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Long-Term Effects of a Commodity Boom: Rubber Slavery in the Amazon

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Can a brief period of economic prosperity leave a legacy of long-term adversity? This study examines the lasting impact of the Amazon Rubber Boom (1870-1914) on contemporary income, inequality, Indigenous presence, and forest conservation. Empirically we combine variation in historical rubber distribution with an instrumental variable strategy using FAO-based rubber suitability and a Regression Discontinuity design around concession boundaries. Municipalities with greater rubber presence experienced short-term gains in 1920 but long-run reversals by 2010, showing lower income, population density, and higher inequality and Indigenous extinction. Grid-level analyses across the Amazon further show that historical rubber suitability is associated with lower economic activity and sparser population today, alongside greater deforestation. The findings, consistent across Brazil, Colombia, Peru, and Bolivia, indicate that the rubber boom's short-lived wealth reinforced extractive institutions and violence against Indigenous peoples, leaving long-lasting economic, social, and environmental scars across the Amazon.

KEYWORDS

Commodity Booms, Forced Labor, Indigenous Peoples, Amazon

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Efectos a Largo Plazo de un Auge de Materias Primas: La Esclavitud del Caucho en la Amazonía

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¿Puede un breve período de prosperidad económica dejar una herencia de adversidad a largo plazo? Este estudio examina el impacto duradero del auge del caucho en la Amazonía (1870-1914) sobre el ingreso, la desigualdad, la presencia indígena y la conservación forestal contemporáneos. La estrategia empírica combina la variación en la distribución histórica del caucho con una estrategia de variables instrumentales basada en el potencial para el cultivo de caucho según la FAO y un diseño de Regresión Discontinua alrededor de los límites de las concesiones. Los municipios con mayor presencia histórica de caucho experimentaron incrementos de corto plazo en 1920, pero reversiones de largo plazo hacia 2010, mostrando menores niveles de ingreso y densidad poblacional, y mayores desigualdad y extinción indígena. Los análisis a nivel de grilla para toda la Amazonía muestran además que la idoneidad histórica del caucho se asocia con menor actividad económica y población actuales, junto con una mayor deforestación. Los resultados, consistentes en Brasil, Colombia, Perú y Bolivia, indican que la riqueza efímera del auge del caucho reforzó instituciones extractivas y la violencia contra los pueblos indígenas, dejando profundas huellas económicas, sociales y ambientales en la región amazónica.

KEYWORDS

Auge de materias primas, trabajo forzado, pueblos indígenas, Amazonía

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1 | INTRODUCTION

The extraction of commodities and natural resources has been part and parcel of Latin America's economic reality throughout history. This legacy of extraction was especially important during colonial times and was later exacerbated by industrial demand for natural products. Notable among these was Amazon rubber, which experienced a boom from 1870 to 1914. In this paper, we scrutinize the short- and long-term impact of this historical episode. Although rubber extraction led to a temporary increase in wealth accumulation in cities such as Iquitos and Manaus, its broader development effects were devastating. Areas that historically extracted rubber are now poorer and have higher levels of inequality. We document this dramatic development reversal and hypothesize that the use of forced Indigenous labor underpinned these deleterious long-run effects. To investigate this, we build a new dataset and run a series of empirical tests. To the best of our knowledge, this is the first empirical economics study of the effects of Indigenous slavery in Latin America, following pioneering work on Indigenous welfare in the Americas by Feir et al. (2024a) and Barsanetti and Ferreira (2022). In addition, we advance the literature on commodities in Latin America by going further back in time than did Méndez and Van Patten (2022). We also examine the impact of rubber in the Americas, complementing the work of Lowes and Montero (2021) for Africa.

Rubber latex was mainly extracted through private concessions in the Amazon basin and exported worldwide to fuel the appetite for bicycle pneumatics and the nascent demand for car tires during the late nineteenth and early twentieth centuries.[1] The geographic coverage of this colossal enterprise spanned Brazil, Peru, Colombia, Ecuador, and Venezuela. The Hevea tree was never domesticated in South America, barring the establishment of plantations. Instead, rubber entrepreneurs relied on exploitative labor arrangements with Indigenous people, which effectively amounted to modern slavery.[2] Although slavery had at the time been formally abolished in Latin America, rubber extraction depended on coercive labor arrangements, particularly debt peonage, that trapped Indigenous people in conditions of forced labor amounting to enslavement. Official reports and literary accounts detail the horrors the local population underwent in stations such as Casa Arana in the Putumayo region.[3] Another key aspect of the Amazon rubber boom is that it was suddenly dominated by rubber plantations in Southeast Asia (Hanson, 1944).[4] This production explosion on the other side of the globe led to a sharp price drop and the sudden collapse of the Amazon rubber industry (see Figure 1).

What was the long-term impact of this natural resource boom? In the short run, the "rubber fever" drew capital to Amazonian hubs; at its peak, from 1870 to 1910, Manaus, the capital of Amazonas state in northern Brazil, was the richest city in South America. With its grand opera house and a city-electrification project among the earliest in the world, it was dubbed the "Paris of the Tropics." But did this prosperity trickle down to the local population over time in terms of development outcomes and public-goods provision? Or was the rubber boom an archetypal enclave economy built on Indigenous exploitation that left enduring economic, social, and environmental scars? The Amazon rubber boom provides a window into the long-term legacies of forced labor. Rubber barons

[1] For the history of private colonization in Brazil, see Martins Secco Luce (2024).

[2] By the time of the rubber boom, slavery had been abolished in all producing countries, the last of which was Brazil, in 1888. *Hevea brasiliensis* is a species native to the Amazon rainforest and the primary source of natural rubber, which is extracted from its bark (Dean, 1987). The exploitation of rubber in the Amazon required an understanding of the suitability of different types of rubber trees.

[3] A particularly vivid picture is provided by Werner Herzog's *Fitzcarraldo* and the reports of Roger Casement, cited above and fictionalized by Mario Vargas Llosa.

[4] Rubber tree seeds were stolen and smuggled by British explorer Henry Wickham to this end.

and traders operated with near-total impunity, enforcing brutal conditions through violence. We document this traumatic historical reality and, combining historical and contemporary sources, provide causal evidence on a first-order socioeconomic and policy issue. To this end, we create a novel dataset comprising a diverse range of archival records, current administrative datasets, and highly disaggregated information from satellite missions, national records, and Indigenous community presence. Sources such as HydroSHEDS, BIOCLIM, and NASA Nighttime Lights allow us to analyze the enduring effects of the Amazon rubber boom on local communities while accounting for geographic and weather conditions. In addition to traditional economic outcomes, we assess deforestation and illegal activities to explore the complex interactions between exploitation, cultural assimilation, and environmental degradation.

We employ two complementary empirical strategies. First, we use an instrumental variable approach that exploits exogenous variation in rubber suitability from the FAO's Global Agro-Ecological Zones dataset to instrument for the historical distribution of rubber presence documented by Schurz et al. (1925). This strategy allows us to isolate the effect of historical rubber activity from potential confounding factors related to geography, settlement, or accessibility. In this first set of analyses, we compare areas with similar environmental characteristics but differing in their predicted suitability for rubber cultivation. Second, we leverage a Regression Discontinuity (RD) design around the boundaries of historical rubber concessions, such as those established by Casa Arana, to capture sharp spatial contrasts in exposure to extractive institutions and coerced labor. Concession boundaries are digitized from maps originally commissioned by the rubber firms themselves.

This paper contributes to the literature on the long-run economic effects of agricultural commodity booms. A close study is Méndez and Van Patten (2022), which documents the positive effects of the United Fruit Company on development outcomes in twentieth-century Costa Rica. For identification, they exploit an RD design around the concessions granted to this multinational. Their main channel is the ability of this monopsonistic firm to attract workers by investing in local amenities, a channel that was not present in the current context. In contrast to the Central American case, we examine an earlier concessions regime in Latin America and test whether the Amazonian rubber boom had adverse long-run consequences. Dell and Olken (2020) also finds a positive effect of the Dutch Cultivation System in Java, Indonesia, where areas with colonial-era sugar factories have better infrastructure and are more industrialized today.[5] We hypothesize the opposite pattern for the Amazon rubber boom due to precarious working conditions and minimal investments in rubber regions.

Across the Americas, a large literature links exploitative regimes, natural endowments, and commodity booms to long-run development. Sokoloff and Engerman (2000) provides a theory for underdevelopment based on natural resources and subsequent colonial institutions. In that vein, Bobonis and Morrow (2014) shows that after the abolition of forced labor in Puerto Rico in 1874, increased coffee prices led to a decline in literacy rates on the island. This evidence is consistent with the findings of Uribe-Castro (2019) on coffee production, human-capital investments, and structural transformation in Colombia. Musacchio et al. (2014) examine the interaction between commodity booms and education in Brazil. Related work shows that ranching specialization in Argentina resulted in persistently slower industrialization compared to cereal-growing regions (Droller and Fiszbein, 2021). On the institutions channel, Naritomi et al. (2012) documents the importance of colonial commodity booms for Brazilian institutional development, focusing on sugar and gold. To the best of our knowledge, no economics paper has examined the impact of the Amazon rubber boom.

We also contribute to the literature on the economic consequences of slavery and coerced labor. Nunn (2008) and Nunn and Wantchekon (2011) document the negative impact of

[5]Similarly, Kok and Lim (2024) finds a positive effect of rubber estates on human capital in Malaysia.

slavery on exporting nations in Africa in terms of income and decreased trust. More closely related, Lowes and Montero (2021) finds negative long-run effects of rubber concessions granted during the Congo Free State: concessions reduced education, wealth, and health outcomes through an institutional-persistence channel in which village chiefs in former concession areas are less likely to be elected and provide fewer public goods. We examine Indigenous slavery during a period of formal abolition in Latin America. Although we share a focus on rubber, the Amazon's geographic, ethnographic, and historical context differs markedly from that in Africa. Our emphasis is on the exploitation of Indigenous people rather than traditional chief authority. We also analyze mechanisms related to environmental outcomes and illegal activities, such as coca cultivation.

More broadly, evidence from Latin America shows that coercive labor arrangements left enduring marks on development. Laudares and Caicedo (2023) studies the long-term impact of transatlantic slavery on Brazilian inequality, while Dell (2010) demonstrates how the mining *mita* labor system decreased consumption and increased stunting in Peru's Southern Highlands. Rivadeneira (2024) highlights the intergenerational legacy of *concertaje*, a debt-based system of forced labor in Ecuadorian farms or *haciendas*, showing adverse effects on descendants' educational and labor market outcomes. More recently, Espinoza and Paredes (2025), drawing on new data on *hacienda* exposure across Peru, finds that districts with larger shares of their population employed on these estates accumulated less human capital throughout the twentieth century. Relatedly, Araujo et al. (2024) shows that illegal mahogany markets in the Amazon perpetuate contemporary forms of forced labor, revealing the persistence of coercive institutions in the region. While these studies highlight the economic legacies of different forms of coerced labor, ours is the first to provide evidence on Indigenous slavery's long-run economic consequences in Latin America. In doing so, we complement the work on Indigenous welfare in North America (Feir, 2016; Feir et al., 2024a) with evidence from South America.[6] Recent work on Indigenous issues considers colonial treaties (Feir et al., 2023) and American Indian wealth (Feir et al., 2024b). In Latin America, research has focused on Indigenous communities in Mexico (Elizalde, 2020), Indigenous groups in Argentina (Dal Bó and Lopez, 2024), and the Mapuche community in Chile (Jaimovich and Toledo, 2021; Jordán, 2021). Still, more research is needed to understand the conditions of the almost 10% of Latin Americans who identify as Indigenous[7].

The rest of the paper is organized as follows. Section 2 covers the background in terms of rubber exploitation in the Amazon and the rubber boom of 1870–1910. Section 3 describes the datasets used in the empirical analysis. Section 4 lays out our empirical strategies, including reduced form and RD estimates. Section 5 presents our results. Finally, Section 6 concludes.

2 | BACKGROUND

2.1 | Rubber in the Amazon

The Spanish Crown arrived in the Amazon region between 1499 and 1500 during expeditions led by the Pinzón brothers and Diego de Lepe. However, it was not until forty years later that Francisco de Orellana successfully completed the first recorded expedition across the Amazon River, reaching Ecuador. In 1616, during the Iberian Union, Francisco Caldeira Castelo Branco's arrival marked Portugal's takeover of the Amazon region. Portugal began distributing donatary captaincies to implement its colonial system in the Americas (Freire

[6] See Reséndez (2016) on the slavery of Indigenous people in North America.

[7] Laudares et al. (2025) explores the relationship between deforestation and Indigenous Peoples' health during the COVID-19 pandemic in Brazil.

et al., 1994; Martins Secco Luce, 2024). Lacking significant deposits of gold or silver, colonial explorers turned to collect forest products and medicinal plants—referred to as "backlands drugs" (*drogas do sertão*)—such as cinnamon, cloves, cocoa, and copaifera, which were exported to Europe. Indigenous peoples, often enslaved, were responsible for extracting these resources throughout the colonial period.[8]

The extraction of latex from the *Hevea brasiliensis* tree became a significant economic activity in the Amazon during the nineteenth century. Once coagulated, this latex produced rubber. The Olmecs, Mayas, and Aztecs were among the first to use rubber for balls and other objects. News of its existence in the Americas reached Europe during Columbus's second voyage in 1493. In 1736, La Condamine introduced a milky, elastic substance called caoutchouc to the French Royal Academy of Sciences. This sparked further experimentation: in 1764, Fresnau dissolved rubber in turpentine, and in 1779, Fabbroni did so using naphtha. Early uses included erasing pencil marks, manufacturing elastic bands, and waterproofing. Nonetheless, the transformative moment in rubber production was Charles Goodyear's invention of the vulcanization process in 1839. Thanks to this technological breakthrough and with rising demand for rubber in industrialized nations, the Amazon became the world's primary supplier until the 1880s. The world needed rubber for tires, surgical gloves, raincoats, and boats. Accordingly, rubber production in the Brazilian Amazon soared, from 31,365 kilograms in 1827 to 2,673,000 kilograms in 1860. Despite this growth, the extraction methods remained similar to those used for "backlands drugs" during colonial times (Weinstein, 1983).

The *seringueiros* (rubber tappers) collected latex by making incisions in Hevea trees and attaching small bowls to collect the sap. This process was labor-intensive, as the trees were scattered across large areas. On weekends, rubber tappers transported the latex to landowners or local merchants (*aviadores*), who sold it in cities like Belém and Manaus. The rubber tappers typically received only half of the sales revenue and were often required to pay commissions on the money or goods they received. In the cities, the latex was prepared for export, primarily by American or British companies. Landowners, as the sole providers of credit, exploited the *seringueiros* extensively. Many workers became indebted to rubber barons through a system that trapped them in continuous labor to repay loans. Journalist Euclides da Cunha described them as "debt slaves" (Cunha, 1955). Living conditions for rubber tappers were harsh. In other parts of the Amazon, particularly in the Colombian and Peruvian region of Putumayo, rubber extraction involved even greater exploitation of Indigenous labor. The Arana family enslaved Indigenous people to extract *caucho* latex from the *Castilla elastica* tree, often employing extreme measures such as torture, mutilation, and killing to enforce labor discipline.

Unlike *Castilloa elastica*, which was destroyed during latex extraction, *Hevea brasiliensis* trees could be harvested for up to fifty years. According to Weinstein (1983), Brazilian landowners extracting Hevea latex had stronger economic incentives to maintain productive relationships with rubber tappers. Additionally, power was more decentralized in the Brazilian Amazon compared to the Arana family's dominance in Peru. The de facto absence of the central state in the Peruvian Amazon gave enormous power to the rubber barons.

2.2 | The Rubber Boom: 1870–1910

Technological advancements in steam navigation and communication facilitated the initial growth of the rubber economy in the 1870s. Steamships significantly reduced transportation costs, while the expansion of telegraph networks connected Amazonian exporters to global

[8] As a matter of fact, Brazilwood or *pau brasil* gave the name to the country.

markets. Rubber exports from Pará and Amazonas, the two primary production hubs, began to dominate Brazil's trade balance, becoming second only to coffee.

The 1890s marked the height of the Amazon rubber boom. By this period, the global demand for rubber had expanded dramatically, fueled by the bicycle craze and the emergence of the automobile industry. The industrialization of transportation systems in Europe and the United States further accelerated demand for rubber, as car tires became an essential product. Figure 1 shows the evolution of wild and plantation rubber production in Brazil (on the left axis), and the value per ton in British pounds (on the right axis) from 1825 to 1925. The main sources of information are Schidrowitz and Dawson (1952); Hotchkiss (1924); Benchimol (2010) and Vayagool (1967).

Brazil's geographical advantage and monopoly on wild rubber extraction supported skyrocketing prices and rapid economic growth. Urban centers like Manaus and Belém transformed into symbols of opulence, with infrastructure projects such as the Manaus Opera House, funded by rubber profits. Population growth in the Amazon surged as immigrants arrived to capitalize on the economic opportunities. By 1910, the population of the Amazon had grown more than 400% and regional incomes had increased by 800% (Barham and Coomes, 1994; Fernandes, 2010). In that year, the country was responsible for 74% of the world's wild rubber production (Fonseca, 1950). Yet, this growth came with deep structural vulnerabilities. The industry's reliance on wild rubber extraction meant that production was labor-intensive and geographically limited. Additionally, the profits of the boom were unevenly distributed. While local elites and foreign investors benefited, rubber tappers lived under harsh conditions, often facing disease, malnutrition, and exploitation. Barham and Coomes (1994) argue that local surplus retention during the boom was significant, with private and state investments focusing on infrastructure and trade. However, this investment pattern created a fragile economic structure heavily dependent on rubber exports. The authors also highlight the phenomenon of "Dutch Disease," whereby the booming rubber sector led to the neglect of other industries, such as agriculture, exacerbating regional inequalities.

