (b): IV regression				
Coca Crops per 1,000 Ha	0.122***	0.057**	0.086***	0.046**
	(0.035)	(0.021)	(0.026)	(0.016)
Observations	15,752	15,752	15,752	15,752
Geographic Controls	✗	✓	✗	✓
F Stat. First Stage	20.39	23.56	30.29	33.06
Effect on GDP (Reduced-Form)	12.6%	10.5%	4.6%	2.8%
Effect on GDP (IV)	6.6%	3.1%	4.6%	2.5%

*** 1 percent ** 5 percent * 10 percent.

Notes: The table reports estimates of the impact of the PNIS announcement and the subsequent coca cultivation boom on the intensity of night-time lights (NTL) and municipal GDP. Panel (a) presents the reduced-form estimates, while Panel (b) provides the instrumental variables (IV) estimates. The effect on GDP is calculated by multiplying the respective coefficients by the estimated elasticity of GDP to NTL for rural areas (see Table 1). For the IV regression, the effect on GDP corresponds to an increase of one standard deviation in coca crop cultivation pre-announcement. Standard errors are clustered at the municipality and department-year levels.

Table 3: Coca Leaf and Cocaine Base Multipliers to GDP $(1 + m)$: Average 2014-2019

	Mean	10th percentile	90th percentile
Coca Leaf Sales Multiplier	1.446	0	4.157
	(0.089)		
Cocaine Base Value Added Multiplier	1.119	0.011	2.907
	(0.067)		

Notes: The table reports the estimated coca leaf and cocaine base multipliers to GDP, based on municipalities that had coca cultivation for at least one year between 2011 and 2013. See Section 5 for details.

Table 4: Effect of the PNIS Announcement on Nigh-Time Lights Intensity by Presence of Armed Groups

	Dep. Var.: (Ln) NTL					
	Armed Group = FARC			**Any Armed Group**		
	(1)	(2)	(3)	(4)	(5)	(6)
Armed Group × Post ($\beta_{\text{Armed-Groups}}$)	0.072	0.053	0.044	0.046	0.035	0.028
	(0.049)	(0.049)	(0.049)	(0.052)	(0.052)	(0.052)
High Prob. PNIS × Post (β_{PNIS})		0.588***	0.369		0.598***	0.402
		(0.161)	(0.318)		(0.160)	(0.338)
High Prob. PNIS × Armed Group × Post ($\beta_{Interaction}$)			0.220			0.202
			(0.266)			(0.300)
Derived Effects						
$\beta_{PNIS} + \beta_{Interaction}$			0.59***			0.60***
			(0.16)			(0.16)
Observations	15,752	15,752	15,752	15,752	15,752	15,752

*** 1 percent ** 5 percent * 10 percent.

Notes: The table reports estimates of the impact of the PNIS announcement and the subsequent coca cultivation boom on the intensity of night-time lights (NTL). We present results interacting an indicator for the post-boom period with an indicator for violent presence of FARC and other armed actors. The models include municipal and department-year fixed effects, as well as geographic controls interacted with the post-announcement indicator. Standard errors are clustered at the municipality and department-year levels.

Table 5: Effect of the PNIS Announcement and the Coca Boom on Violence Indicators

	Dep. Var.: Violence metrics								
	= 1 if Armed Groups Presence	= 1 if Disputes between Armed Groups	Number of Armed Groups with Violent Presence	Homicides Rate (x100,000)	Victims Rate (x100,000)	Youth Armed Recruitment Rate (x100,000)	Forced Displacement Rate (x100,000)	= 1 if Confinement	Social Leaders Killings Rate (x100,000)
Panel (a): Reduced form estimates									
High Prob. PNIS × Post Announcement	0.039	0.031	0.170	10.535	-573.505	-0.625	-398.125	18.782	1.326**
	(0.053)	(0.043)	(0.188)	(7.871)	(1223.768)	(1.496)	(1168.563)	(79.392)	(0.525)
Panel (b): IV regression									
Coca Crops per 1,000 Ha	0.004	0.003	0.016	1.004	-54.251	-0.059	-37.661	1.777	0.125**
	(0.005)	(0.004)	(0.018)	(0.726)	(119.076)	(0.143)	(112.960)	(7.530)	(0.056)
Observations	15,752	15,752	15,752	10,276	15,743	15,743	15,743	15,743	15,729
Summary Stats									
Av. Dep. Var	0.22	0.12	0.46	31.78	1571.25	1.41	1345.13	0.10	0.10
	(0.41)	(0.32)	(1.11)	(39.58)	(3098.21)	(5.50)	(2774.38)	(9.26)	(1.03)
F Stat. First Stage	23.56	23.56	23.56	21.96	23.56	23.56	23.56	23.56	23.57

*** 1 percent ** 5 percent * 10 percent.

Notes: The table reports estimates of the impact of the PNIS announcement and the subsequent coca cultivation boom on violence metrics. Panel (a) presents the reduced-form estimates, while Panel (b) provides the instrumental variables (IV) estimates. These models include municipal and department-year fixed effects, as well as geographic controls interacted with the post-announcement indicator. Standard errors are clustered at the municipality and department-year levels.

