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Abstract[1]

Can a brief period of economic prosperity leave a legacy of long-term adversity for local populations? This study investigates the enduring impact of the Amazon rubber boom around 1900 on contemporary income, inequality, Indigenous groups presence, and forest conservation. Identification exploits variation in historical rubber suitability across municipalities and discontinuities around rubber concession boundaries. Municipalities with larger shares of rubber-suitable land experienced an initial economic surge, as evidenced by higher per capita GDP in the 1920 Census, but this prosperity was not sustained by 2010. Increased ethnic mixing, already visible in the 1872 Census, indicates that earlier economic expansion intensified contact with Indigenous groups. In the long run, rubber-suitable areas show lower population density, higher extinction of Indigenous groups, and greater income inequality. Consistent with the disproportionate violence and labor coercion inflicted on Indigenous groups, our Regression Discontinuity analysis further documents long-lasting environmental effects, with higher rates of deforestation, coca cultivation, and cattle raising in former rubber concession areas. Together, the results suggest that while the rubber boom generated short-term wealth, it left a legacy of persistent underdevelopment, social transformation, and environmental degradation.

JEL Codes: N36, O15, J15, O13, N56, Q33, D31
Keywords: Commodity exploitation, Rubber, Latin America, Amazon, Indigenous peoples, Forced labor, Persistence, Private concessions, Economic History

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I've blown up the Devil's Paradise in Peru!... Putumayo will be cleansed—although nothing can bring back the murdered tribes—poor souls.

Roger Casement, 1912, *Blue Book*.

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. (2024b) 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.[2] The geographic coverage of this colossal enterprise spanned Brazil, Peru, Colombia, Ecuador, and Venezuela. Because the Hevea tree was never domesticated in South America, rubber entrepreneurs relied on exploitative labor arrangements with Indigenous people, which effectively amounted to modern slavery.[3] Official reports and literary accounts detail the horrors the local population underwent in stations such

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

[3]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.

as Casa Arana in the Putumayo region.[4] Another key aspect of the Amazon rubber boom is that it was suddenly dominated by rubber plantations in Southeast Asia (Hanson, 1944).[5] 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, 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. 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. Rubber barons 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 leverage two empirical strategies. First, to find a reasonable control group we use rubber suitability to identify areas where the crop might have thrived but was not necessarily exploited. Second, we rely on a Regression Discontinuity (RD) design around the rubber concessions, such as the ones established by Casa Arana. We compile concession locations from maps 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 pthe ositive 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

[4] 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.

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

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 find 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.[6] 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) provide a theory for underdevelopment based on natural resources and subsequent colonial institutions. In that vein, Bobonis and Morrow (2014) show 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. 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) document 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 slavery on exporting nations in Africa in terms of income and decreased trust. More closely related, Lowes and Montero (2021) find 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 the exploitation of Indigenous people rather than chiefly 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) study 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.

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

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, find that districts with larger shares of their population employed on these estates accumulated less human capital throughout the twentieth century. 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., 2024b) with evidence from South America.[7] Recent work on Indigenous issues considers colonial treaties (Feir et al., 2023) and American Indian wealth (Feir et al., 2024a). 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[8].

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 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,

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

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

often enslaved, were responsible for extracting these resources throughout the colonial period.[9]

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 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

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

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. Steamships significantly reduced transportation costs, while the expansion of telegraph networks connected Amazonian exporters to global 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, eds (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*. Simultaneously, the development of rubber plantations in British and Dutch colonies in Southeast Asia introduced a low-cost, labor-intensive production system that outcompeted 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. Yet, the plantation model was 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 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).[10] 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.

Rubber exposure. In order to measure early rubber exposure, we have digitized the historical rubber suitability map developed by Schurz et al. (1925), which encompasses Brazil, Peru, Colombia, Ecuador, and Venezuela. Schurz et al. (1925) assessed rubber suitability 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 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 shapefiles for Brazil and neighboring countries onto the digitized Schurz et al. (1925) suitability polygons, calculating for each municipality the fraction of land classified as suitable by Schurz et al.

As shown in Figure 3, this allows us to construct municipality-level estimates of suitability

[10]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.

for rubber almost 60 years prior to the boom.[11] 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).[12]

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 contribute to differential suitability for rubber cultivation, even within the Amazon region. By employing more nuanced 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. He further divided Indigenous groups between existing and extinct.[13] To the best of our knowledge, only one paper, by Barsanetti and Ferreira (2022), has recently 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

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

[12]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.