On the other side of the Brazilian border, Casa Arana—the notorious rubber enterprise of Julio César Arana—played a brutal and pivotal role in the Amazon rubber boom. In the Putumayo region of Peru and Colombia, Arana ruled a private fiefdom, allegedly as large as Belgium, through his British-registered Peruvian Amazon Company, subjecting Indigenous populations to a systematic regime of forced labor, exploitation, and violence (Goodman, 2010; Tully, 2011; Pineda, 2000). Under this coercive arrangement, nearly 30,000 Indigenous individuals were enslaved, with approximately 4,000 tons of rubber extracted under conditions of extreme brutality (Tully, 2011). Initially highly profitable, Arana's operations contributed substantially to the prosperity of Amazonian ports such as Iquitos, but the wealth generated depended heavily on severe human rights abuses (Pineda, 2000). The exposure of these atrocities through eyewitness accounts, notably by journalist W. E. Hardenburg and British consul Roger Casement between 1909 and 1912, sparked international outrage and led to increased scrutiny by humanitarian organizations such as the Anti-Slavery and Aborigines' Protection Society (Goodman, 2010). Casa Arana remains emblematic of the profound human cost underlying extractive booms and the enduring social and economic legacies of historical exploitation in the Amazon.

The rapid rise in global demand for rubber by the turn of the century exposed the limitations of the Amazonian rubber production. Wild rubber could not meet the insatiable demand due to labor shortages and the natural scarcity of *Hevea brasiliensis*, leading to the initial price increase (Figure 1). Simultaneously, the development of rubber plantations in British and Dutch colonies in Southeast Asia introduced a low-cost, labor-intensive production system that out-competed Amazonian producers. Seeds were smuggled from the

Amazon to establish plantations on the other side of the globe. Dean (1987) chronicled how the smuggling of *Hevea brasiliensis* seeds by Henry Wickham in 1876 allowed the British to establish plantations in Ceylon, Singapore, and Malaysia. By 1910, Asian plantations had matured and began flooding the market with cheap rubber, eroding the South American dominance, and leading to a collapse in the prices. The plantation model was still unsuccessful in the Amazon, mostly due to diseases and soil erosion.

The collapse of global rubber prices with the expansion of the Asian rubber plantations (denoted as plantation rubber in Figure 1) had devastating effects on the Amazonian economy. Many export houses and traders went bankrupt, urban real estate values crashed, and service industries dependent on rubber profits withered. The social and economic gains of the boom evaporated, leaving the region impoverished and underdeveloped. We next document this reversal empirically.

3 | DATA

As in a standard persistence study, we have a three-layered data structure. First, there is the historical information, in this case, about the regional variation in exposure to the rubber boom. Second, we compile data on modern development outcomes such as measures of economic activity (e.g., night lights, income). This information is accessible through standard modern censuses as well as socio-demographic or specialized surveys (e.g., for Indigenous populations).[9] Third, we utilize a large set of remote sensing data. This includes, among others, data on modern patterns of economic activity, environmental conservation (deforestation, cattle farming, and coca cultivation) as outcomes of interest, as well as geographic and weather data as control variables to help isolate the effect of historical variables on modern outcomes.

3.1 | Historical Exposure & Indigenous Demographics

We make use of the rich historiography about rubber in the Amazon, most notably, the consular report of Robert Casement in 1904 for the British Foreign Office. There are extant official and written testimonies by French explorer Eugene Robuchon, from 1907, and judge Carlos Valcarcel, published in 1915. Rubber was an important commodity, so its price was followed by newspapers and its development by specialized magazines such as *India Rubber World*. There are also a series of high-quality secondary sources including Schurz et al. (1925); Hanson (1944); Le Cointe (1947); Weinstein (1983); Barham and Coomes (1994); Stanfield (1998); Nugent (2017). Two historical sources that measured early rubber exposure and Indigenous demographics are worth highlighting.

Historical Rubber Distribution. In order to measure early rubber exposure, we have digitized the historical rubber distribution map developed by Schurz et al. (1925), which encompasses Brazil, Peru, Colombia, Ecuador, and Venezuela. Schurz et al. (1925) assessed rubber distribution using a combination of environmental, ecological, and geographic criteria available at the time (Figure 2). Their evaluation drew upon extensive fieldwork, expert observation, local knowledge, and information from earlier expeditions and reports. Key criteria included (i) climatic conditions—such as relative humidity, rainfall, and temperature conducive to *Hevea brasiliensis*; (ii) vegetation cover, that is, observed or reported wild rubber groves; (iii) proximity to rivers and water bodies for both ecological suitability and

[9] For the study cases of Peru and Colombia, an additional original survey will be implemented, tracing individuals with family backgrounds linked to Casa Arana to study impacts in all of these dimensions but also more rubber-specific dynamics linked to cultural change and attitudes/beliefs towards environmental issues.

extraction logistics; (iv) qualitative assessments of topography and soils; and (v) areas of documented historical rubber extraction. To construct municipality-level estimates, we overlaid the most recent administrative municipality or grid shapefiles for Brazil and neighboring countries onto the digitized Schurz et al. (1925) distribution polygons, calculating for each municipality the fraction of land classified as rubber-present by Schurz et al.

As shown in Figure 3, this allows us to construct municipality-level estimates of rubber distribution in 1925.[10] While there seems to be no granular data on migration from the Northeast, especially Ceará, to the Amazon region, the historiographic literature mentions the main municipalities to which Northeast migrants headed. More specific to the study cases of Peru and Colombia, we have also digitized the boundaries of the main rubber concession alongside the modern border (1913, 1932), Casa Arana, spanning 9 million hectares, and included the geocoding of extraction camps, military posts, fluvial transport routes, etc. This map was obtained in agreement with the Ministry of Foreign Affairs of Peru (Direction of Limits, Historical Archive) (Figure 4).[11]

FAO rubber suitability. To complement and validate the historical map of rubber distribution, we use the FAO Global Agro-Ecological Zones (GAEZ) dataset, which provides agronomic suitability indices for *Hevea brasiliensis* based on modern biophysical and climatic parameters, such as temperature, precipitation, and soil characteristics. We aggregate the FAO rubber suitability measure to the municipal and grid-cell levels, allowing comparability with the historical data from Schurz et al. (1925). The FAO measure is conceptually independent of human settlement or economic activity, capturing only natural conditions conducive to rubber cultivation. Its spatial correlation with the Schurz distribution is strong (Figures 6 and 17), confirming that early-twentieth-century assessments of rubber potential aligned closely with objective environmental determinants. We use this FAO suitability index as an instrument for the historical rubber distribution to mitigate concerns about endogenous placement of extraction activity in more accessible or economically attractive areas. This validation exercise establishes both the reliability of the historical data and the exogeneity of our instrumental variable, strengthening the empirical foundation of our identification strategy.

It is relevant to note that the rubber tree has a broad presence across the Amazon, potentially spanning up to ten countries. However, there are specific ecological niches within the Amazon where conditions are particularly conducive to its growth. Variability in factors like soil fertility, texture, drainage, pH levels, and microclimatic conditions contributes to differential suitability for rubber cultivation, even within the Amazon region. By employing measures of rubber tree suitability, which consider a combination of climatic, environmental, and soil characteristics, we are able to observe meaningful variation even within the ostensibly homogeneous Amazon basin. Therefore, while the rubber tree may grow across the expanse of the Amazon, not all areas are equally conducive to its commercial exploitation.

Indigenous demographics. An important data source for identifying Indigenous populations is that originally produced by the German anthropologist Curt Nimuendaju, with more than two thousand entries for tribes in Brazil and neighboring countries (Nimuendajú, 1981), see Figure 5. He further divided Indigenous groups between existing and extinct.[12] To the best of our knowledge, only one paper, by Barsanetti and Ferreira (2022), has recently

[10] Darker shades of blue indicate higher shares of suitable area within a municipality.

[11] In addition, we have digitized and geolocated the full set of Amazonian land concessions in Peru between 1890 and 1930 (3,169 application files), which allows us to factor in the impacts of the Casa Arana within the full set of Amazonian concessions in the country.

[12] We follow Barsanetti and Ferreira (2022) and define extinct groups as groups that do not exist anymore as an autonomous community due to population decline or assimilation.

used this information in the context of deforestation. We still believe that this record has been severely understudied and can help us unlock important information about Indigenous tribes in the Amazon and beyond. This information could be useful for researchers on other topics beyond slavery and has the potential to become the new Murdock map for the Americas.

3.2 | Remote Sensing / Satellite Data

The emerging widespread availability of granular remote sensing data since the early 2000s allows us to construct both grid-cell-level outcomes of interest, as well as geographical and weather-related measures, in order to isolate the impacts of the historical exposure to rubber from more structural/geographical features. In terms of contemporary development, some examples include night lights from NASA as a proxy of local economic activity and inequality, and the mapping of low-density urbanization patterns and fluvial transport routes from HydroSHEDS (key for most Amazonian regions). In terms of local activities, important progress has been made in terms of the remote sensing measurement of deforestation (e.g., global forest change by Hansen et al. (2019)), artisanal and illegal mining (Saavedra, 2024), coca cultivation (Est, 2022), and biodiversity (Cavender-Bares et al., 2022), among others. In addition, more standard geographic (altitude, ruggedness, etc.) and weather data (rainfall, temperatures, etc.) are included as control variables to help isolate the effect of historical variables on modern outcomes. We incorporate controls for rainfall and temperature utilizing data from WorldClim 2.1. This dataset provides average monthly climate data for the period 1970–2000.

4 | EMPIRICAL STRATEGY

4.1 | Baseline OLS Estimates

This first section presents some initial regressions that examine how historical rubber distribution correlates with present-day development outcomes. The arrow of time—running from the historical rubber boom to current conditions reduces concerns about reverse causality, but there may still be unobserved factors correlated with both rubber exposure and contemporary outcomes. Thus, we include a rich set of control variables and fixed effects to mitigate potential endogeneity issues. We estimate:

$$y_i = \alpha + \beta\,\text{RubberDistribution1925}_i + \mathbf{X}_i\gamma + \delta + \varepsilon_i, \tag{1}$$

where y_i is a contemporary outcome of interest for area i (e.g., income or inequality). Rubber Distribution $(1925)_i$ is the standardized share of each area's surface covered by the Schurz et al. (1925) map of rubber distribution. $\mathbf{X}_i$ includes controls for environmental conditions (e.g., rainfall, temperature, ruggedness, and altitude) and proximity to key transportation routes (e.g., distance to rivers and coasts). δ in the equation can represent δ_c or δ_s, capturing country- or state-level fixed effects, respectively. ε_i is the error term. The specification then accounts for broad regional differences while focusing on the partial correlation between historical rubber exposure and different development outcomes.

The coefficient β represents an estimate of whether historically rubber-exposed areas systematically diverge in present-day income and inequality. A positive β would imply that these areas tend to exhibit higher outcomes (for instance, higher income), whereas a negative β suggests the opposite. Because these regressions do not establish a strict

causal mechanism, the focus is on comparing areas with different levels of exposure, while controlling for a range of potential confounders.

4.2 | Instrumental Variable

To address concerns about the potential endogeneity of historical rubber distribution, we employ an instrumental variables (IV) strategy that exploits exogenous variation in natural rubber suitability from the Food and Agriculture Organization (FAO). The FAO suitability index captures the agroecological conditions—such as temperature, precipitation, and soil characteristics—most favorable for the cultivation of *Hevea brasiliensis*. These biophysical features are determined by long-run climatic and geological factors, making them plausibly exogenous to subsequent economic, social, or institutional developments. Importantly, the FAO suitability measure is based on modern satellite and agronomic data and was constructed independently of the historical rubber boom, providing a reliable source of exogenous variation that can serve as a valid instrument for the intensity of historical rubber distribution observed in 1925.

Formally, to test this correlation, we estimate the following system using two-stage least squares (2SLS):

$$\text{RubberDistribution1925}_i = \pi_0 + \pi_1 \, \text{RubberSuitability}_i + \mathbf{X}_i \boldsymbol{\Gamma} + \nu_i, \tag{2}$$

$$y_i = \alpha_0 + \alpha_1 \, \widehat{\text{RubberDistribution1925}}_i + \mathbf{X}_i \boldsymbol{\beta} + \varepsilon_i, \tag{3}$$

Where $\text{RubberDistribution1925}_i$ denotes the historical intensity of rubber exploitation in municipality i, and $\text{RubberSuitability}_i$ provides the exogenous source of variation based on natural growing conditions. $\mathbf{X}_i$ includes geographic controls.

The key identifying assumption is that the FAO-based suitability index affects contemporary outcomes only through its influence on where rubber was produced. This assumption is supported by two features of the data. First, the FAO measure depends on physical attributes that are fixed over time and unrelated to local economic or institutional shocks. Second, the instrument performs well in the first stage (See Fig. 6 and 17): higher FAO suitability strongly predicts a greater historical presence of rubber, consistent with the historical geography of extraction. As a result, this strategy isolates variation in historical rubber exposure driven by exogenous agroecological endowments, enabling a more credible assessment of the long-run consequences of the rubber economy.

4.3 | Regression Discontinuity Design

In a third empirical approach, we exploit the arbitrary demarcation of the largest Amazonian twentieth-century rubber concession along the modern frontier between Peru and Colombia, spanning 9 million hectares, granted to the rubber baron Julio César Arana, circa 1900–1912. The plausibly exogenous comparison of areas around the concession borders comes from the fact that the borders were defined based on salient geographic features at a time when little was known about the cartography of the concession areas. More precisely, the concession was delimited along the Caquetá (north) and Putumayo (south) river basins, as shown in Figure 4.

The rubber concessions disproportionally exerted intense violence over the Indigenous labor force and did not entail productive investments in their area of influence. Given the demarcation of the concession borders, following particular rivers, we can estimate the causal effect of exposure to the Casa Arana concession on grid-cell-level outcomes (1km by

1km) such as deforestation, as well as the intensity of present-day illegal economies linked to land-use transitions towards coca cultivation and cattle raising. The specification for grid-cell level outcomes is shown next.

$$y_i = \alpha + \gamma AranaConcession_i + f(location_i) + \mathbf{X}_i\boldsymbol{\beta} + \phi + \varepsilon_i \tag{4}$$

for $i \in bw$ (bandwidth), where y_i is the outcome of a 1km-by-1km grid cell i (e.g., the share of tree cover within a grid cell); $AranaConcession_i$ is an indicator equal to 1 if i is inside a rubber concession area and 0 otherwise; $\mathbf{X}_i$ is a vector of covariates for grid cell i, including geographic characteristics (elevation, slope, rainfall, etc.); ϕ is a 50km-segment coarse grid fixed effect; and $f(location_i)$ is the RD first-order polynomial, which controls for smooth functions of geographic location for grid cell i. The coefficient of interest is γ: the effect of being just inside the concession area on outcome y_i. Remote sensing data on structural features (e.g., elevation, ruggedness, rainfall, land suitability, river characteristics, etc.) allow us to check whether this design is valid by testing discontinuities in other relevant dimensions.

5 | EMPIRICAL RESULTS

5.1 | Brazilian Data Analysis

5.1.1 | Municipality-level Data

The rubber boom in the Brazilian Amazon generated a short-lived surge in economic activity under conditions of profound coercion and labor exploitation. This section examines the long-term local consequences of that episode by presenting correlational and instrumental variable (IV) evidence linking historical rubber activity to contemporary socioeconomic, demographic, and environmental outcomes. Using OLS graphical analyses that account for geographic and climatic features, including rainfall, temperature, ruggedness, altitude, and distance to rivers and the coast, we document how the initial prosperity associated with rubber extraction gave way to enduring underdevelopment. Municipalities with higher historical rubber suitability exhibited greater per capita GDP in 1920, consistent with the temporary wealth created during the boom. Yet by 2010, these same areas display lower average incomes and higher income inequality, including within Indigenous populations, alongside evidence of demographic changes such as increased Indigenous–non-Indigenous intermarriage observable as early as the 1872 Census. We also find higher deforestation activity and higher extinction rates of Indigenous groups in historically rubber-intensive areas. The results suggest that the rubber boom's economic gains were not only transitory but also accompanied by persistent social, demographic, and environmental scars, reinforcing the view that extractive growth based on coerced labor produces legacies of inequality and marginalization.

Figure 2 outlines the geographical extent of the rubber industry by presenting the historical rubber suitability map from Schurz et al. (1925), which encompasses Brazil, Peru, Colombia, Ecuador, and Venezuela. Due to the availability of historical data, our initial focus is on the Brazilian Amazon, where detailed municipal-level data are available. We include other Amazonian countries at the grid-cell level in the next subsection. Figure 3 displays the historical mean rubber distribution by municipality, providing a detailed visualization of variation in suitability across Brazilian municipalities. These figures set the foundation for our analysis by identifying the specific areas likely impacted by the rubber boom, allowing us to examine whether the benefits of this economic event permeated local populations

over time or if they exemplified an enclave economy with limited lasting benefits for the masses. Complementing these maps, Figure 6 presents the FAO-based rubber suitability measure for Brazilian municipalities, which serves as the instrument in our IV specifications. The spatial distribution of the FAO measure closely mirrors that of the historical rubber activity, with higher suitability concentrated along the western Amazon basin. Figure 7 reports the first-stage relationship between the two measures, revealing a strong positive correlation at the municipal level. This correspondence indicates that areas historically active in rubber extraction were located precisely where agronomic and climatic conditions were most favorable for *Hevea brasiliensis*, lending empirical support to the validity of the FAO suitability measure as a relevant instrument for historical rubber distribution.