Table 6: Effect of the PNIS Announcement and the Coca Boom on Land Use and Deforestation

	Dep. Var.:					
	Agricultural area (%)	Cattle headcount	Deforestation ratio	Agricultural area (%)	Cattle headcount	Deforestation ratio
Panel (a): Reduced form						
High Prob. PNIS × Post Announcement	0.058	-16.887	0.341***			
	(0.141)	(15.178)	(0.078)			
(Std.) Prob. PNIS × Post Announcement				-0.015	3.871	0.089**
				(0.021)	(3.473)	(0.027)
Panel (b): IV regression						
Coca Crops per 1,000 Ha	0.006	-1.686	0.032***	-0.005	1.192	0.026***
	(0.015)	(1.605)	(0.007)	(0.007)	(1.073)	(0.006)
Observations	14,672	11,566	15,677	14,672	11,566	15,677
Summary Stats						
Dep. Var.	2.16	456.79	0.44	2.16	456.79	0.44
	(9.79)	(371.41)	(0.64)	(9.79)	(371.41)	(0.64)
F Stat. First Stage	22.67	22.91	23.9	32.38	31.24	33.66

*** 1 percent ** 5 percent * 10 percent.

Notes: The table presents estimates of the impact of the PNIS announcement and the subsequent coca cultivation boom on land use, including agricultural area, cattle headcount per 1,000 municipality hectares, and deforestation rate. Panel (a) reports the reduced-form estimates, while Panel (b) provides the instrumental variables (IV) estimates. At the bottom of the table, we report the effect of a one standard deviation increase in hectares of coca crops (measured pre-announcement) on the deforestation ratio, using the IV estimates. The models include municipal and department-year fixed effects, as well as geographic controls interacted with the post-announcement indicator. Standard errors are clustered at the municipality and department-year levels.

Table 7: Effect of the PNIS Announcement on Deforestation by Local Presence of Armed Groups

	Dep. Var.: Deforestation Ratio					
	FARC Presence			**Any Armed Group**		
	(1)	(2)	(3)	(4)	(5)	(6)
Armed Group × Post ($\beta_{\text{Armed-Groups}}$)	0.009	-0.002	-0.009	-0.000	-0.006	-0.006
	(0.030)	(0.030)	(0.031)	(0.037)	(0.036)	(0.037)
High Prob. PNIS × Post (β_{PNIS})		0.342***	0.153		0.342***	0.343**
		(0.078)	(0.142)		(0.078)	(0.170)
High Prob. PNIS × Armed Group × Post ($\beta_{Interaction}$)			0.191			-0.001
			(0.136)			(0.159)
Observations	15,677	15,677	15,677	15,677	15,677	15,677
Derived Effects						
$\beta_{PNIS} + \beta_{Interaction}$			0.34***			0.34***
			(0.08)			(0.08)

*** 1 percent ** 5 percent * 10 percent.

Notes: The table presents estimates of the impact of the PNIS announcement and the subsequent coca cultivation boom on deforestation rates. The models include an interaction between the post-boom period indicator and the prior presence of FARC and other armed actors. They also incorporate municipal and department-year fixed effects, along with geographic controls interacted with the post-announcement indicator. Standard errors are clustered at both the municipality and department-year levels.

Table 8: Effect of the PNIS Announcement and the Coca Boom on Local Tax Revenues

	Dep. Var.: (Log) Tax revenue					
	Industry and commerce	Property	Fuel surcharge	Industry and commerce	Property	Fuel surcharge
Panel (a): Reduced form						
High Prob. PNIS × Post Announcement	-0.159	0.061	0.119			
	(0.133)	(0.123)	(0.244)			
(Std.) Prob. PNIS × Post Announcement				0.006	0.014	0.030
				(0.029)	(0.026)	(0.039)
Panel (b): IV regression						
Coca Crops per 1,000 Ha	-0.015	0.006	0.011	0.002	0.004	0.009
	(0.013)	(0.012)	(0.023)	(0.008)	(0.007)	(0.011)
Observations	15,513	15,494	15,602	15,513	15,494	15,602
Summary Stats						
Dep. Var.	4.80	5.50	4.44	4.80	5.50	4.44
	(1.88)	(1.51)	(2.40)	(1.88)	(1.51)	(2.40)
First Stage						
F Stat. First Stage WideF	24.05	23.21	23.49	34.26	33.22	32.71

*** 1 percent ** 5 percent * 10 percent.

Notes: This table reports estimates of the impact of the PNIS announcement and the subsequent coca cultivation boom on local tax revenue. Panel (a) presents the reduced-form estimates, while Panel (b) provides the instrumental variables (IV) estimates. The models incorporate municipal and department-year fixed effects, along with geographic controls interacted with the post-announcement indicator. Standard errors are clustered at both the municipality and department-year levels.