[13]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.

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 Reduced Form

This first section presents the reduced-form regressions that examine how historical rubber exposure 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

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

where y_i is a contemporary outcome of interest for area i (e.g., income or inequality). RubberExposure$_i$ is the standardized share of each area's surface covered by the Schurz et al. (1925) map of rubber suitability. $\mathbf{X}_i$ 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 Regression Discontinuity Design

As the second 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 arbitrary demarcation of the concession borders, 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.

$$y_i = \alpha + \gamma AranaConcession_i + f(location_i) + \mathbf{X}_i\boldsymbol{\beta} + \phi + \varepsilon_i \tag{2}$$

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 was a period marked by unprecedented economic growth and exploitative labor practices. This section presents correlational evidence on the enduring effects of the rubber boom by utilizing OLS graphical representations, controlling for environmental and geographical factors such as rainfall, temperature, ruggedness, distance to rivers and the coast, and altitude. We will see that while municipalities with higher historical rubber suitability experienced greater per capita GDP in 1920—reflecting this initial prosperity—the sustainability of this wealth, particularly for Indigenous communities subjected to labor practices akin to modern slavery (Hanson, 1944), remains untested. Our empirical findings indicate that by 2010 these areas exhibited lower average incomes and higher income inequality, including *within* Indigenous populations, as well as increased Indigenous-white miscegenation observable as early as the 1872 census. This suggests that the initial economic benefits were not sustained and may have had long-term adverse consequences on income, education, and cultural assimilation in these communities.

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 historical data availability, our initial focus is on the Brazilian Amazon, where detailed municipal-level data are accessible. We include other Amazonian countries at the grid-cell level in the next subsection. Figure 3 displays the mean of the historical rubber suitability by municipality, providing a detailed visualization of the 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.

Figure 5 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 6, 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.

Lastly, and following the previous discussion, Figure 7 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.

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

In this section, we complement our municipality-level findings with a finer geographic resolution by conducting grid-level analyses across the Amazon. Specifically, we employ grid cells measuring 0.5 by 0.5 degrees and define our continuous treatment measure as the share of each grid-cell area historically suitable for rubber production based on data from Schurz et al. (1925). This measure is presented in Figure 8. To quantify contemporary local economic activity, we utilize nighttime luminosity data derived from the Long-term consistent Nighttime Light dataset (Long NTL), which provides satellite-based observations of luminosity intensity in the year 2000. In addition, we employ population density data obtained from the Gridded Population of the World version 4 (GPWv4), dataset revision 11 for the year 2000, providing precise measures of population density at a comparable grid resolution of 30 arc-minutes (approximately 0.5 degrees). As before, we standardize both dependent variables for ease of interpretation.

Table 1 displays Ordinary Least Squares (OLS) results of regressions estimating relationships between historical rubber suitability and the contemporary outcomes of nighttime luminosity and population density. Columns (1) and (2) reveal a negative and significant correlation between historical rubber suitability and nighttime luminosity intensity in the year 2000. More specifically, a grid with one standard deviation greater historical rubber suitability exhibits on average 0.0198 standard deviations lower luminosity in the specification without controls (column 1) and a reduction of 0.0108 standard deviations after adding our extensive baseline environmental and geographical controls (rainfall, temperature, ruggedness, altitude, and distances to rivers and coasts) in column (2). These estimates are statistically significant at the 1% level, suggesting that historical rubber suitability corresponds to contemporary underdevelopment captured by less intense nighttime economic activity.

Columns (3) and (4) similarly report significant negative correlations for population density. Grids historically more suitable for rubber extraction experience systematically lower contemporary population densities, with estimated impacts of -0.0506 and -0.0387 standard deviations without and with baseline controls, respectively. These findings suggest that historical rubber-extractive regions have not only lower economic activity, as indicated by lower luminosity levels, but also fewer inhabitants today, as an alternative measure of urbanization. Also, Table 2 presents regressions of standardized nighttime lights in 2000 on standardized rubber suitability, estimated separately by country. The results show consistently negative associations between rubber suitability and current nighttime lights, with statistically significant effects in Bolivia, Brazil, and Colombia. Notably, the effect size for Colombia (-0.0314) is larger than for Brazil (-0.0092), indicating a stronger negative relationship in Colombia. While the coefficient for Peru is negative and relatively large in magnitude (-0.0799), it is not statistically significant, likely reflecting the smaller sample size. We focus on Colombia and Peru in the next section. The results for Ecuador and Venezuela are also not significant, but the point estimates are also negative. Overall, these findings suggest that areas highly suitable for historical rubber extraction tend to be less developed today in several countries.[14]

Our regression results are complemented by Figure 9, which visually illustrates the underlying OLS correlations between historical rubber suitability and contemporary outcomes of luminosity. 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.