Figure 8 presents two panels that depict correlations between rubber suitability and economic outcomes, controlling for environmental and geographical factors such as rainfall, temperature, ruggedness, distance to rivers and the coast, and altitude. Panel A displays a positive relationship between rubber suitability and the logarithm of per capita GDP from the 1920 Brazilian Census, indicating that municipalities with higher suitability for rubber extraction experienced greater economic prosperity during the rubber boom. This aligns with historical accounts of wealth accumulation in regions like Manaus, where the rubber industry initially spurred significant economic activity (Hanson, 1944). In stark contrast, Panel B shows a negative correlation between rubber suitability and the logarithm of average income in the 2010 Brazilian Census, suggesting that these same municipalities faced economic decline in the long run. This contrast between initial prosperity and later underperformance supports our hypothesis that the benefits of the rubber boom were not sustained over time. The results highlight the paradox of the rubber boom: areas that once thrived economically are now lagging, emphasizing the lasting impacts of historical extractive industries on contemporary economic outcomes.

In Figure 9, we examine the relationship between historical rubber suitability and income inequality in Brazilian municipalities in 2010, controlling for environmental and geographical factors such as rainfall, temperature, ruggedness, distance to rivers and the coast, and altitude. In Panel A, we observe a positive correlation between rubber suitability and the general Gini Index from the 2010 Census, indicating that municipalities with higher suitability for rubber extraction tend to have greater income inequality. This suggests that the economic benefits of the rubber boom were unevenly distributed, possibly favoring elites while leaving the broader population with limited gains. Panel B shows a similar positive relationship between rubber suitability and the Indigenous Gini Index, highlighting that income inequality within Indigenous populations is also higher in these areas. We interpret the higher Indigenous Gini index observed in municipalities with greater historical rubber suitability as stemming from two related mechanisms. First, intensive rubber extraction often led to significant disruption of Indigenous societies, with some communities or groups being brought into the rubber economy, sometimes as workers or intermediaries, while others were left out or remained on the economic margins. Second, as the rubber economy declined and new opportunities appeared, access to resources, jobs, or government help connected to the old rubber trade may have been shared unequally among Indigenous people. This finding implies that Indigenous communities, who were often subject to exploitative labor practices during the rubber boom, experienced within-group disparities in wealth distribution. The increased inequality among the general and Indigenous populations supports our hypothesis that the long-term consequences of the rubber boom implied heightened social stratification and that the initial prosperity did not translate into equitable economic development. These results underline the historical extractive industries' profound impact on income distribution in affected regions.

Figure 10 explores the relationship between historical rubber suitability and demographic

changes in Brazilian municipalities by presenting the correlation between rubber suitability and the share of Indigenous-white mixed-race individuals (mestizos) in the 1872 Brazilian Census, controlling for environmental and geographical factors such as rainfall, temperature, ruggedness, distance to rivers and the coast, and altitude. The figure shows a positive correlation, indicating that areas with higher rubber suitability had a greater proportion of mestizo populations even before the peak of the rubber boom. This suggests that these regions were already experiencing significant interactions between Indigenous populations and outsiders, likely due to the early extractive activities. The increased miscegenation may reflect the initial stages of cultural assimilation and a disruption of Indigenous societies, which may set the stage for the more exploitative labor practices that occurred during the rubber boom. This demographic shift supports our hypothesis that the rubber industry's expansion intensified contact between Indigenous communities and non-Indigenous settlers. These results also motivate our exploration of Indigenous extinction in the next subsection. In sum, the findings highlight how historical economic activities can influence economic outcomes and the demographic and cultural composition of affected regions over time.

The patterns documented in Figure 11 extend to broader forms of social conflict and environmental degradation. Figures 11a–11d show that municipalities with higher historical rubber suitability experience higher levels of conflict activity, deforestation, mining, and forest burning today, controlling for environmental and geographical conditions. These positive correlations suggest that the same historical forces that normalized coercive labor relations during the rubber boom also weakened local institutions and governance structures, laying the groundwork for persistent instability. In areas where coercion and extractive practices were once common, social and political conflicts remain more frequent, and resource extraction continues to drive environmental damage. The evidence points to a reinforcing mechanism: weak state presence and unequal power relations foster conditions where violence, deforestation, and informal mining thrive. Together with the previous results, these findings reveal a consistent pattern: historical extractive economies left behind social and institutional legacies that continue to shape how local communities interact with labor, land, and natural resources.

Finally, in Figure 12 we present the estimated effects of historical rubber distribution on municipal income across several census years between 1920 and 2010. The results reveal a striking reversal of fortunes. In 1920, municipalities historically engaged in rubber extraction exhibited significantly higher per capita income, reflecting the short-lived prosperity generated by the rubber boom. Because the Brazilian Census did not report comparable municipal income data for the Amazon between 1930 and 1960, and the 1960 Census lacks coverage for most of the region, the next available observation appears in 1970. By that decade, the relationship between historical rubber exposure and income had fully reversed: municipalities that had once been more prosperous were now relatively poorer. The negative association persists through 1980, 1991, 2000, and 2010, and the error bars show that these patterns are both economically meaningful and statistically robust. This evidence underscores the central mechanism of the paper: initial prosperity built on an extractive and coercive system failed to generate durable development. Over time, regions enriched by the rubber boom fell behind, leaving a legacy of underdevelopment rooted in the exploitative institutions and social disruptions of the early 20th century.

As a robustness test, Figure 13 presents estimates of the association between historical rubber activity and average income across time, using both OLS and IV specifications with controls. The OLS estimates rely on the historical distribution of rubber extraction in 1925, while the IV approach instruments this measure with rubber crop suitability from the FAO dataset, thereby addressing concerns about the endogenous location of rubber extraction in more productive or accessible areas. The OLS results point to an initial positive

association between rubber activity and income in 1920, consistent with the short-run prosperity generated during the boom. By contrast, in 2010, the estimated coefficients became negative across both OLS and IV specifications, indicating that historically rubber-intensive municipalities are now poorer relative to otherwise similar locations. The IV estimates, while less precisely estimated, reinforce the direction of the effect and suggest that the reversal in relative income persists after accounting for potential endogeneity. The stability of the results when including geographic controls further rules out that this pattern is driven by permanent differences in geography or agricultural potential.

Building on the evidence of persistent economic decline, Figure 14 examines how historical rubber intensity relates to the survival of Indigenous groups. Municipalities with greater rubber extraction in 1925 show a markedly higher share of extinct Indigenous tribes today. This pattern holds when using both the observed distribution of historical rubber activity (Panel a) and the FAO-based rubber suitability measure (Panel b), suggesting that the relationship is not simply driven by the endogenous placement of extraction sites. The results highlight the demographic and cultural costs of the rubber boom: areas most integrated into the coerced labor economy experienced the most severe depopulation and disappearance of Indigenous groups. These findings complement the long-run income reversal documented in Figure 13, pointing to a dual legacy of economic underdevelopment and social collapse rooted in extractive institutions. The evidence is consistent with historical accounts describing widespread violence and the destruction of Indigenous communities during the boom, whose consequences appear to persist more than a century later.

The instrumental variable estimates reported in Figure 15 reinforce that the relationships documented above are not driven by endogenous placement of rubber extraction sites. Using FAO rubber suitability as an instrument for the historical distribution of rubber activity, we find consistent positive effects on contemporary conflict, deforestation, mining activity, forest burning, and the extinction of Indigenous groups. The IV coefficients, while less precisely estimated, remain similar in magnitude to the OLS estimates and are robust to the inclusion of detailed geographic controls. This stability reinforces the interpretation that the legacy of rubber extraction operates through mechanisms related to institutional weakness and persistent extractive practices rather than through geography or natural endowments alone. The continued significance of the extinction outcome in particular suggests that forced labor and violence against Indigenous communities were foundational to the spatial pattern of rubber extraction, setting in motion developmental trajectories characterized by social fragmentation, ecological exploitation, and limited capacity for collective governance.

5.1.2 | Grid-level Analysis: Indigenous Extinction, Night Lights, and Population Density in 2000

In this section, we complement our municipality-level evidence with a finer geographic perspective by conducting grid-level analyses across the Amazon. Specifically, we divide the region into 0.5×0.5 degree cells and define our continuous treatment variable as the share of each grid cell historically suitable for rubber production, based on the distribution reported by Schurz et al. (1925). Figure 17 presents this measure, illustrating the historical concentration of rubber activity around the central and western Amazon basin. To construct the corresponding instrumental variable at the grid level, we rely on the FAO rubber suitability index, displayed in Figure 17, which captures exogenous variation in agronomic potential for rubber cultivation. Figure 18 documents the first-stage relationship between the two measures, showing a strong positive correlation consistent with the pattern observed at the municipal level. For contemporary outcomes, we employ nighttime luminosity

data from the Long-Term Consistent Nighttime Light Dataset (Long NTL) and population density from the Gridded Population of the World, Version 4 (GPWv4, Revision 11), both standardized for comparability. In addition, we construct a grid-level measure of Indigenous group extinction, enabling us to assess whether areas with historically present rubber experienced a greater loss of Indigenous presence. This grid-level approach allows us to extend the analysis to the entire Amazon basin and verify that the historical patterns identified for Brazilian municipalities also hold when examined at finer spatial resolution.

Table 1 reports the relationship between historical rubber distribution and contemporary measures of development—nighttime lights and population density, at the grid level. Columns (1)–(3) present estimates for nighttime luminosity in the year 2000, while columns (4)–(6) report analogous results for population density. Across all specifications, the coefficients on historical rubber distribution are negative and statistically significant, indicating that areas with greater historical rubber activity remain less developed today. The OLS estimate in column (1) shows that a one–standard deviation increase in historical rubber distribution is associated with roughly 0.005 standard deviations lower nighttime luminosity, even after controlling for rainfall, temperature, ruggedness, altitude, and distance to rivers and the coast. The IV results in column (3), instrumenting historical rubber activity with FAO rubber suitability, confirm this relationship and yield somewhat larger magnitudes. A similar pattern emerges for population density, where grids historically engaged in or suitable for rubber extraction exhibit lower contemporary population concentration. The IV estimates in columns (5)–(6) reinforce this negative association, underscoring that the long-run effects are not driven by endogenous location choices. The consistency of these results can also be seen visually in Figure 22, where both OLS and IV estimates lie below zero across specifications, highlighting the persistent negative relationship between historical rubber exposure and modern economic activity. Collectively, the evidence from both the table and the figure suggests that areas historically integrated into the rubber economy continue to display weaker economic activity and lower settlement density, consistent with the enduring legacy of extractive and coercive development during the boom.

Also, Table 3 presents OLS and IV estimates of the relationship between historical rubber distribution and contemporary nighttime luminosity, estimated separately by country. The coefficients are predominantly negative, indicating that areas historically engaged in rubber extraction remain less developed today. Statistically significant effects are observed in Bolivia, Brazil, Colombia, and Peru. Among these, the IV estimates for Brazil (–0.0149) and Peru (–0.0396) suggest a robust negative association even after accounting for potential endogeneity in the spatial allocation of extraction. Colombia also displays economically meaningful and statistically significant coefficients (–0.0136 to –0.0917), pointing to a pronounced legacy of underdevelopment in historically rubber-intensive regions. Bolivia shows smaller negative but still significant effects, while coefficients for Ecuador, Guyana, Suriname, and Venezuela are negative but not statistically different from zero, likely due to smaller sample sizes. Taken together, these results show that the inverse relationship between historical rubber activity and present-day development observed in Brazil extends across Amazonian countries, corroborating the persistence of extractive legacies at a broader regional scale.

Our regression results are complemented by Figures 19 and 20, which visually illustrate the underlying OLS correlations between historical rubber presence and contemporary outcomes of luminosity and population density. Again, we find a negative relationship, further emphasizing our conclusion that areas endowed with historical rubber suitability now systematically experience lower levels of economic development. Overall, these grid-level findings support our earlier municipal-level analyses, indicating the lasting adverse effects of the historical rubber boom. Specifically, areas historically suitable for rubber

production—despite early short-term prosperity—appear to have experienced sustained long-term economic decline and lower demographic concentrations.

Figures 21 and 23 present the main results using digitized ethnohistorical data on Indigenous tribe extinctions, originally mapped by Curt Nimuendajú and digitized by Barsanetti and Ferreira (2022). The Nimuendajú map is a foundational ethnographic source documenting the geographic distribution and fates of Indigenous groups across Brazil and the Amazon Basin during the early twentieth century, recording which tribes persisted and which had already disappeared by the time of his fieldwork. The extinction measure is constructed at the grid-cell level and captures the share of Indigenous groups that became extinct within each 0.5×0.5 degree grid. Figure 20 shows a clear positive relationship between historical rubber activity and Indigenous group extinction, using both the historical rubber distribution and the FAO rubber suitability measure. The correlation persists when controlling for environmental characteristics such as rainfall, temperature, ruggedness, altitude, and distances to rivers and coasts. Figure 23 complements this evidence with OLS and IV estimates, reinforcing that the relationship remains strong when instrumenting with FAO rubber suitability. The IV coefficients are larger in magnitude, suggesting that the extent of rubber extraction in the late nineteenth and early twentieth centuries had a substantial and lasting impact on the disappearance of Indigenous groups.

5.2 | Regression Discontinuity: Casa Arana's Rubber Concession in Peru and Colombia

Our RDD analysis allows us to examine potential mechanisms of transmission with causal inference methods. First, with more granular data for Colombia and Peru we can examine what happened after the boom ended. This was an area that was particularly affected by violent extraction and Indigenous labor. In terms of modern outcomes, we can focus on specific processes such as deforestation, or land transitions towards coca cultivation and cattle raising, which are widespread around former rubber extraction zones. The proposed empirical design exploits the demarcation of the largest rubber concession along the modern frontier between Peru and Colombia, granted to the rubber baron Julio Cesar Arana, circa 1900–1912. This subsection provides evidence of the validity of the empirical design and results at a grid-cell level on long-term deforestation patterns and land-use transitions around the Casa Arana boundaries.

5.2.1 | Balance on Geographic Characteristics

A natural concern for identification is the possibility that the concession borders were chosen strategically, based on local characteristics that could have directly affected our outcomes of interest. For instance, areas exposed to Casa Arana might have shared geographical characteristics, enabling different agricultural production possibilities or population settlement patterns around the concession borders. The location and period when the concession was granted mitigate this concern. During the early twentieth century, despite earlier mapping efforts, the vastness and dense rainforest of the Amazon posed significant challenges to realize accurate and comprehensive cartography. As a result, rivers were commonly used to delineate borders and concessions, a feature that would last at least until 1922, when the modern border between Peru and Colombia was established.

To support the continuity of structural characteristics around the concession border, Table 4 reports summary statistics and RD estimates using specification (4) for a set of geographical covariates at the Casa Arana boundary. The analysis is conducted at the 1km by 1km grid-cell level, with standard errors clustered at the 50km-segment level. As

shown, except for slope and ruggedness, where differences arise in the comparisons with alternative bandwidths, plausibly because concession borders coincided with rivers, we find balance across all covariates. Importantly, these imbalances are largely mitigated once we use the RD estimation with optimal bandwidths and fixed effects. RD plots for each of these variables are shown in Figure 24. To ensure consistency, in the following RDD estimations, we include all of these covariates as controls and 50km-segment fixed effects. In addition, we implement a donut RDD specification as a robustness check.

5.2.2 | RDD Results: Deforestation

Having established the balance of geographic covariates, Table 5 presents the results of a geographic RDD exploiting the historical boundaries of the early twentieth-century rubber concession known as Casa Arana. The unit of observation is a 1km by 1km grid cell. The table reports results for different bandwidths (50km, 20km, 10km, and an optimal range selected using an MSE-minimizing procedure). The main outcome is tree cover in the year 2000, measured as the percentage of each grid cell covered by vegetation taller than 5 meters. Across specifications, tree cover by the year 2000 is estimated to be 4.2 to 14.6 percentage points lower inside the former concession relative to comparable areas just outside the boundary. The magnitude of the effect increases as the bandwidth narrows, even after including the full set of controls and segment fixed effects. Bias-corrected and robust estimates reinforce this conclusion[13].

Taken together, these results point to a persistent reduction in tree cover within the former concession's boundaries, evident almost a century after its dissolution. A plausible explanation is that the concession period, through its disproportionate violence and coercion against Indigenous groups, disrupted the transmission of traditional knowledge and weakened local capacities for forest stewardship. Nevertheless, alternative mechanisms cannot be ruled out. In particular, contemporary drivers of deforestation, such as coca cultivation and cattle ranching, which have expanded significantly in the Amazon since the 1980s, may exert differential pressures inside and outside the former concession area, potentially shaping the observed patterns of forest cover. The following subsection presents results based on land-use changes linked to the main drivers of deforestation in Colombia since the 1980s.

5.2.3 | RDD Results: Coca Farming and Cattle Ranching

By 2000, in Colombia, around 80,000 *cocalero* families supplied two-thirds of the world's coca production, with close to 50% cultivated in natural protected areas or Indigenous- or Afro-descendant territories (UNODC-SIMCI, 2019). Along with coca cultivation, illegal cattle ranching has been identified as a central driver of deforestation. By 1995, 70% of previously forested land in the Amazon and 91% of land deforested since 1970 had been converted for cattle ranching (Margulis, 2004). While the increasing demand for pasture expansion plays a role, in Colombia, forest conversion to cattle ranching has been pointed out as a way to legalize informal or illegal landholdings (Van Dexter and Visseren-Hamakers, 2020); more precisely, by reflecting farmers' investments in cattle as a way to secure claims to land plausibly connected to laundering drug profits (Richani, 2012). In this subsection, we examine whether these illegal activities could be acting as mechanisms of persistence.