Table 9: Effect of the PNIS Announcement and the Coca Boom on Schooling, Literacy and Labor Force Participation

	Dep. Var.:							
	Population (log)	Immigration (%)	Literacy (%)	School Attendance (%)	Labour Force Participation (%)	Electricity (%)	Aqueduct (%)	Sewerage (%)
Panel (a): Reduced form								
High Prob. PNIS × Post Announcement	-0.038	-0.355	1.474**	3.204**	1.801	6.695**	2.395	-0.385
	(0.139)	(1.873)	(0.710)	(1.045)	(2.257)	(3.108)	(3.933)	(2.503)
Panel (b): IV regression								
Coca Crops per 1,000 Ha	-0.003	-0.029	0.119**	0.259**	0.146	0.541**	0.194	-0.031
	(0.011)	(0.151)	(0.058)	(0.107)	(0.198)	(0.234)	(0.302)	(0.207)
Observations	1,922	1,922	1,922	1,922	1,922	1,922	1,922	1,922
Summary Stats								
Dep. Var.	9.40	8.25	89.70	33.25	37.82	87.06	67.22	41.83
	(0.95)	(6.13)	(5.79)	(4.16)	(8.19)	(13.82)	(20.92)	(25.73)
First Stage								
F Stat. First Stage	16.79	16.79	16.79	16.79	16.79	16.79	16.79	16.79

*** 1 percent ** 5 percent * 10 percent.

Notes: This table presents estimates of the impact of the PNIS announcement and the subsequent coca cultivation boom on social outcomes employing data from the 2005 and 2018 Colombian census. Panel (a) shows the reduced-form estimates, while Panel (b) provides the instrumental variables (IV) estimates. Summary statistics correspond to the two waves of the census (2005 and 2018). The models incorporate municipal and department-year fixed effects, as well as geographic controls interacted with the post-announcement indicator. Standard errors are clustered at the municipality and department-year levels.

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A Online Appendix

A.1 Data Appendix

Agricultural Land. We use the MODIS Land Cover dataset from NASA satellite imagery, which classifies land into 17 types of licit crops with a 500-meter resolution. Croplands are defined as areas where cultivated land covers more than 60% of the grid. We then calculate the share of agricultural land use at the municipality level. However, this threshold may be high for the Colombian context, potentially limiting the accuracy of these measurements, as only large-scale changes would be detectable. To address this, we supplement our analysis with data from the Agricultural and Rural Development Ministry of Colombia, which provides detailed reports on planted, harvested, and total agricultural production from 2006 to 2018.

Cattle Headcount . To address the geographic limitations of Murillo-Sandoval et al. (2023) and its focus on the transformation of coca crops into pastures for cattle ranching—which may not accurately reflect the presence or intensity of cattle—we use data from the Colombian Government that measures cattle headcount at the municipality-year level. This data, compiled by the Colombian Agricultural Institute (ICA, by its Spanish acronym) and available from 2008 to 2018, is based on mandatory cattle vaccination records. Since vaccinations are required for the commercialization of cattle under Colombian law, this approach helps mitigate concerns about under-reporting and measurement errors. For our analysis, we normalize the cattle headcount by 1,000 hectares of municipal area.

Deforestation . We assess deforestation using high-resolution data (30m $\times$ 30m per pixel) on tree cover loss from the Global Forest Change dataset (Hansen et al. 2013). Hansen et al. (2013) employed remote-sensing techniques to identify pixels that, as of the year 2000, had vegetation taller than 5 meters, based on Landsat satellite imagery. Pixels were subsequently coded to indicate complete canopy removal from one year to the next during the 2001–2019 period. We calculate deforestation rates as the annual area deforested in each municipality relative to the total number of pixels with tree cover in that municipality in 2000. Following Sexton et al. (2016), we consider a pixel to have tree cover if it exceeds the 30% canopy threshold. Using this information, we construct annual municipal-level deforestation rates. As a robustness test, we also estimate the models using an alternative normalization: the deforested area relative to the total rural area of each municipality. The results remain consistent across both definitions.

Coca to Cattle. We rely on the classification from Murillo-Sandoval et al. (2023), which employs annual Landsat imagery and a deep learning model to identify coca, pastures for cattle, and forest areas. The reference data for these classifications are derived from official and published sources. Coca patches were obtained exclusively within Protected Areas from SIMCI at the plot level, visually delineated using high-resolution imagery, and confirmed through aerial inspection. Although the methods used by SIMCI for mapping coca are not thoroughly documented, coca records within Protected Areas are well-established and suitable for use as training data. Further validation of SIMCI coca patches was conducted using high-resolution imagery from Google Earth.