Table 3 presents the main results using digitized ethnohistorical data on Indigenous tribe extinctions, originally mapped by Curt Nimuendajú and recently digitized and made publicly available by Barsanetti and Ferreira (2022). The Curt Nimuendajú map is an ethnohistorical source that documents the locations and fates of Indigenous tribes across Brazil and the Amazon Basin as observed by Nimuendajú during his research in the early-to-mid twentieth century. The map records which tribes persisted and which had already become extinct by the time of his fieldwork, based on both his extensive travels and archival sources. Thus, the data provides a snapshot of the state of Indigenous societies around the time Nimuendajú was active, reflecting both historical presence and recent extinctions up to the early twentieth century. The extinction data is measured at the grid-cell level and captures the disappearance of Indigenous tribes across the Amazon, as documented in the Nimuendajú map. The dependent variable,

[14]Standard errors are clustered at the grid level.

extinction rate of Indigenous tribes, is regressed on a standardized measure of rubber suitability, controlling for key grid-level factors including rainfall, temperature, ruggedness, distance to rivers and the coast, and altitude (columns 1–4). In our preferred specification (columns 1 and 2), a one standard deviation increase in rubber suitability is associated with an 0.08–0.12 standard deviation increase in Indigenous extinction, depending on the inclusion of country fixed effects and sample restrictions. The results are robust to restricting the sample to areas with evidence of precolonial Indigenous presence (columns 3 and 4).[15] We expand on such potential mechanisms of transmission in the next section. These results suggest deep, enduring negative legacies of historical extractive industries like rubber production on contemporary socioeconomic and demographic outcomes within the Amazon region.

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

[15] Again, standard errors are clustered at the grid level.

and concessions, a feature that would last at least until 1922, when the modern border between Peru and Colombia was established.

To support empirically the continuity of structural characteristics around the concession border, Table 4 reports summary statistics and RD estimates using specification (2) 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, with the exception of slope and ruggedness—where differences arise only in the comparisons with fixed boundaries, plausibly because concession borders coincided with rivers—we find balance across all covariates. Importantly, in all cases these imbalances vanish once we use the RD estimation with optimal bandwidths and fixed effects. RD plots for each of these variables are shown in Figure 10. 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 outcomes are tree cover in the year 2000, measured as the percentage of each grid cell covered by vegetation taller than 5 meters, and forest loss over the period 2000–2023, defined as stand-replacement disturbances or transitions from forest to non-forest states.

Across specifications, tree cover by the year 2000—capturing the stock of standing forest at that point in time—is estimated to be 5.3 to 15.7 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. By contrast, estimates for forest loss between 2000 and 2023—a flow measure of deforestation over time—are small and generally not statistically significant. The coefficient in the 50km bandwidth specification is positive and significant, but for narrower bandwidths, the point estimates are close to zero or negative and insignificant. RD plots for both outcomes are shown in Figure 11.

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. The absence of consistent effects on forest loss after 2000 aligns with this view: rates of deforestation appear to have stabilized following the 1990s, when the Colombian government formally recognized the former concession area as an Indigenous *resguardo*, thereby granting legal protection and enabling stronger conservation outcomes under Indigenous governance. 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 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 2. Due to the geographical coverage of Murillo-Sandoval et al. (2023)'s dataset, we restrict the analysis to the discontinuity within Colombia. Table 6 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 6.8–8.6 percentage points in coca conversion and 8.4–11.0 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 12. 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 6 using a donut RD that excludes all 1km by 1km cells within 3km and 4km of the cutoff (the maximum width of the Putumayo and Caqueta rivers), reselecting MSE-optimal bandwidths on the trimmed sample while retaining the triangular kernel and local linear fits. As reported in Table 7, our main result holds: estimates for tree cover remain robust in both sign and statistical significance across all specifications. Results for land transitions into coca and cattle are less stable, yet they remain significant for the bias-corrected estimates.