To explore the role of these deforestation drivers in our setting, we rely on a high-resolution land-use classification dataset for the Colombian Amazon, by Murillo-Sandoval

[13]Table 6 reports similar results using a local quadratic RD specification.

et al. (2023), covering the period from 1985 to 2019. The authors use a supervised deep-learning approach based on Landsat satellite imagery to classify land cover into four main categories: (1) Forest, (2) Coca crops, (3) Cattle pasture, and (4) Other (including agriculture, settlements, and bare land). The model is trained and validated further using a combination of ground-truth observations, aerial photographs, and existing land-use datasets, achieving high classification accuracy (overall accuracy exceeding 90%). Notably, the coca crop classification is validated against government coca monitoring data from the UNODC-SIMCI program to ensure reliability. To the best of our knowledge, this is the most granular and longitudinal dataset to track land transitions in the Colombian Amazon. The dataset has a spatial resolution of 30 meters and provides annual maps of land-use transitions, enabling the identification of when and where deforestation occurs, linked to each of these transitions.

We exploit this information using land transitions as outcomes under the same RDD structure described by Equation 4. Due to the geographical coverage of Murillo-Sandoval et al. (2023)'s dataset, we restrict the analysis to the discontinuity within Colombia. Table 7 shows the results. As before, the unit of observation is a 1km by 1km grid cell, and results for MSE-optimal bandwidths are reported. Columns (1) to (4) report RD estimates for land transitions to coca and cattle by 1985 (the earliest year available). Each cell is coded as one if it experienced a transition from prior land uses into coca (columns 1 and 2) or cattle (columns 3 and 4). The results show increases of approximately 3.8–4.0 percentage points in coca conversion and 4.0–7.1 percentage points towards cattle transition by 1985 inside the former concession area relative to comparable locations outside the boundary, with the lower-bound magnitudes when including controls and segment fixed effects. RD plots for both outcomes are shown in Figure 25. These results indicate that land transitions into coca and cattle—both tied to the expansion of illegal economies—help explain the persistent deforestation observed within the former Casa Arana boundaries nearly a century after its dissolution. This pattern is consistent with the disproportionate violence and coercion inflicted on Indigenous groups in concession zones, which undermined local institutions and capacities for forest stewardship.

5.2.4 | Robustness: Donut RD Estimates

Because our geographical cutoff coincides with river boundaries—the Putumayo and Caqueta rivers delineating Casa Arana's concession—cells immediately adjacent to the border may display mechanical, bank-related additional discontinuities in characteristics such as terrain and hydrology, potentially violating the RD smoothness assumption. We therefore re-estimate Tables 5 and 7 using a donut RD that excludes all 1km by 1km cells within 0.5km and 1km of the cutoff, while retaining the triangular kernel and local linear fits. As reported in Table 8, our main result holds: estimates for tree cover remain robust in both sign and statistical significance across bias-corrected specifications. Results for land transitions into coca and cattle are less stable, yet remain significant for the coca bias-corrected estimates, in the base.

6 | CONCLUSION

Our findings shed light on the complex economic legacy of the Amazon rubber boom at the turn of the twentieth century. While municipalities historically suited for rubber extraction initially prospered, evidenced by higher per capita GDP in the 1920 Brazilian Census, this prosperity was not sustained. By 2010, these same municipalities displayed

markedly lower average incomes and higher levels of income inequality compared with less rubber-intensive areas. The persistence of inequality within Indigenous populations, who were disproportionately subjected to coercive labor, underscores the long-run social and distributive consequences of the boom. Consistent with historical accounts, we document higher rates of Indigenous group extinction and evidence of demographic transformation, including increased Indigenous–non-Indigenous mixing visible as early as the 1872 Census. Beyond these socioeconomic effects, we find lasting environmental and institutional repercussions. Municipalities historically engaged in rubber production today exhibit higher rates of deforestation, mining, and forest burning, as well as greater conflict intensity, patterns that our instrumental variable strategy (using suitability measures) supports as causal rather than outcomes of geographic or environmental confounders. Complementing these results, grid-level evidence across the Amazon basin strengthens the regional interpretation: grids more historical rubber distribution have lower nighttime light intensity, lower population density, and higher Indigenous extinction rates, with consistent negative effects across Brazil, Colombia, Peru, and Bolivia. Together, the municipal and grid-level results suggest that the rubber boom's short-term prosperity was built on fragile and coercive foundations that entrenched extractive economic structures.

Our Regression Discontinuity Design results, which focused on the Casa Arana concessions in Peru and Colombia, complement this analysis by looking at deforestation in the Amazon, an environmental outcome associated with Indigenous rights and territorial presence. In 2000, areas within the Arana concession exhibited significantly more deforestation compared to areas outside the border. Consistent with these patterns, land transitions from forest to coca cultivation and cattle ranching further contributed to forest loss. More recent trends, however, suggest signs of recovery, possibly due to modern protections such as designated Indigenous protected areas (Baragwanath and Bayi, 2020; Laudares, 2016; Qin et al., 2023).

Our findings on the historical persistence of a relevant commodity boom in the Amazon region can offer policymakers clues on how to address current environmental and institutional challenges in exploring natural resources in the Region. It is not an exaggeration to say this remains the main challenge for Amazonian policymakers. The rubber boom did not transform wealth into common goods. The question that remains is how current policy makers will write a different, and hopefully, a more positive history for the next generations.

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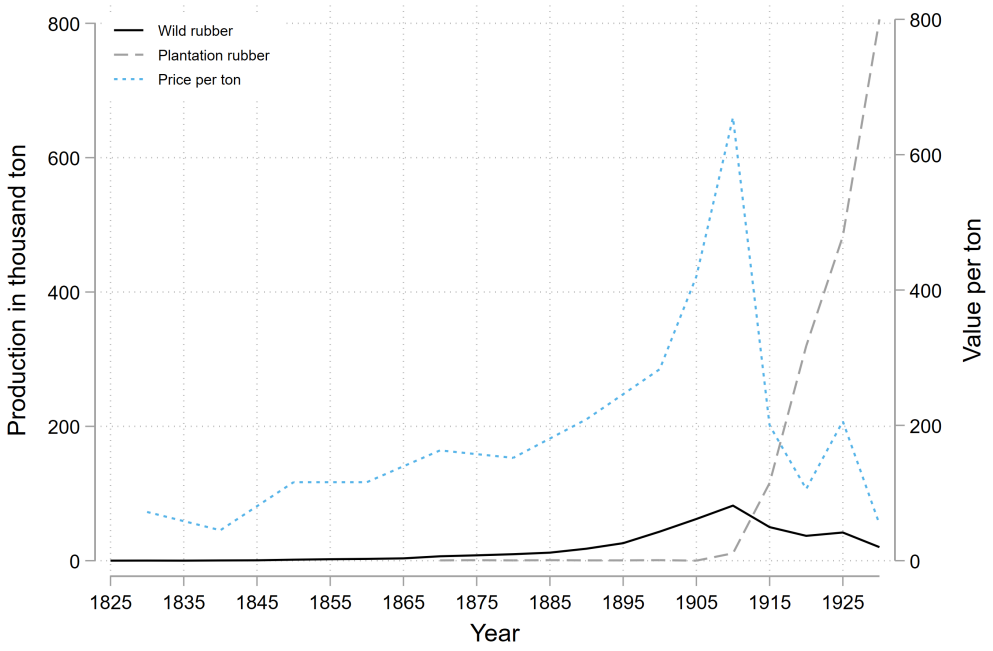
FIGURES

FIGURE 1 Wild and Plantation Rubber Production and Rubber Value Per Ton (Pounds): 1825 to 1930

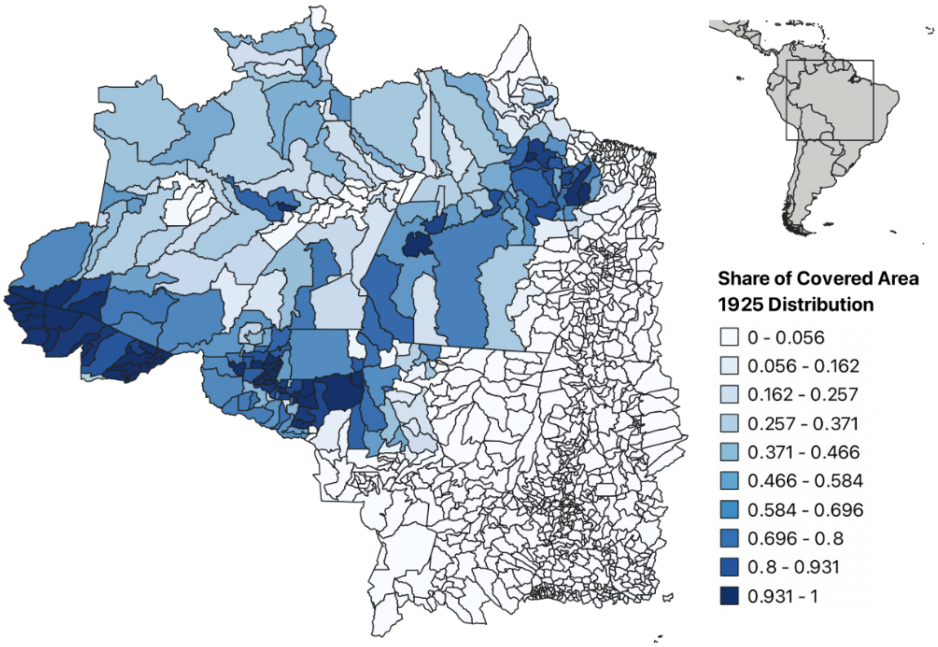


Notes: The graph shows the evolution of wild and plantation rubber production (on the left axis), and the value per ton in British pounds (on the right axis) from 1825 to 1925. The main sources of information are Schidrowitz and Dawson (1952); Hotchkiss (1924); Benchimol (2010); Vayagool (1967).

FIGURE 2 Historical Rubber Distribution in 1925

Notes: The figure displays the historical rubber distribution map from Schurz et al. (1925). The darker shaded areas represent regions identified with rubber presence in 1925.

FIGURE 3 Historical Rubber Distribution (1925) in Brazilian Municipalities

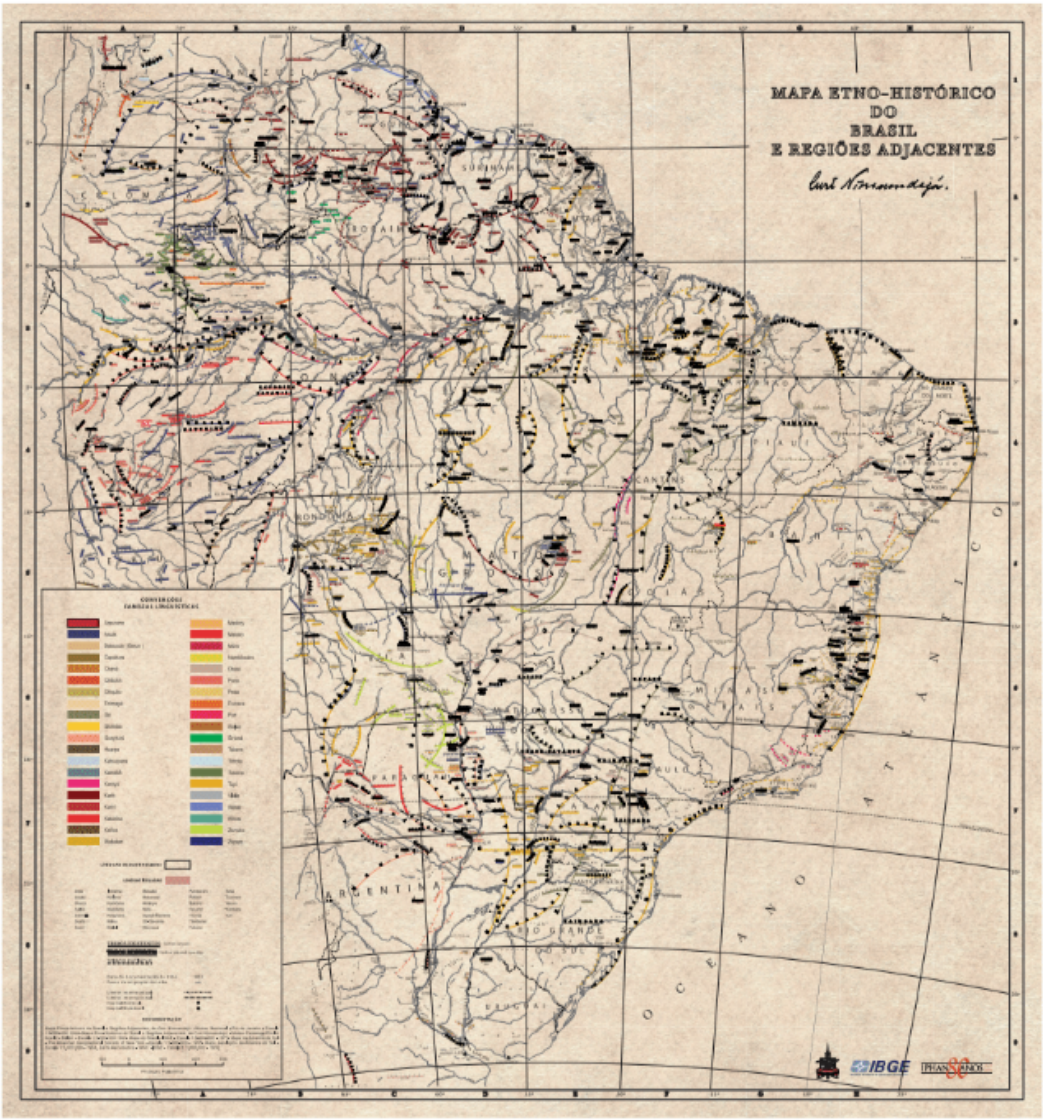


Notes: The figure displays the mean of the historical rubber distribution map from Schurz et al. (1925) by municipalities in Brazil. The share of land with rubber in each municipality is presented in shades of blue.

FIGURE 4 Casa Arana: Demarcation, Extraction Camps, and Trading Routes (1913)

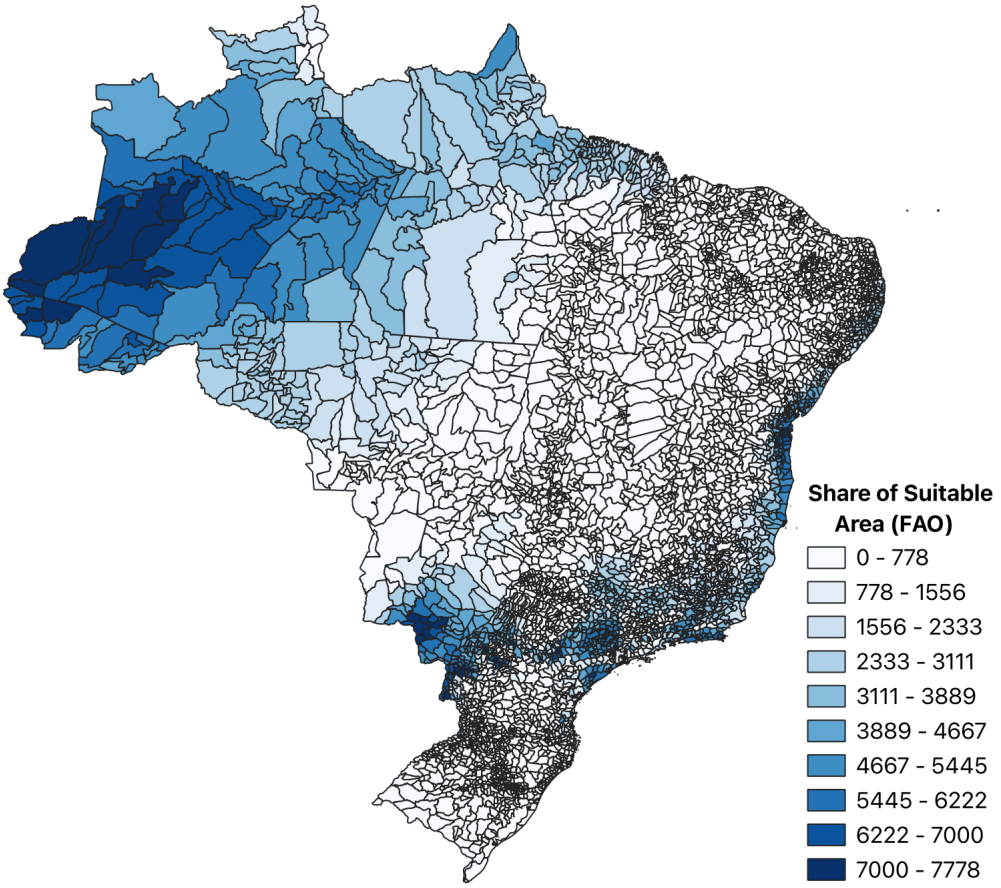
Notes: The figure shows the original concession map obtained in the Agreement with the Ministry of Foreign Affairs of Peru (Direction of Limits, Historical Archive).