For cattle lands, Murillo-Sandoval et al. (2023) combined land cover maps from Corine

Land Cover (CLC) for 2002 and 2018, focusing on the pasture class, and incorporated annual land cover maps (2000-2019) from Murillo-Sandoval et al. (2021). The typical size of cattle farms ranges from 80 to 390 hectares, with forest coverage within these farms varying between 50% and 63%, leading to smaller areas exclusively dedicated to cattle ranching (UAESPNN 2015). To improve the detection of cattle lands, Murillo-Sandoval et al. (2023) spatially constrained annual pastures using CLC and annual land cover maps to select patches larger than 12 hectares. Cattle areas were further corroborated using high-resolution imagery from Google Earth. This step was crucial to exclude small pasture plots not necessarily linked to large-scale cattle expansion, as confirmed through visual inspection. The accuracy of coca classification is approximately 70%, while cattle classification accuracy reaches about 92%. Since Murillo-Sandoval et al. (2023) focuses exclusively on the Amazon region, we restrict our analysis of the transition from coca to pastures for cattle to this specific area.

Industry and Commerce Tax . This tax applies to individuals and entities engaged in industrial, commercial, or service activities within a municipality's jurisdiction. Revenue from this tax typically constitutes 17% to 34% of the overall municipality-level revenue.

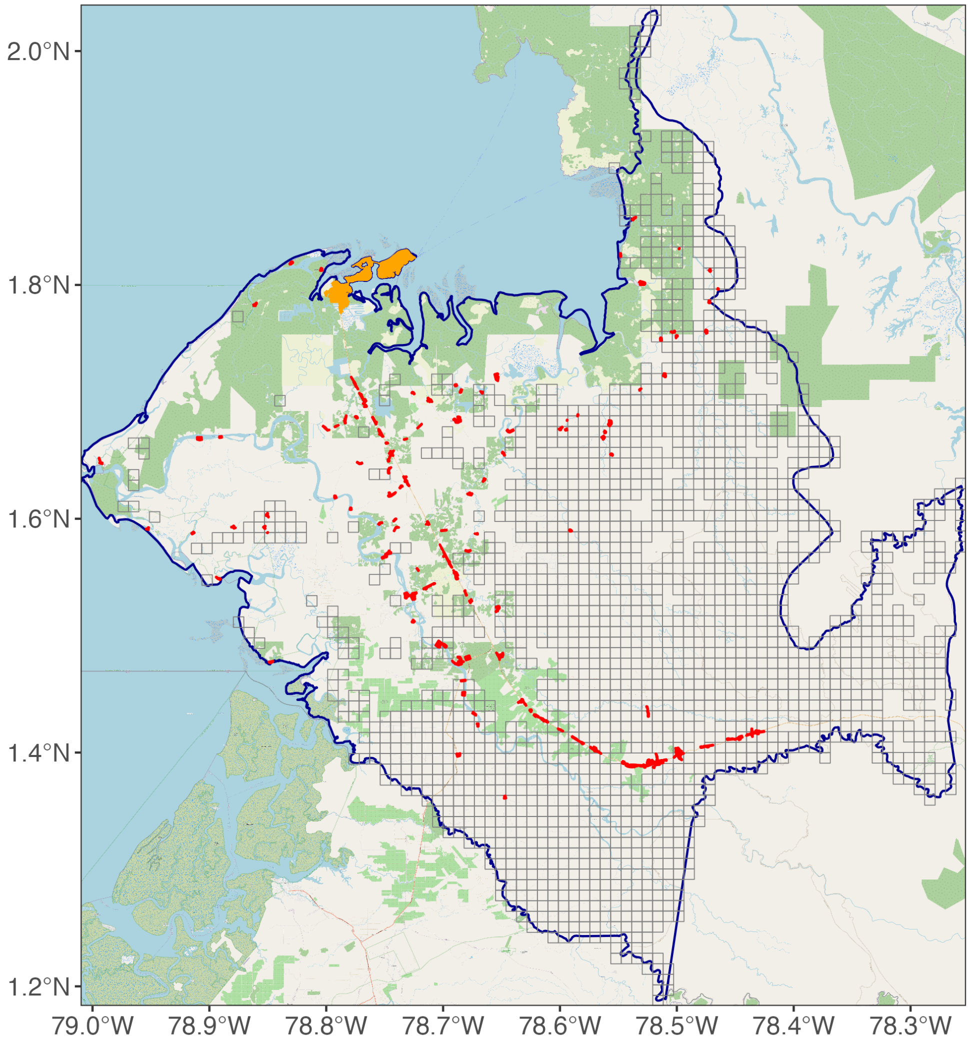
Property Tax . This tax is imposed annually on the ownership of real estate properties, including land, buildings, and improvements. The tax base is determined by the cadastral value of the property, established by local governments, and accounts for 22% to 37% of the overall municipality-level revenue.

Fuel Surcharge . This tax is an additional charge on fuel transactions imposed at the national level and collected by municipalities. We explore the potential effects of the coca boom on this source of tax revenue due to the role of fuel in the process of transforming coca crops into cocaine base.

Census Data. We use census data from 2005 and 2018 provided by the National Administrative Statistics Department (DANE, by its Spanish acronym).

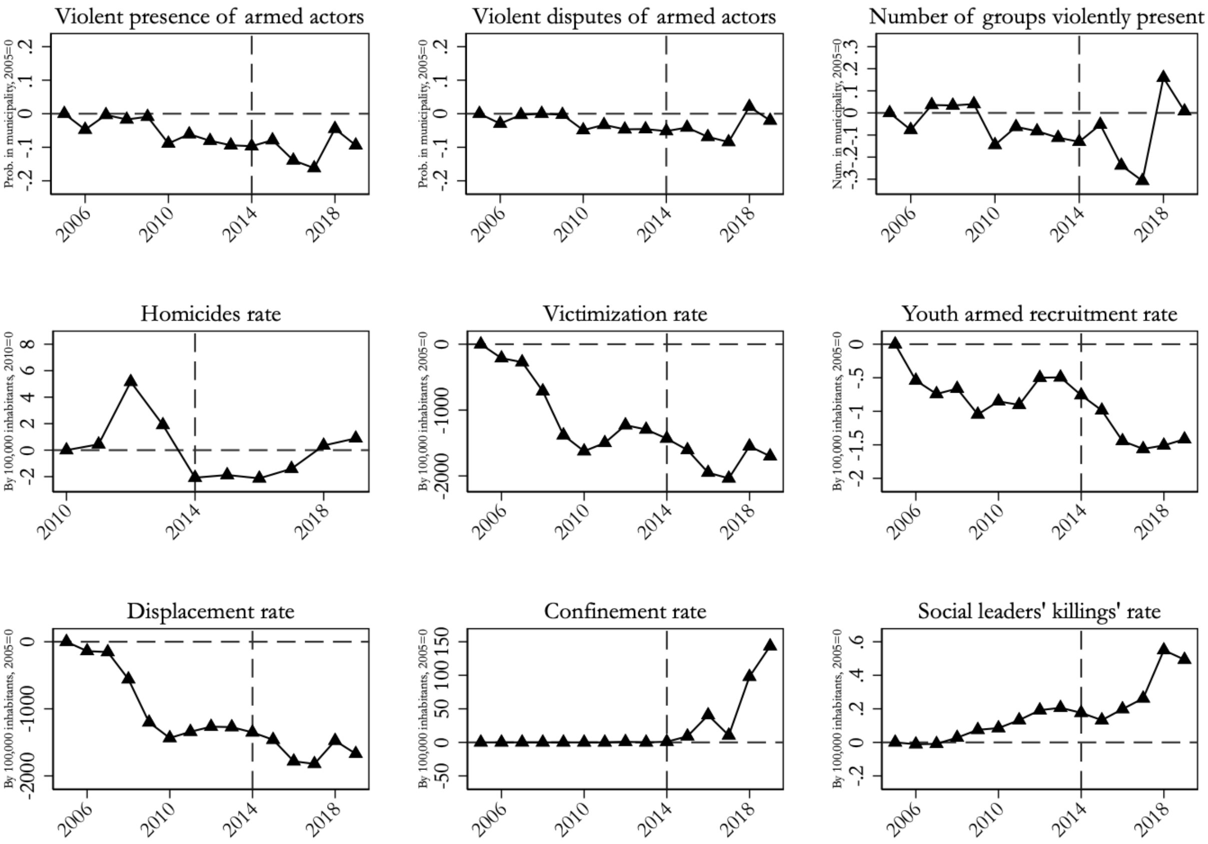
A.2 Appendix Figures and Tables

Figure A.1: Geographic Areas Within Colombian Municipalities



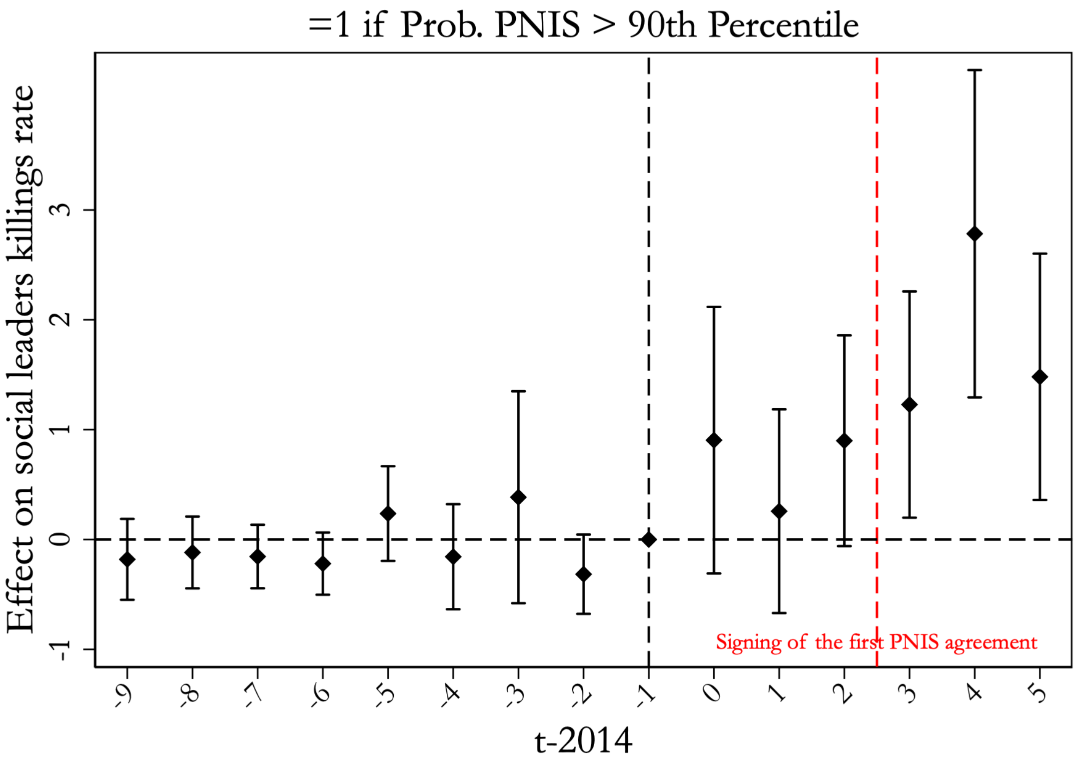
Notes: The figure depicts different geographic areas within a Colombian municipality. The area in orange corresponds to the municipality's capital, the