FIGURE 5 Indigenous Groups in the Amazon Region According to the Nimuendajú Ethno-Historical Map



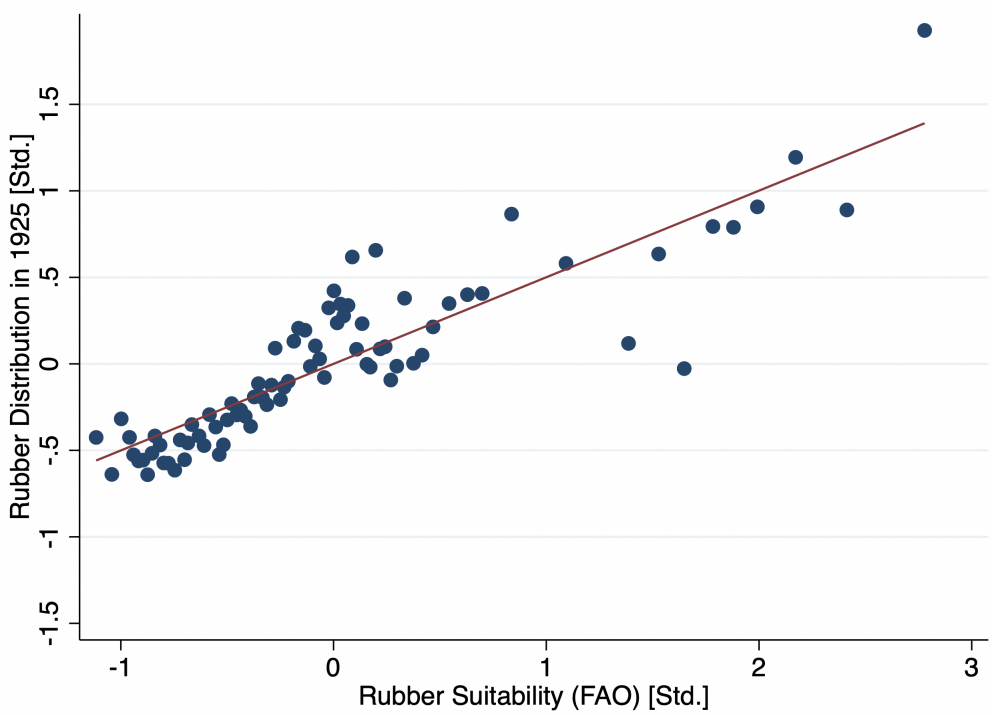
Notes: The figure shows the spatial distribution of Indigenous groups in Brazil and adjacent regions as documented by Curt Nimuendajú in his Mapa Etno-Histórico do Brasil e Regiões Adjacentes (first compiled circa 1944, published by IBGE, 1981 edition). Distinct colors denote different Indigenous linguistic families, while symbols indicate groups' historical presence and extinction status up to the mid-20th century. *Source:* (Nimuendajú, 1981).

FIGURE 6 Rubber Suitability (FAO) in Brazilian Municipalities



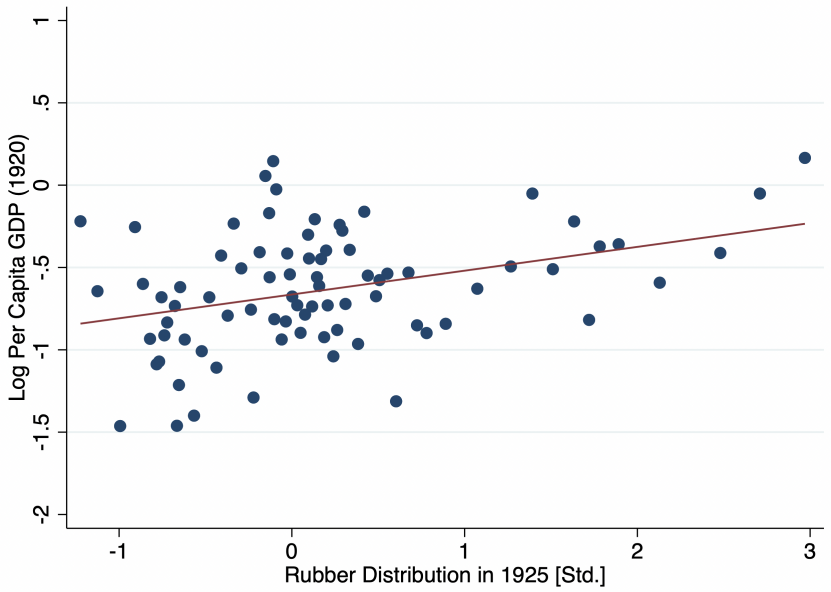
Notes: The figure displays the mean of the Rubber Suitability from FAO by municipalities in Brazil. The scale of land suitable for rubber in each municipality is presented in shades of blue (0-10,000).

FIGURE 7 First Stage: Historical Rubber Distribution in 1925 and FAO Rubber Suitability at Municipality-Level

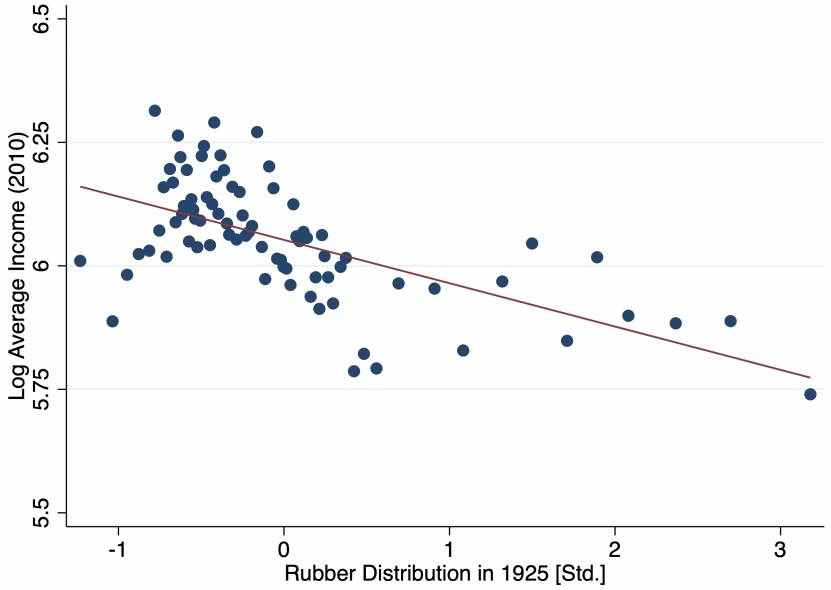


Notes: The figure displays the correlation between the historical rubber distribution in 1925 from Schurz et al. (1925) by municipality and the FAO Rubber Suitability.

FIGURE 8 Income Reversal in Rubber Areas



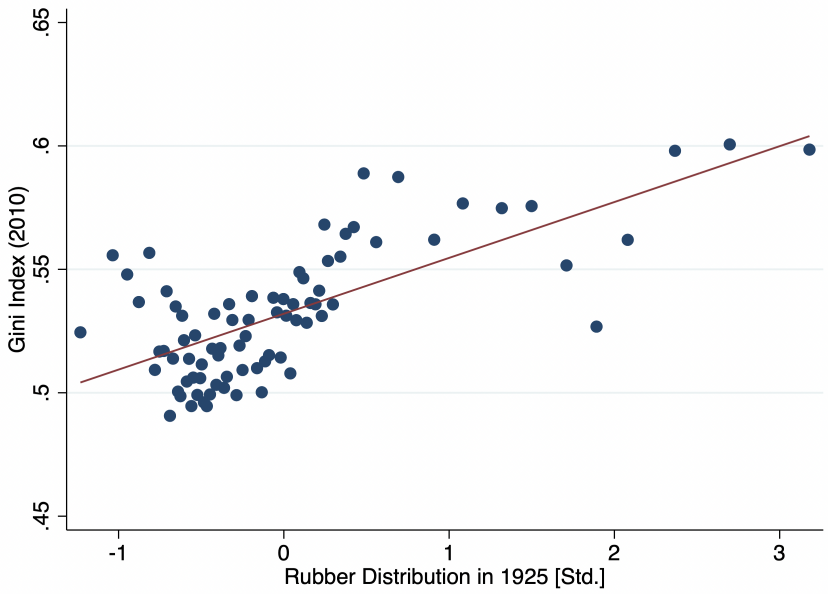
(a) Log Per Capita GPD in 1920



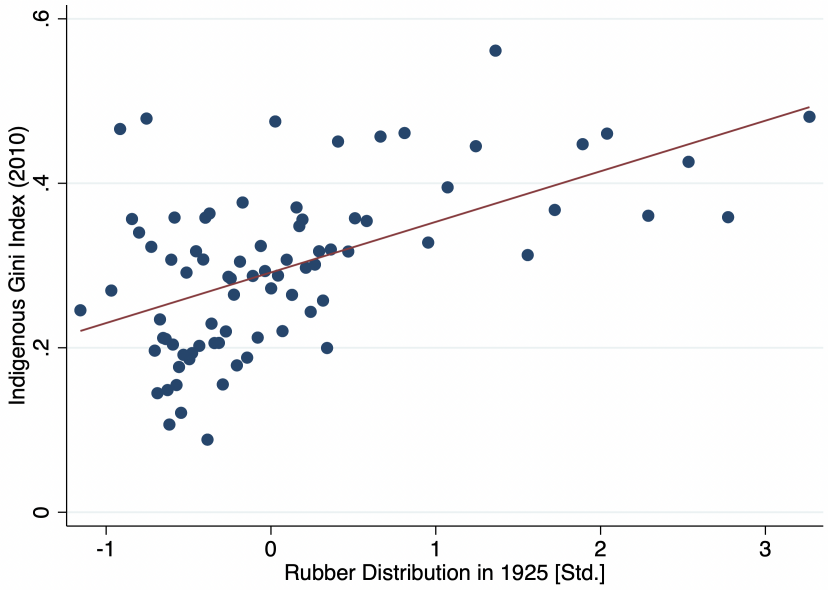
(b) Log Average income in 2010

Notes: Panel A presents the relation between the log. per capita GDP in the 1925 Brazilian Census and the historical rubber distribution in Brazilian municipalities [Std.]. Panel B presents the relation between log. average income in the 2010 Brazilian Census and the rubber suitability in Brazilian municipalities [Std.].

FIGURE 9 Rubber Cultivation and Contemporary Inequality



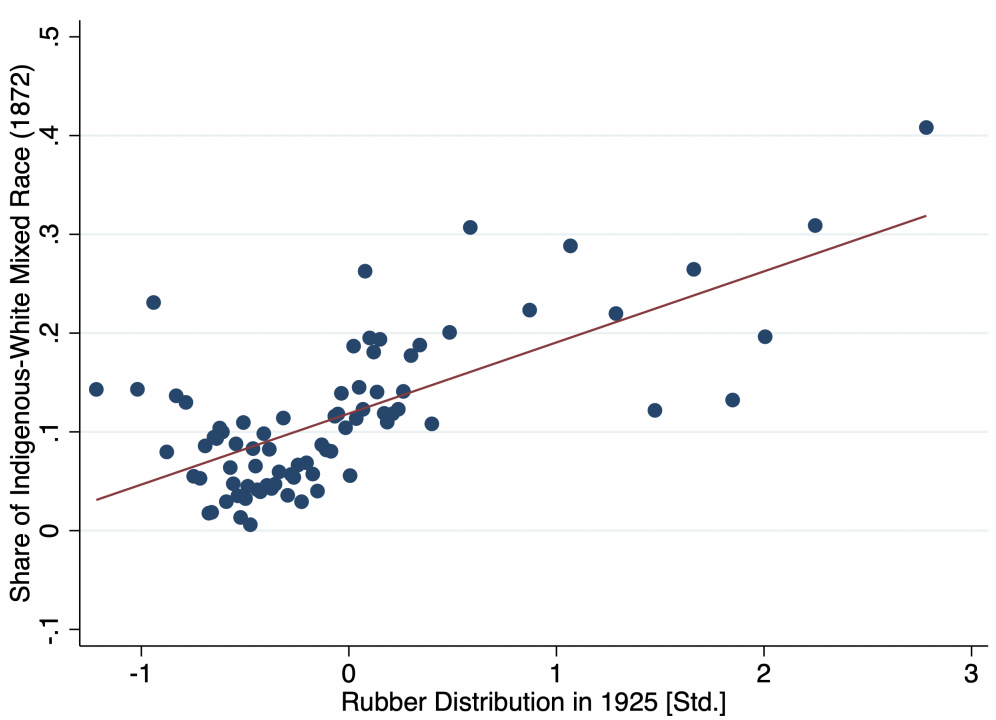
(a) General Gini Index in 2010



(b) Indigenous Gini Index in 2010

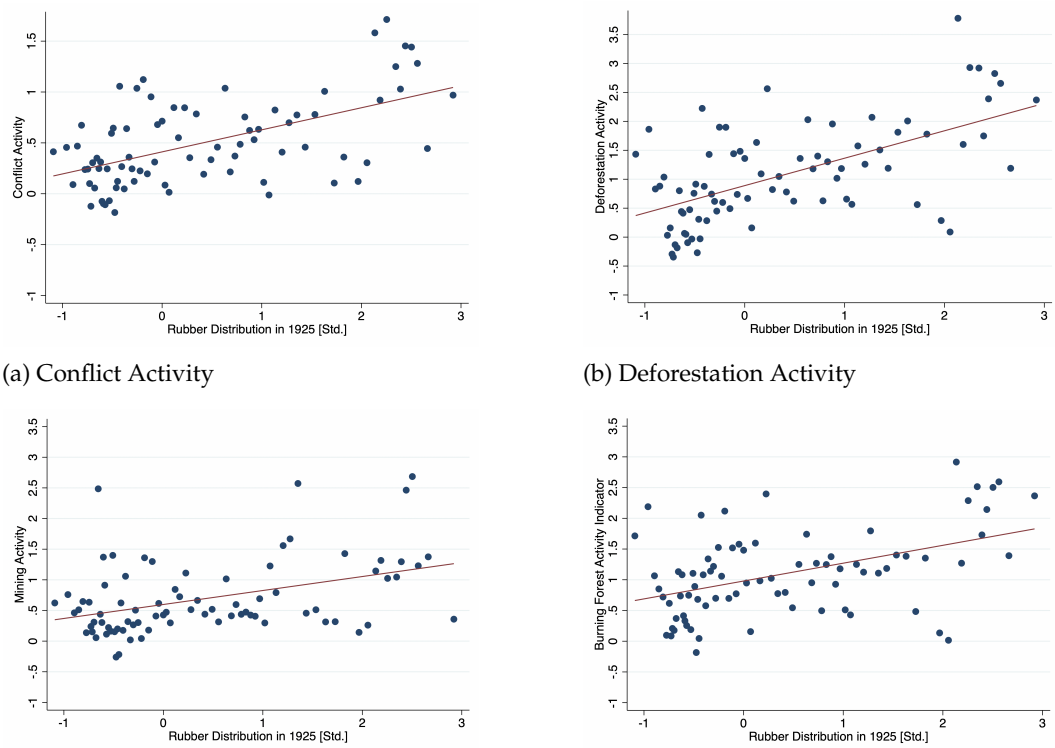
Notes: Panel A presents the relation between the general Gini Index in the Brazilian 2010 Census and the historical rubber distribution in Brazilian municipalities [Std.]. Panel B presents the relation between the Indigenous Gini Index in the Brazilian 2010 Census and the historical rubber distribution in Brazilian municipalities [Std.].

FIGURE 10 Historical Miscegenation in Rubber Areas



Notes: The figure displays the relation between the share of Indigenous-white mixed race in the 1872 Brazilian Census and the historical rubber distribution in Brazilian municipalities [Std.].

FIGURE 11 Historical Rubber Activity and Contemporary Conflict, Mining, and Environmental Outcomes

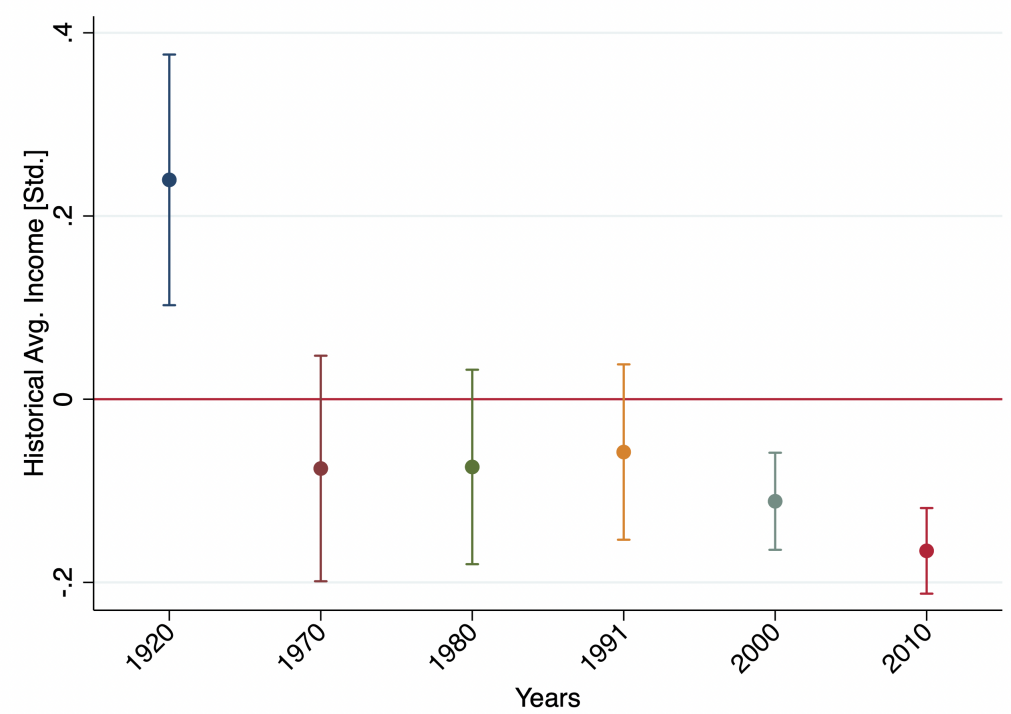


(a) Conflict Activity (b) Deforestation Activity

(c) Mining Activity (d) Forest Burning Activity

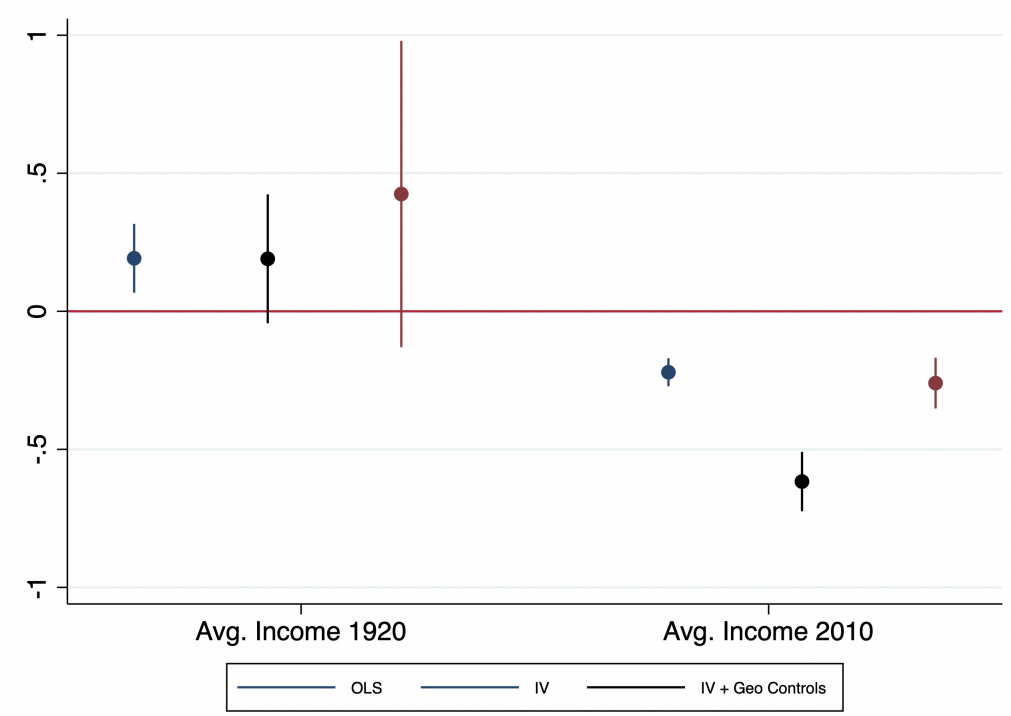
Notes: Each panel plots the relationship between the historical distribution of rubber activity in 1925 (standardized) and contemporary municipal outcomes obtained from the Mapa dos Conflitos. The dependent variables—Conflict Activity (Panel a), Deforestation Activity (Panel b), Mining Activity (Panel c), and Forest Burning Activity (Panel d) represent standardized indices of event frequency or intensity over the 2000–2020 period. Lines correspond to fitted values from bivariate regressions. Observations are at the municipal level.