one in red represents populated areas, and the non-colored space within the municipality's boundaries (blue line) denotes the rural area. The gray grids represent the areas with illicit crops in the municipality (1 km x 1 km grids of UNODC).

Figure A.2: Aggregate national violence trends



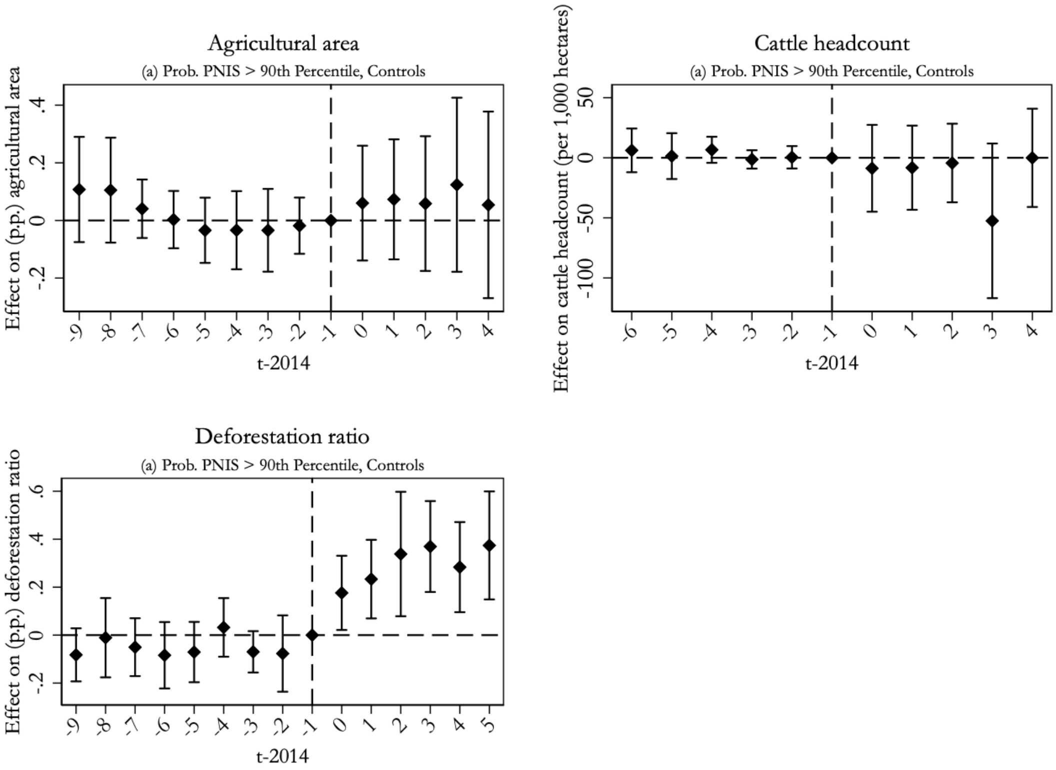
Notes: These figures present the national trends for the nine indicators of violence, with all measures normalized to the 2005 baseline.

Figure A.3: Dynamic Effects of the Coca Boom on Social Leaders' Killings



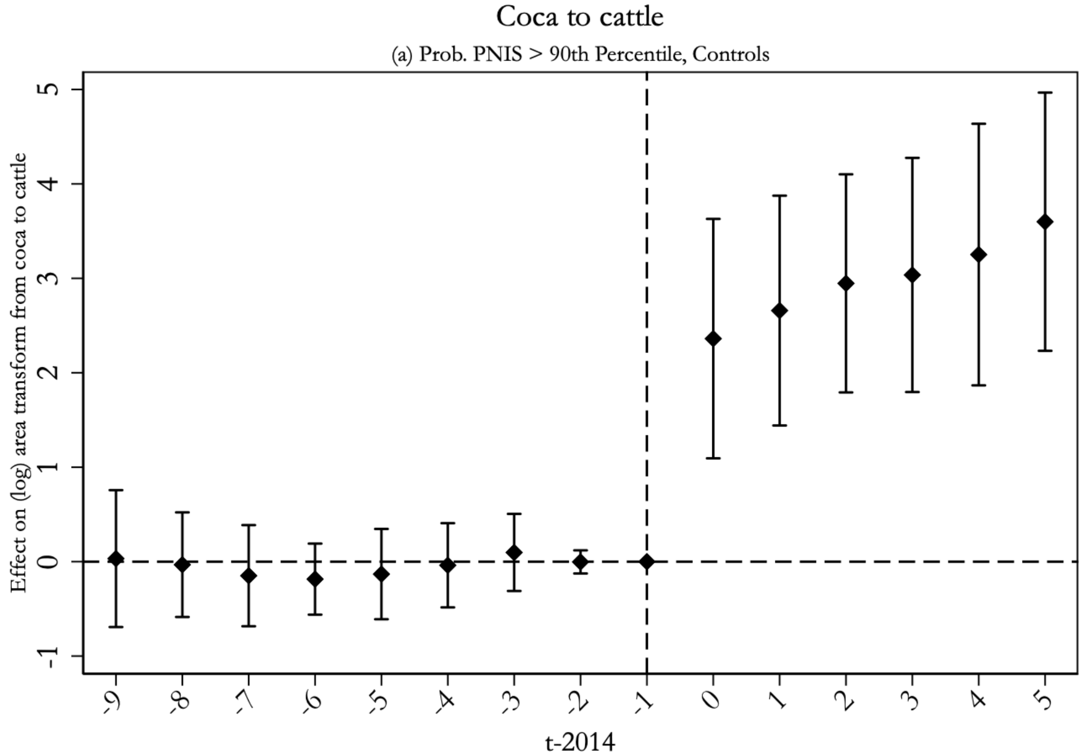
Notes: The figure reports estimates of the τ coefficients from the dynamic specification described in equation (3) employing the binary classification of municipalities and social leaders' killing rate as the dependent variable. The models incorporate municipal and department-year fixed effects, along with geographic controls interacted with the post-announcement indicator. Standard errors are clustered at the municipality and department-year levels.

Figure A.4: Dynamic Effects of the Coca Boom on Land Use Changes



Notes: The figure reports estimates of the τ coefficients from the dynamic specification described in equation (3) employing the binary classification of municipalities and land use outcomes. Panel (a) corresponds to the agricultural area,Panel (b) to cattle headcount per 1,000 municipality's hectares, and Panel (c) to the deforestation ratio. The models incorporate municipal and department-year fixed effects, along with geographic controls interacted with the post-announcement indicator. Standard errors are clustered at both the municipality and department-year levels.

Figure A.5: Dynamic Effects of the Coca Boom on the Transformation from Coca Crops to Pastures for Cattle Ranching



Notes: The figure reports estimates of the τ coefficients from the dynamic specification described in equation (3) employing the binary classification of municipalities and the log of hectares transformed from coca crops to pastures for cattle ranching as the dependent variable. The models incorporate municipal and department-year fixed effects, along with geographic controls interacted with the post-announcement indicator. Standard errors are clustered at the municipality and department-year levels.

Table A.1: Probability of *Ex-Ante* Selection to PNIS

	Dep. Var.: = 1 if the Municipality was Elegible for PNIS in 2017			
	Estimated Parameters		**Marginal Effects**	
	Coefficient	Std. Error	dy/dx	Std. Error
Multidimensional Poverty Index	0.02608	(0.00513)	0.00248	(0.00043)
Coca Crops per 1,000 Ha	0.28103	(0.07749)	0.02722	(0.00811)
Constant	−3.60593	(0.39081)		
Observations	1,068			
Log pseudolikelihood	−214.66314			

Notes: This table reports estimates from Equation 1, which predicts the probability of a municipality being designated as eligible for PNIS by the government in 2017. The regressors in this model include the multidimensional poverty index from 2005 and the average hectares of coca cultivated per 1,000 hectares at the municipality level between 2011 and 2013.