FIGURE 12 Historical Rubber Distribution in 1925 and Average Income Across Census Data



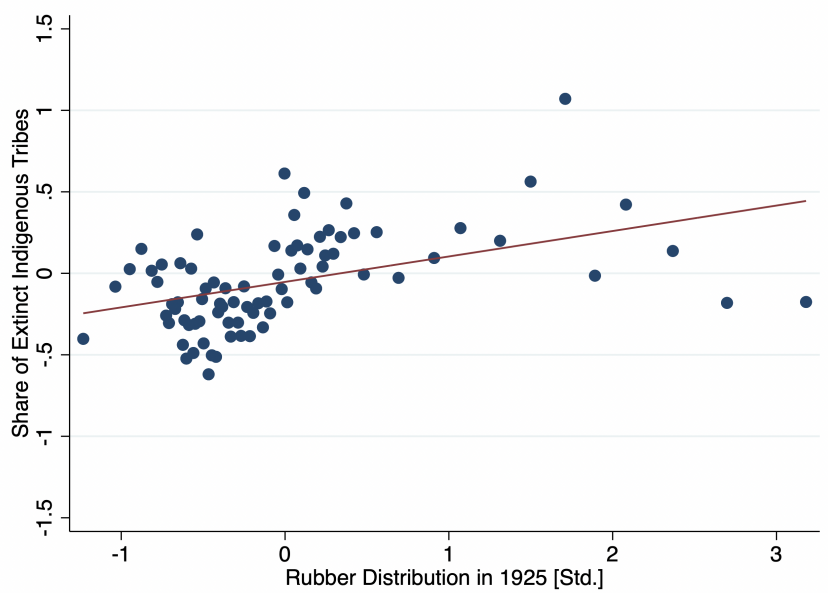
Notes: The figure displays the relation between the Historical Rubber Distribution in 1925 and Average Income Across Census Data, 1872 Brazilian Census, and the historical rubber distribution in Brazilian municipalities [Std.].

FIGURE 13 Historical Rubber Distribution in 1925 and Average Income: OLS and IV

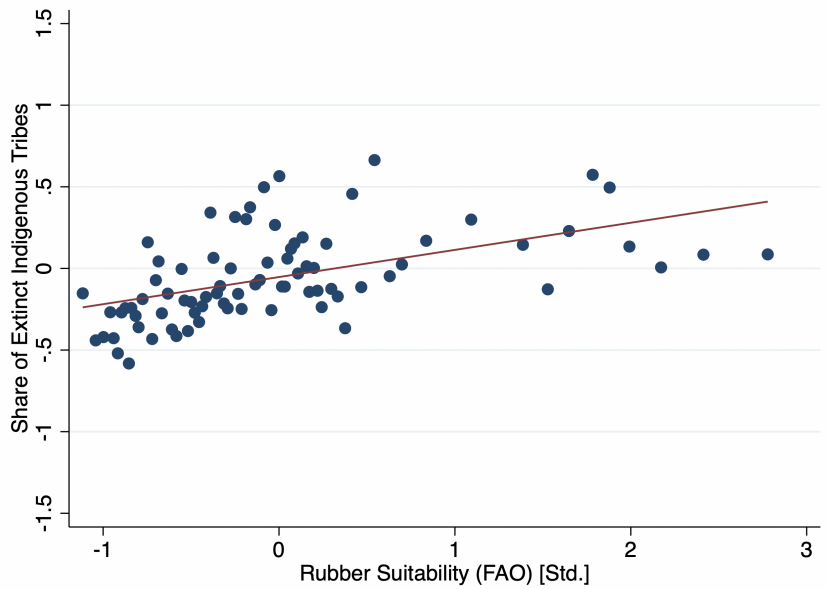


Notes: The figure displays OLS and IV estimates of the relation between the Historical Rubber Distribution in 1925 and Average Income in 1920 and 2010 in Brazilian municipalities [Std.]. The OLS estimates use the historical rubber distribution, while the IV specifications instrument this measure with Rubber Suitability from the FAO dataset. Estimates are presented with and without geographic controls.

FIGURE 14 Historical Rubber Distribution in 1925 and Extinction of Indigenous Groups



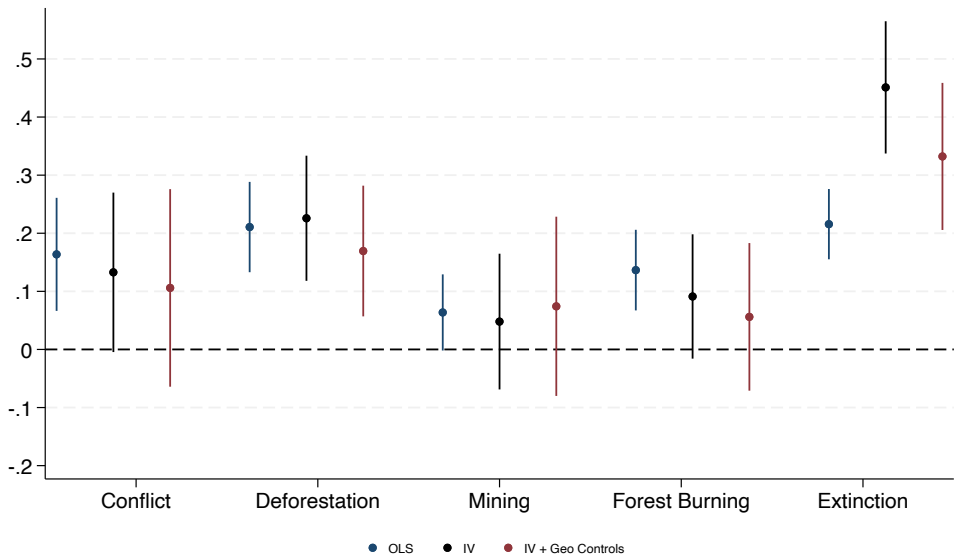
(a) Rubber Distribution in 1925



(b) Rubber Suitability

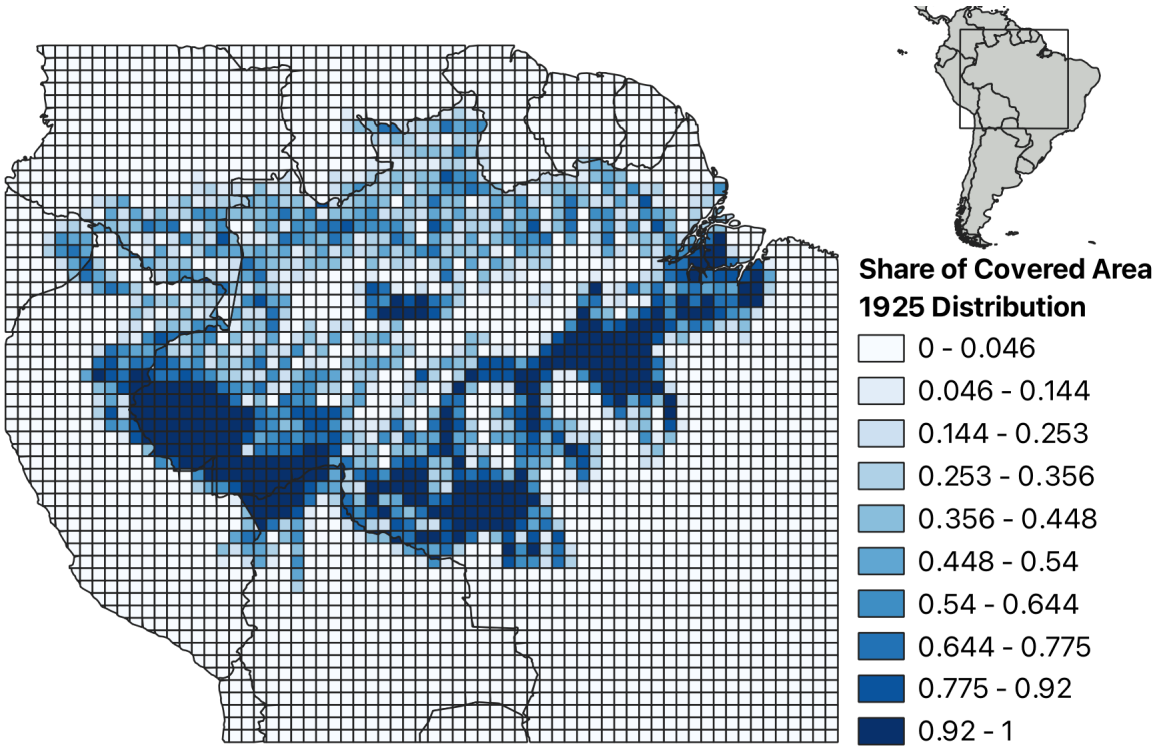
Notes: The figure displays the relation between the Historical Rubber Distribution in 1925, and Rubber Suitability (FAO), with the Extinction of Indigenous groups in Brazilian municipalities [Std.].

FIGURE 15 Historical Rubber Distribution in 1925 Main Correlates: Baseline and IV Specifications



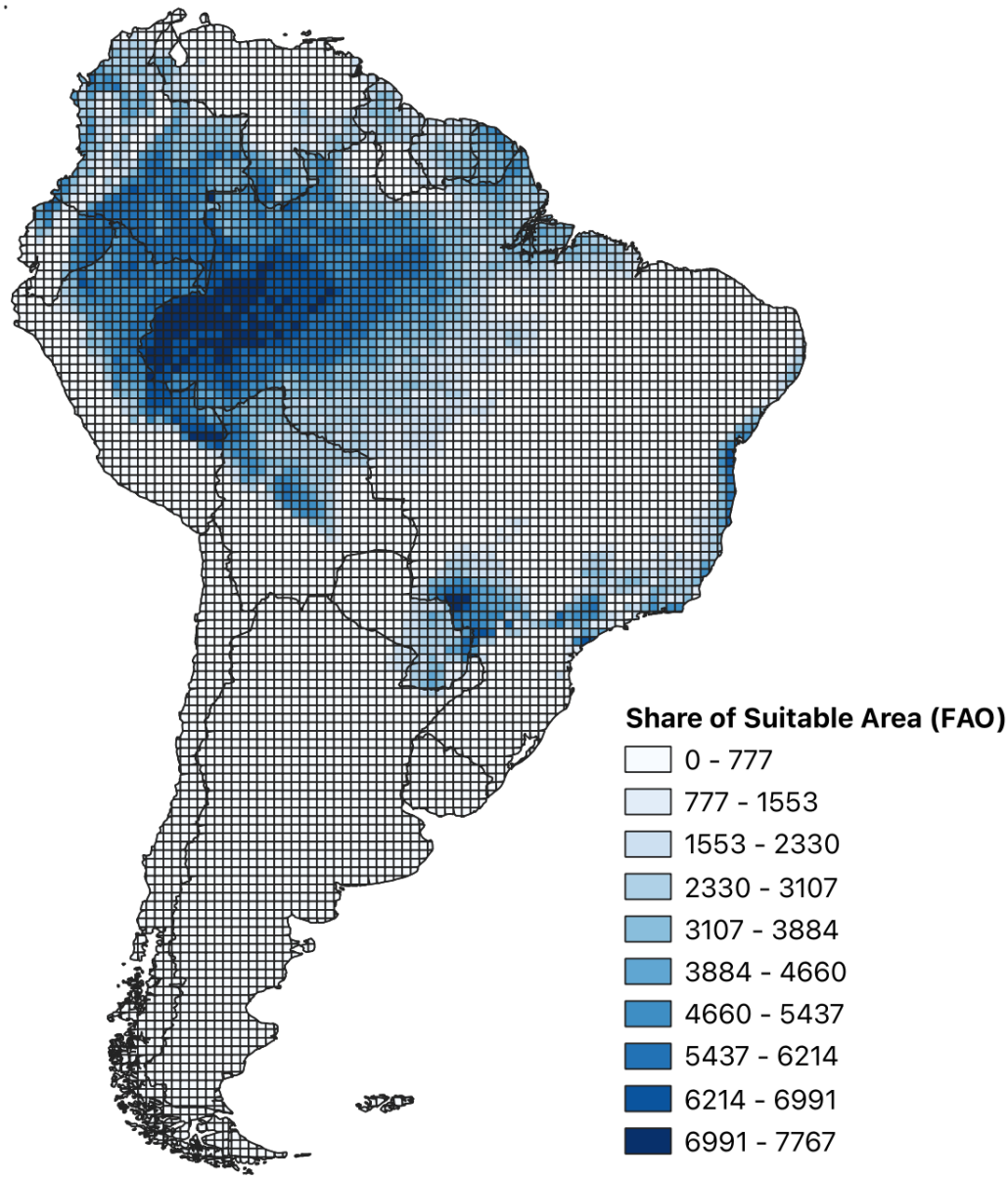
Notes: The figure displays the relation between the Historical Rubber Distribution in 1925 and contemporary municipal outcomes obtained from the *Mapa dos Conflitos*. The first coefficient is the OLS regression, the second is the Instrumental Variable, and in the third, we include geographical controls.

FIGURE 16 Historical Rubber Distribution in 1925: Grid Level



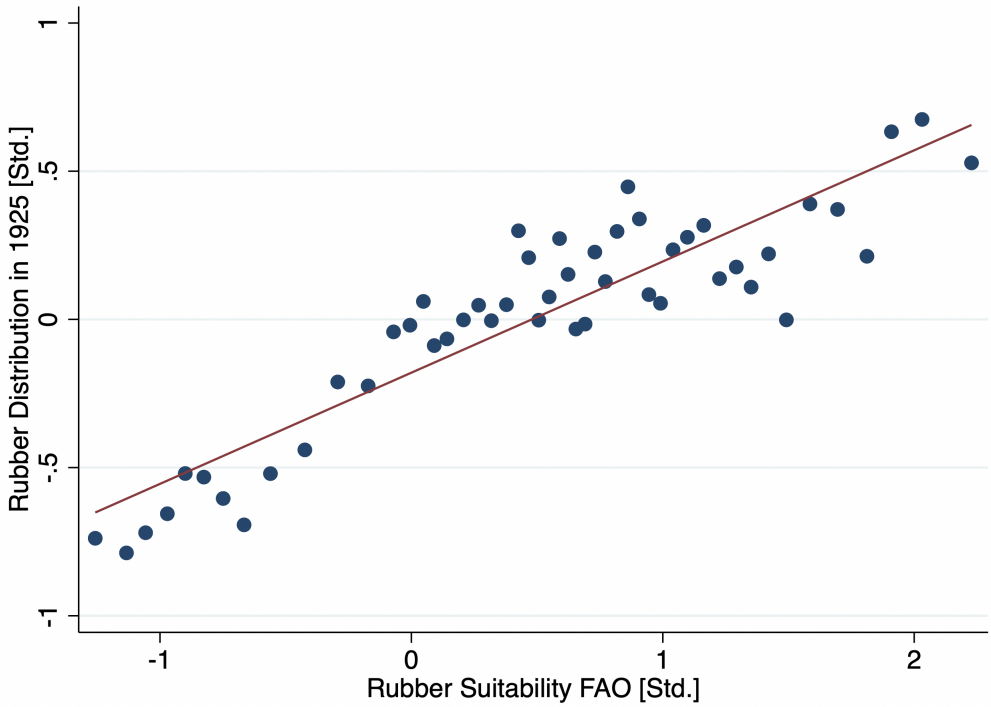
Notes: The figure displays the mean of the historical rubber distribution map from Schurz et al. (1925) by 0.5 × 0.5 degree grid cells. The share of land with rubber in each grid is presented in shades of blue.