Table A.2: Effect of the PNIS Announcement on NTL in High-Probability PNIS Municipalities and Their Neighbors

	Dep. Var.: NTL				
	Overall	Urban	Capital	Populated Centers	Rural
High Prob. PNIS × Post Announcement	0.682***	0.189**	0.007	0.517***	0.759***
	(0.165)	(0.090)	(0.068)	(0.113)	(0.169)
Neighbors High Prob. PNIS × Post Announcement	0.166**	-0.005	-0.025	0.121**	0.249**
	(0.070)	(0.032)	(0.026)	(0.051)	(0.078)
Observations	15,752	15,502	15,430	11,203	15,747

*** 1 percent ** 5 percent * 10 percent.

Notes: This table presents estimates of the PNIS announcement's impact on *NTL*, using an alternative definition of the treatment group. Specifically, we define multiple treatment arms, estimating effects for municipalities above the 90th percentile and those adjacent to treated municipalities. The control group consists of all other municipalities. The models include municipal and department-year fixed effects, as well as geographic controls interacted with the post-announcement indicator. Standard errors are clustered at both the municipality and department-year levels.

Table A.3: Effect of the PNIS Announcement and the Coca Boom on Nigh-Time Lights Intensity: Excluding the Department of Cauca

	Dep. Var.: (Ln) NTL	
	(1)	(2)
Panel (a): Reduced form estimates		
High Prob. PNIS × Post Announcement	0.656***	
	(0.190)	
(Std.) Prob. PNIS × Post Announcement		0.154**
		(0.047)
Panel (b): IV regression		
Coca Crops per 1,000 Ha	0.059**	0.044**
	(0.024)	(0.018)
Observations	15,164	15,164
Geographic Controls	✓	✓
F Stat. First Stage	19.81	27.92

*** 1 percent ** 5 percent * 10 percent.

Notes: This table reports estimates of the impact of the PNIS announcement and the subsequent coca cultivation boom on the intensity of night-time lights (NTL) excluding the Cauca department. Panel (a) presents the reduced-form estimates, while Panel (b) provides the instrumental variables (IV) estimates. Standard errors are clustered at the municipality and department-year levels.

Table A.4: Effect of the PNIS Announcement on Nigh-Time Lights Intensity by Presence of Gold Mining Activities

	Dep. Var.: (Ln) NTL		
	Gold Mining		
	(1)	(2)	(3)
Gold Mining × PostArmed Group × Post (β_{Gold})	0.128	0.116	0.091
	(0.084)	(0.083)	(0.086)
High Prob. PNIS × Post (β_{PNIS})		0.594***	0.543**
		(0.158)	(0.170)
High Prob. PNIS × Gold Mining × Post ($\beta_{Interaction}$)			0.166
			(0.181)
Observations	15,752	15,752	15,752
Derived Effects			
$\beta_{PNIS} + \beta_{Interaction}$			0.71***
			(0.19)

*** 1 percent ** 5 percent * 10 percent.

Notes: This table presents estimates of the impact of the PNIS announcement and the subsequent coca cultivation boom on the intensity of night-time lights (NTL). The model includes an interaction term between a post-boom period indicator and an indicator for gold mining activities, allowing us to assess heterogeneous effects. The models include municipal and department-year fixed effects, as well as geographic controls interacted with the post-announcement indicator. Standard errors are clustered at the municipality and department-year levels.

Table A.5: Effect of the PNIS Announcement on Violence Indicators in Neighboring coca boom municipalities

	Dep. Var.: Violence indicators								
	Armed presence	Disputes	Number groups	Homicides rate	Victims rate	Youth armed recruitment	Displacement	Confinement	Social leaders killings rate
High Prob. PNIS × Post Announcement	0.041	0.037	0.190	10.905	-757.933	-0.795	-576.053	30.298	1.389**
	(0.054)	(0.044)	(0.202)	(8.092)	(1287.633)	(1.517)	(1215.439)	(71.943)	(0.537)
Neighbors High Prob. PNIS × Post Announcement	0.003	0.013	0.043	0.758	-388.389	-0.358	-374.698	24.251	0.133
	(0.023)	(0.020)	(0.076)	(2.676)	(274.855)	(0.304)	(229.981)	(45.712)	(0.117)
Observations	15,752	15,752	15,752	10,276	15,743	15,743	15,743	15,743	15,729
Summary Stats									
Av. Dep. Var	0.22	0.12	0.46	31.78	1571.25	1.41	1345.13	0.10	0.10
	(0.41)	(0.32)	(1.11)	(39.58)	(3098.21)	(5.50)	(2774.38)	(9.26)	(1.03)

*** 1 percent ** 5 percent * 10 percent.

Notes: This table presents estimates of the impact of the PNIS announcement and the subsequent coca cultivation boom on the planted agricultural area, the harvested area, and overall agricultural production. Panel (a) shows the reduced-form estimates, while Panel (b) provides the instrumental variables (IV) estimates. The models incorporate municipal and department-year fixed effects, as well as geographic controls. Standard errors are clustered at the municipality and department-year levels.