FIGURE 17 Rubber Suitability (FAO): Grid Level



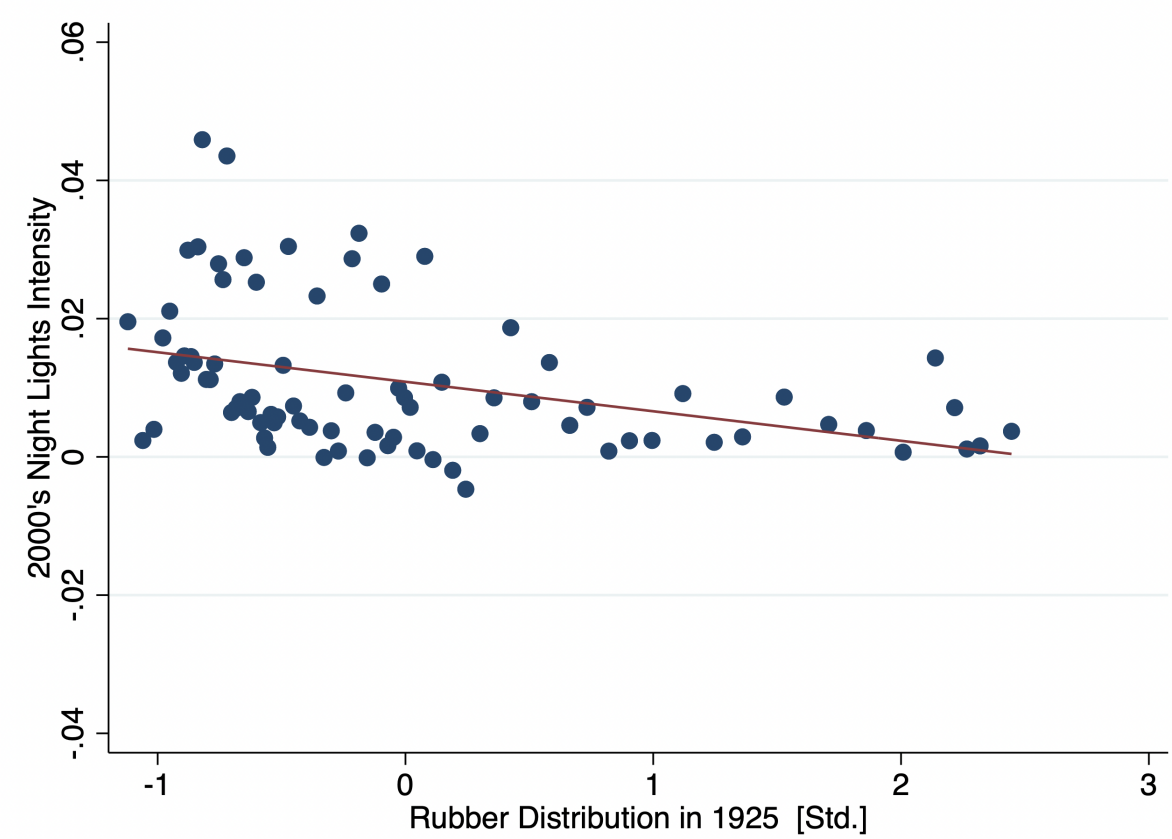
Notes: The figure displays the mean of the historical rubber distribution map from Schurz et al. (1925) by 0.5 × 0.5 degree grid cells. The scale of land suitable for rubber in each municipality is presented in shades of blue (0-10,000).

FIGURE 18 First Stage: Historical Rubber Distribution in 1925 and FAO Rubber Suitability at Grid-Level



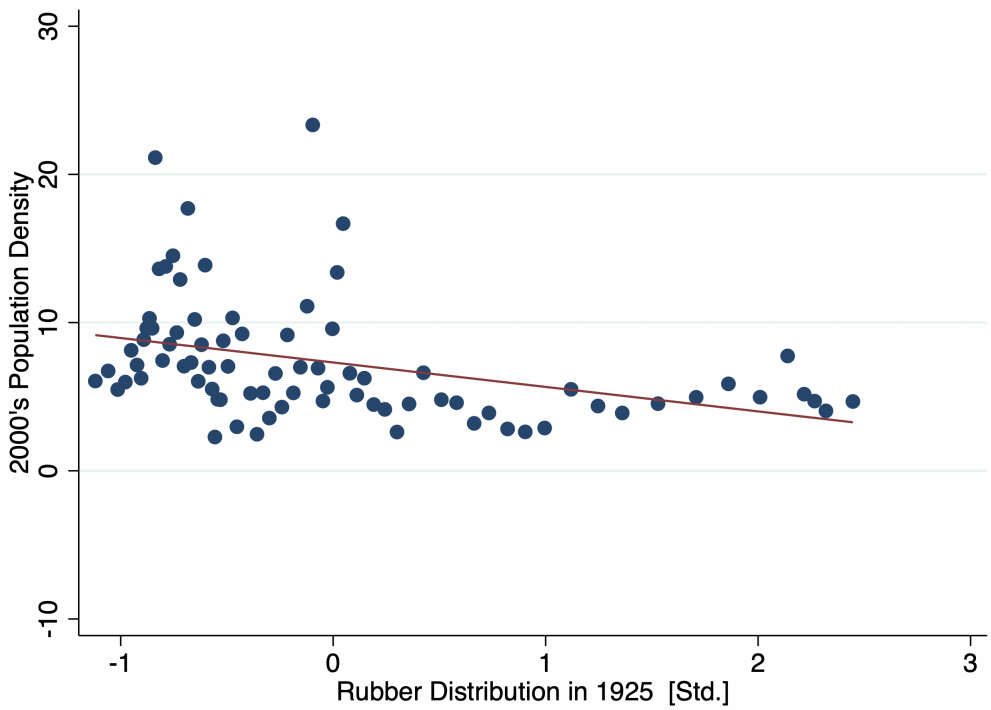
Notes: The figure displays the correlation between of the historical rubber distribution in 1925 from Schurz et al. (1925) by grid and the FAO Rubber Suitability. The first-stage coefficient is 0.425 (s.e. = 0.017), with a Robust F-statistic of 653.72, well above the Stock and Yogo (2002) threshold of 10.

FIGURE 19 2000's Night Lights Intensity and Historical Rubber Distribution 1925: Grid Level



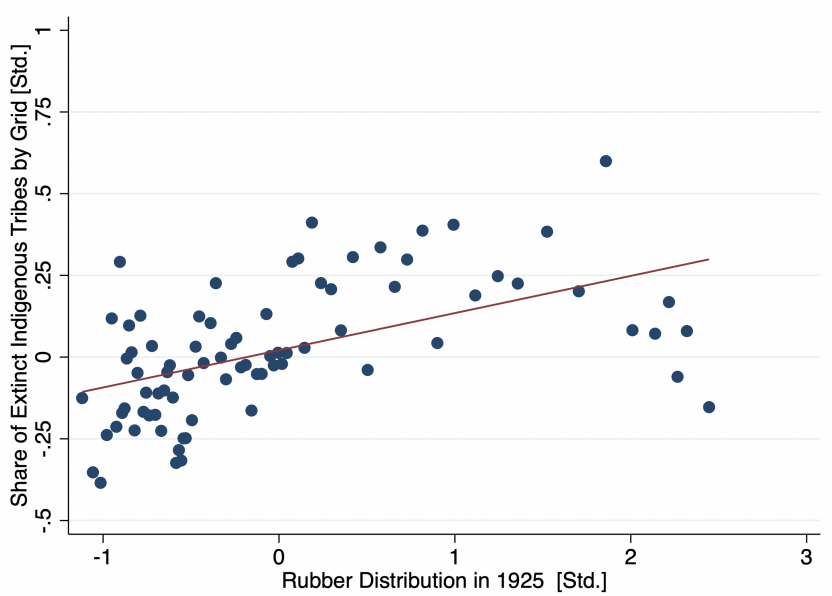
Notes: The figure displays the relation between the 2000's night lights intensity and the historical rubber distribution in Brazilian 0.5×0.5 degree grid-level data [Std.]. We keep only grids with Night Light intensity below the 99th percentile.

FIGURE 20 2000's Population Density and Historical Rubber Distribution 1925: Grid Level Grids

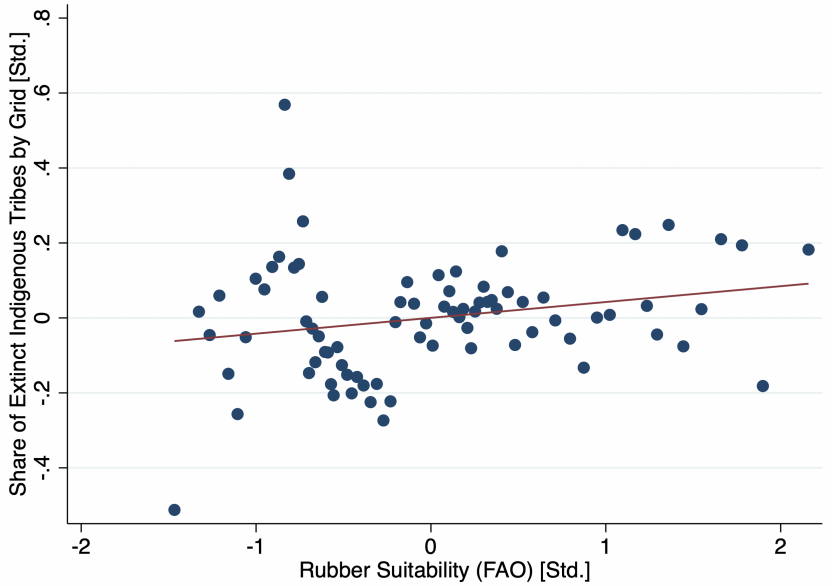


Notes: The figure displays the relation between the 2000's population density and the historical rubber distribution in Brazilian 0.5 × 0.5 degree grid-level data [Std.]. We keep only grids with Population density below the 99th percentile.

FIGURE 21 Historical Rubber Distribution in 1925 and Extinction of Indigenous Groups: Grid Level



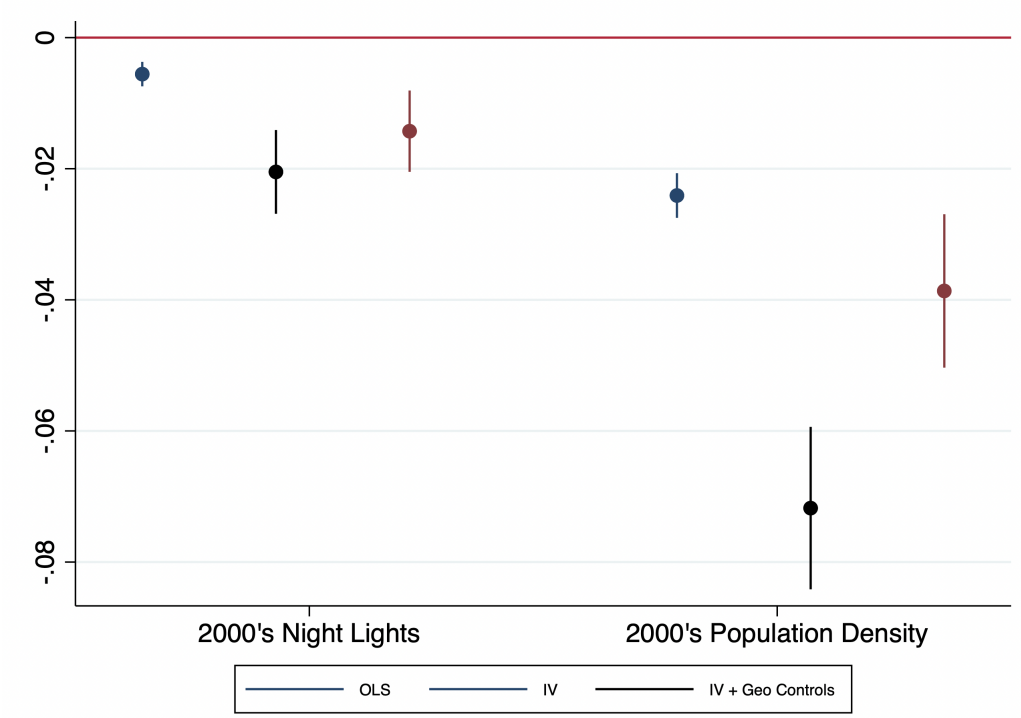
(a) Rubber Distribution in 1925



(b) Rubber Suitability

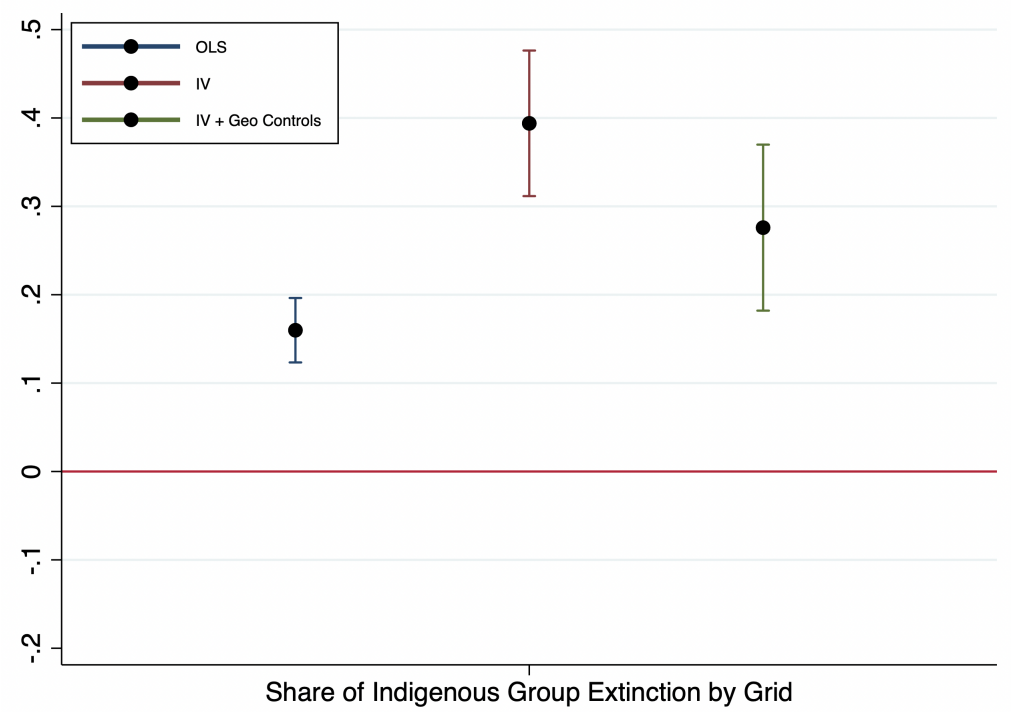
Notes: The figure displays the relation between the Historical Rubber Distribution in 1925, and Rubber Suitability (FAO), with the Extinction of Indigenous groups at the grid level [Std.].

FIGURE 22 Population Density and Night Lights by Grid: OLS and IV



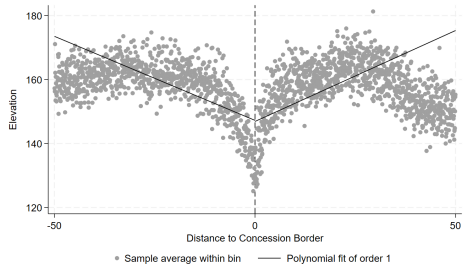
Notes: The figure displays the relation between the Historical Rubber Distribution in 1925, and Rubber Suitability (FAO), with Population Density and Night Lights at the grid level [Std.].

FIGURE 23 Share of Indigenous Groups Extinct by Grid: OLS and IV

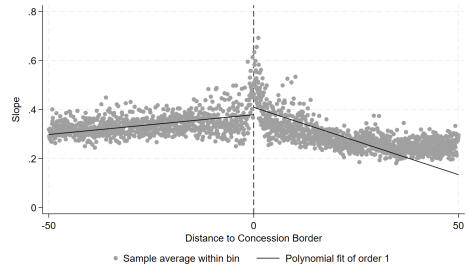


Notes: The figure displays the relation between the Historical Rubber Distribution in 1925, and Rubber Suitability (FAO), with the Extinction of Indigenous groups at the grid level [Std.].

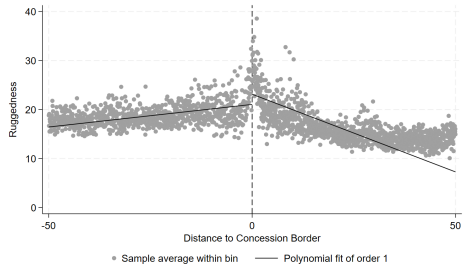
FIGURE 24 RD Balance for Geographic and Environmental Covariates



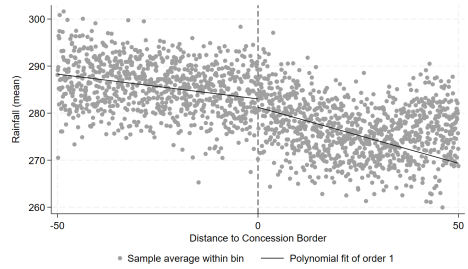
(a) Elevation



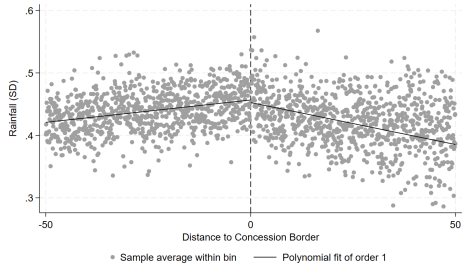
(b) Slope



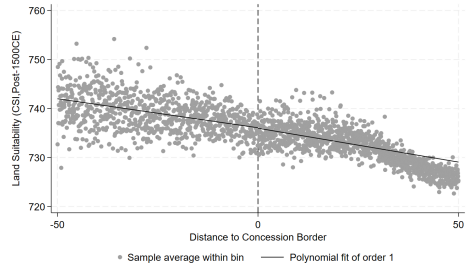
(c) Ruggedness



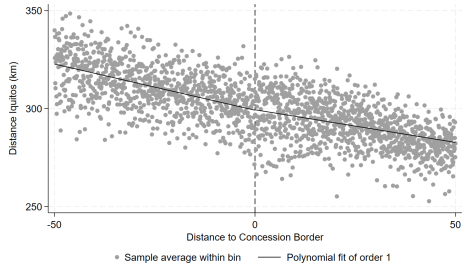
(d) Mean Rainfall (2003)



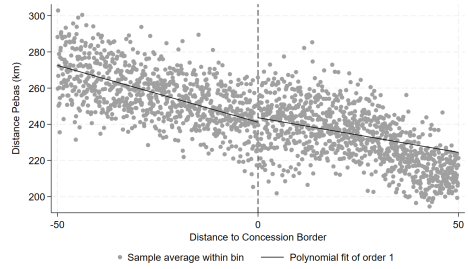
(e) Rainfall SD (2003)



(f) Land Suitability



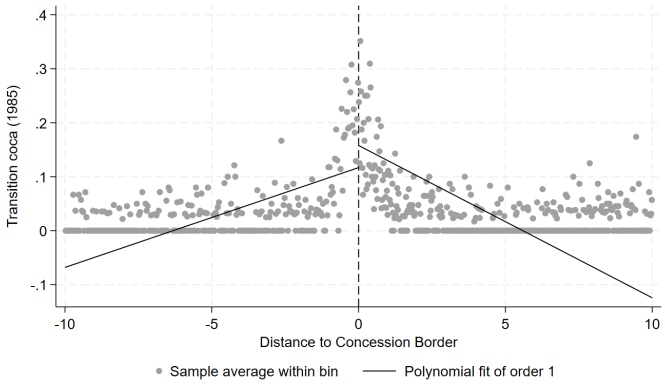
(g) Distance to Iquitos



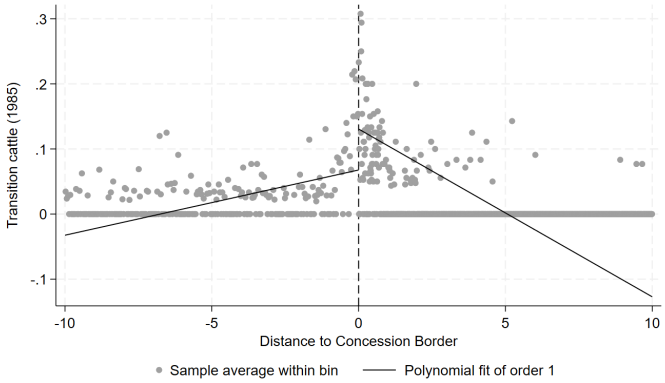
(h) Distance to Pebas

Notes: The figure presents RD plots for a set of geographical characteristics along the running variable (distance to concession border), with positive distance values inside the concession boundaries. Each plot uses the corresponding variable as its outcome using a local linear specification estimated separately on each side of the concession boundary, with optimal estimated bandwidths and a triangular kernel. The RD MSE-optimal bandwidth is determined using the procedure suggested by Cattaneo et al. (2020).

FIGURE 25 RD Plots for Illegal Economies



(a) Transition Coca (1985)



(b) Transition Cattle (1985)

Notes: The figure presents RD plots for two land transition outcomes linked to illegal economies along the running variable (distance to concession border), with positive distance values inside the concession boundaries. These outcomes are generated based on Murillo-Sandoval et al. (2023)'s deep-learning model (U-Net) to classify Landsat Collection 1 surface reflectance images (since 1984), trained with additional data for coca, cattle, and forest plots from official/published sources. Each 1km by 1km pixel is classified as equal to 1 if exhibiting a transition from previous land uses to coca and cattle, respectively. Each plot uses a local linear specification estimated separately on each side of the concession boundary, with optimal estimated bandwidths and a triangular kernel. The RD MSE-optimal bandwidth is determined using the procedure suggested by Cattaneo et al. (2020).

TABLES

TABLE 1 Nighttime Lights and Population Density in 2000 and Historical Rubber Distribution

	Nighttime Lights (2000) [Std.]			Population Density [Std.]		
	(1)	(2)	(3)	(4)	(5)	(6)
Rubber Distribution in 1925 [Std.]	-0.0056	-0.0051	-0.0143	-0.0241	-0.0126	-0.0386
	[0.0010]***	[0.0011]***	[0.0032]***	[0.0017]***	[0.0016]***	[0.0060]***
# Grids	3681	3681	3681	3682	3682	3682
Method	OLS	OLS	IV	OLS	OLS	IV
Baseline Controls	No	Yes	Yes	No	Yes	Yes

Notes: OLS estimates in all columns. Our historical rubber distribution variable is standardized. Standard errors shown in parentheses are robust.. The baseline controls include grid-level information on rainfall, temperature, ruggedness, distance to rivers and the coast, and altitude. (***$p \leqslant 0.01$, **$p \leqslant 0.05$, *$p \leqslant 0.1$)

TABLE 2 Indigenous Extinction and Historical Rubber Distribution

	Extinction of Indigenous Tribes [Std.]			
	(1)	(2)	(3)	(4)
Rubber Distribution in 1925 [Std.]	0.1598	0.1138	0.3939	0.2759
	[0.0186]***	[0.0194]***	[0.0420]***	[0.0479]***
# Grids	3692	3692	3692	3692
R-squared	0.0501	0.1209	0.0502	0.0787
Method	OLS	OLS	IV	IV
Baseline Controls	No	Yes	No	Yes

Notes: OLS estimates in all columns. Our historical rubber distribution variable is standardized. Standard errors shown in parentheses are robust.. The baseline controls include grid-level information on rainfall, temperature, ruggedness, distance to rivers and the coast, and altitude. (***$p \leqslant 0.01$, **$p \leqslant 0.05$, *$p \leqslant 0.1$)

TABLE 3 Night-time Lights in 2000 and Historical Rubber Distribution by Country

	Nighttime Lights (2000) [Std.]							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Rubber Distribution in 1925 [Std.]	-0.0034	0.0013	-0.0049	-0.0149	-0.0136	-0.0917	-0.0315	-0.1656
	[0.0020]*	[0.0107]	[0.0012]***	[0.0031]***	[0.0042]***	[0.0391]**	[0.0179]*	[0.0941]*
# Grids	389	389	2012	2012	356	356	63	63
Country	Bolivia	Bolivia	Brazil	Brazil	Colombia	Colombia	Ecuador	Ecuador
	Nighttime Lights (2000) [Std.]							
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Rubber Distribution in 1925 [Std.]	-0.0029	0.0197	-0.0092	-0.0396	-0.0080	-0.0520	-0.0011	-0.0041
	[0.0025]	[0.0288]	[0.0027]***	[0.0118]***	[0.0074]	[0.0684]	[0.0010]	[0.0038]
# Grids	83	83	462	462	65	65	155	155
Country	Guyana	Guyana	Peru	Peru	Suriname	Suriname	Venezuela	Venezuela
Method	OLS	IV	OLS	IV	OLS	IV	OLS	IV
Baseline Controls	No	No	No	No	No	No	No	No

Notes: OLS estimates in all columns. Our historical rubber distribution variable is standardized. Standard errors shown in parentheses are robust.. (***p $\leqslant$ 0.01, **p $\leqslant$ 0.05, *p $\leqslant$ 0.1)

TABLE 4 Balance on Geographical Characteristics

	Within 20km				Within 10km				RD estimate				
	Inside	Outside	SE	p-val	Inside	Outside	SE	p-val	Coeff.	SE	p-val	N left	N right
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Elevation	153.155	153.606	2.485	0.933	148.008	147.496	1.987	0.963	-0.306	4.399	0.945	19550	18723
Slope	0.354	0.360	0.016	0.088	0.391	0.371	0.013	0.026	0.059	0.035	0.091	44724	35344
Ruggedness	19.923	20.044	0.811	0.046	22.051	20.551	0.664	0.004	4.054	1.822	0.026	33364	28482
Rainfall (mean)	278.949	283.994	1.292	0.117	280.743	283.491	0.731	0.105	-0.296	1.279	0.817	18547	17980
Rainfall (SD)	0.438	0.450	0.010	0.237	0.447	0.454	0.008	0.285	0.009	0.011	0.374	36125	30276
Land Suitability (CSI)	734.896	737.350	1.724	0.185	735.097	736.559	0.885	0.179	-0.394	1.402	0.779	26052	23522
Distance Iquitos (km)	296.642	303.929	3.377	0.414	297.669	301.539	1.938	0.425	0.469	2.796	0.867	18912	18243
Distance Pebas (km)	240.855	247.611	3.191	0.248	241.045	244.039	1.917	0.331	0.439	2.714	0.872	18240	17707
Obs.	23711	26333			13889	13394							

Notes: The unit of observation is a 1km by 1km grid cell. Columns (1), (2), (5), and (6) present the mean of the corresponding variable. Columns (3) and (7) present clustered standard errors for the difference in means clustered at a 50km-segment level. Inside and Outside indicate whether a grid cell is inside or outside the former Casa Arana concession area respectively. Columns (9) and (10) give the estimated RD coefficient and standard error that uses the corresponding variable as its outcome using a local linear specification estimated separately on each side of the concession boundary, with optimal estimated bandwidths and a triangular kernel. The RD MSE-optimal bandwidth is determined using the procedure suggested by Cattaneo et al. (2020). Regressions include a 50km-segment fixed effect.

TABLE 5 Rubber Concessions and Deforestation (Local Linear RD)

	Tree cover 2000 (% per 1x1km)				
	(1)	(2)	(3)	(4)	(5)
	50km	20km	10km	Optimal	Optimal
Inside Concession (Conventional)	-4.185***	-8.331***	-11.94***	-14.56***	-9.894***
	(0.153)	(0.285)	(0.440)	(0.821)	(1.677)
Inside Concession (Bias-corrected)	-7.508***	-12.01***	-14.63***	-14.45***	-10.94***
	(0.153)	(0.285)	(0.440)	(0.821)	(1.677)
Inside Concession (Robust)	-7.508***	-12.01***	-14.63***	-14.45***	-10.94***
	(0.250)	(0.445)	(0.659)	(0.861)	(1.940)
Controls	No	No	No	No	Yes
Segment FE (50km)	No	No	No	No	Yes
Observations	112,198	50,044	27,283	21,940	44,868
Bandwidth	50.00	20.00	10.00	3.23	11.18
Mean Dep. Var.	98.02	96.95	95.52	90.57	97.72
SD Dep. Var.	8.500	11.186	13.860	19.907	8.654

Notes: The unit of observation is 1km $\times$ 1km grid cell. All regressions include a local linear specification estimated separately on each side of the Arana concession boundary and use a triangular kernel. Optimal bandwidths are chosen using the MSE-minimizing procedure suggested by Cattaneo et al. (2020) and are reported in km. *Tree cover* in the year 2000 is defined as canopy closure for all vegetation taller than 5m in height. Encoded as a percentage per output grid cell, in the range 0–100. Columns (1) to (5) show RD coefficients estimated within 50km, 20km, 10km and optimal bandwidth ranges around the concession boundaries for each outcome; the fifth column add controls (elevation, slope, ruggedness, rainfall mean and SD, land suitability, and distances to Iquitos and Pebas) and 50km-segment fixed effects. Coefficients significantly different from zero are denoted by: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

TABLE 6 Rubber Concessions and Deforestation (Local Quadratic RD)

	Tree cover 2000 (% per 1x1km)				
	(1)	(2)	(3)	(4)	(5)
	50km	20km	10km	Optimal	Optimal
Inside Concession (Conventional)	-7.508***	-12.01***	-14.63***	-14.72***	-11.83***
	(0.250)	(0.445)	(0.659)	(0.685)	(2.055)
Inside Concession (Bias-corrected)	-10.31***	-14.18***	-14.46***	-14.62***	-12.83***
	(0.250)	(0.445)	(0.659)	(0.685)	(2.055)
Inside Concession (Robust)	-10.31***	-14.18***	-14.46***	-14.62***	-12.83***
	(0.351)	(0.599)	(0.864)	(0.814)	(2.356)
Controls	No	No	No	No	Yes
Segment FE (50km)	No	No	No	No	Yes
Observations	112,198	50,044	27,283	28,975	47,439
Bandwidth	50.00	20.00	10.00	9.29	15.93
Mean Dep. Var.	98.02	96.95	95.52	95.30	97.98
SD Dep. Var.	8.500	11.186	13.860	14.205	8.040

Notes: The unit of observation is 1km $\times$ 1km grid cell. All regressions include a local quadratic specification estimated separately on each side of the Arana concession boundary and use a triangular kernel. Optimal bandwidths are chosen using the MSE-minimizing procedure suggested by Cattaneo et al. (2020) and are reported in km. *Tree cover* in the year 2000 is defined as canopy closure for all vegetation taller than 5m in height. Encoded as a percentage per output grid cell, in the range 0–100. Columns (1) to (5) show RD coefficients estimated within 50km, 20km, 10km and optimal bandwidth ranges around the concession boundaries for each outcome; the fifth column add controls (elevation, slope, ruggedness, rainfall mean and SD, land suitability, and distances to Iquitos and Pebas) and 50km-segment fixed effects. Coefficients significantly different from zero are denoted by: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

TABLE 7 Rubber Concessions and Land-Use Transitions

	Transition coca (2000)		*Transition cattle (2000)*	
	(1)	(2)	(3)	(4)
Inside concession (Conventional)	0.040***	0.024	0.071***	0.040***
	(0.008)	(0.017)	(0.010)	(0.015)
Inside concession (Bias-corrected)	0.038***	0.025	0.073***	0.047***
	(0.008)	(0.017)	(0.010)	(0.015)
Inside concession (Robust)	0.038***	0.025	0.073***	0.047***
	(0.010)	(0.021)	(0.010)	(0.017)
Controls	No	Yes	No	Yes
Segment FE (50km)	No	Yes	No	Yes
Observations	33,477	45,756	26,840	40,822
Bandwidth	11.64	16.90	6.79	14.60
Mean Dep. Var.	0.05	0.03	0.05	0.01
SD Dep. Var.	0.214	0.169	0.210	0.120

Notes: The unit of observation is 1km $\times$ 1km grid cell. Each column shows RD coefficients estimated within optimal bandwidth ranges around the concession boundaries for each outcome. Optimal bandwidths are chosen using the MSE-minimizing procedure suggested by Cattaneo et al. (2020) and are reported in km. Dependent variables are generated based on Murillo-Sandoval et al. (2023)'s deep-learning model (U-Net) to classify Landsat Collection 1 surface reflectance images (since 1984), trained with additional data for coca, cattle, and forest plots from official/published sources. Each 1km by 1km pixel is classified as equal to 1 if exhibiting transition from previous land uses to coca and cattle, respectively. Columns (2) and (4) include controls (elevation, slope, ruggedness, rainfall mean and SD, land suitability, and distances to Iquitos and Pebas) and 50km-segment fixed effects. Coefficients significantly different from zero are denoted by: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

TABLE 8 Donut Hole RD Estimates - Tree Cover and Land-Use Transitions (2000)

	Tree cover (2000)			*Transition coca (2000)*			*Transition cattle (2000)*		
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
	Base	0.5km	1km	Base	0.5km	1km	Base	0.5km	1km
Conventional	-11.938***	0.164	0.602**	0.041***	-0.001	-0.003	0.063***	-0.004	-0.010*
	(0.440)	(0.282)	(0.244)	(0.009)	(0.008)	(0.007)	(0.008)	(0.006)	(0.005)
Bias-corrected	-14.628***	-1.051***	-0.657***	0.031***	0.012	0.018**	0.074***	0.007	-0.002
	(0.440)	(0.282)	(0.244)	(0.009)	(0.008)	(0.007)	(0.008)	(0.006)	(0.005)
Robust	-14.628***	-1.051*	-0.657	0.031**	0.012	0.018	0.074***	0.007	-0.002
	(0.659)	(0.536)	(0.503)	(0.014)	(0.015)	(0.015)	(0.011)	(0.011)	(0.011)
Observations	27,283	24,031	22,653	21,971	18,963	17,817	21,971	18,963	17,817
Bandwidth	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00	10.00
Mean Dep. Var.	97.62	97.62	97.62	0.04	0.04	0.04	0.02	0.02	0.02
SD Dep. Var.	8.824	8.824	8.824	0.187	0.187	0.187	0.132	0.132	0.132

Notes: The unit of observation is 1km $\times$ 1km grid cell. Columns (1), (4) and (7) show baseline RD estimates with a 10km bandwidth. To mitigate river-bank discontinuities, the last two columns for each outcome implement a *donut RD* that excludes observations within 0.5km and 1km of the boundary on either side, i.e., $|\text{distance}| \leqslant 1$ km are dropped. All regressions include a local linear specification estimated separately on each side of the Arana concession boundary and use a triangular kernel. *Tree cover* in the year 2000 is defined as canopy closure for all vegetation taller than 5m in height. Encoded as a percentage per output grid cell, in the range 0–100. *Transition coca* and *Transition cattle* are generated based on Murillo-Sandoval et al. (2023)'s deep-learning model. Each 1km by 1km pixel is classified as equal to 1 if exhibiting transition from previous land uses to coca and cattle, respectively. Coefficients significantly different from zero are denoted by: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.