6 Conclusion

Our findings shed light on the complex economic legacy left by the Amazon rubber boom at the turn of the twentieth century. While municipalities historically suited for rubber extraction initially prospered—demonstrated by their higher per capita GDP in the 1920 Brazilian Census—this prosperity was not sustained. By 2010, these same municipalities had notably lower average incomes and higher levels of income inequality compared to areas with lower rubber suitability. Particularly striking is the persistence of elevated inequality within Indigenous populations, who bore the brunt of exploitative labor arrangements during the boom. This result aligns with historical accounts emphasizing widespread coercion and forced labor practices targeting Indigenous populations. Demographic shifts, evident through increased Indigenous-white miscegenation recorded as early as the 1872 Census, provide additional evidence of how the intrusive labor practices associated with rubber extraction may have fundamentally reshaped social structures. Additionally, by complementing our municipality-level analysis with high-resolution grid-cell data, we show that historically rubber-suitable areas experienced lower contemporary levels of economic activity, lower population density, and higher rates of Indigenous tribe extinction. These grid-level results reinforce the deep and persistent negative legacies of extractive industries in the region.

Our Regression Discontinuity Design results that 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).

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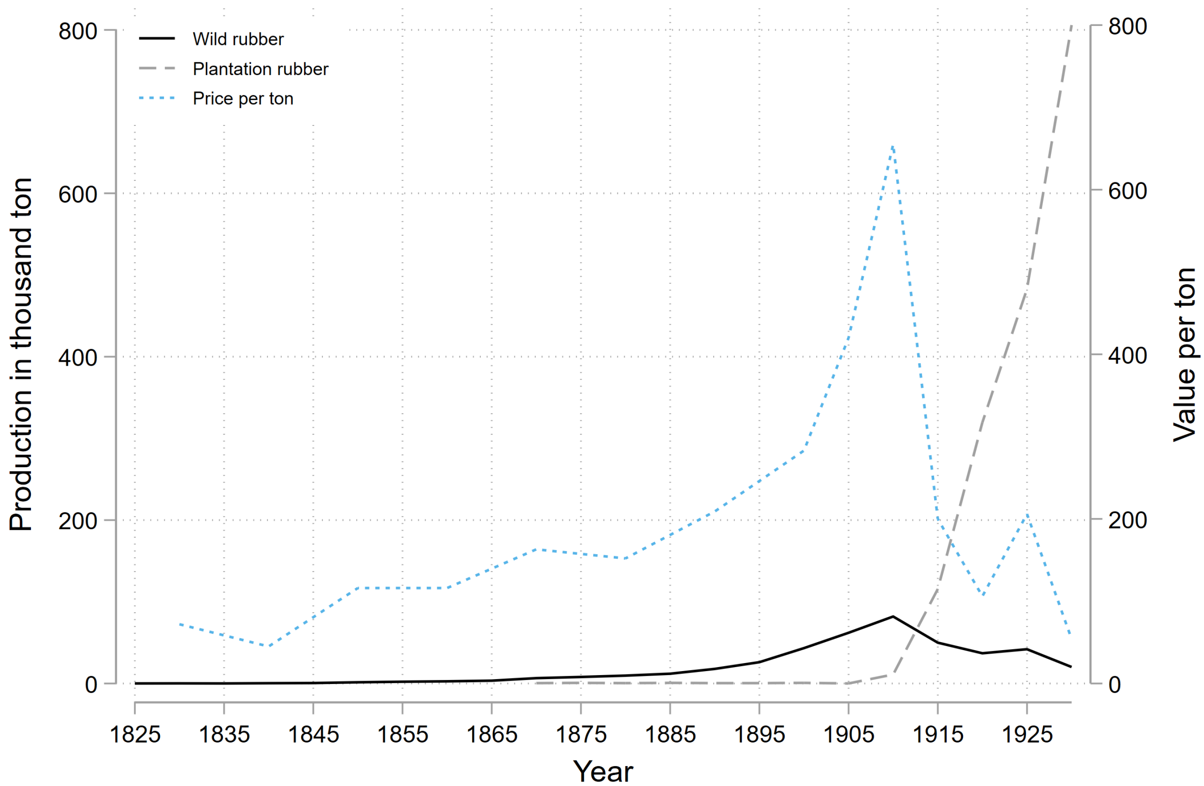
Figures

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

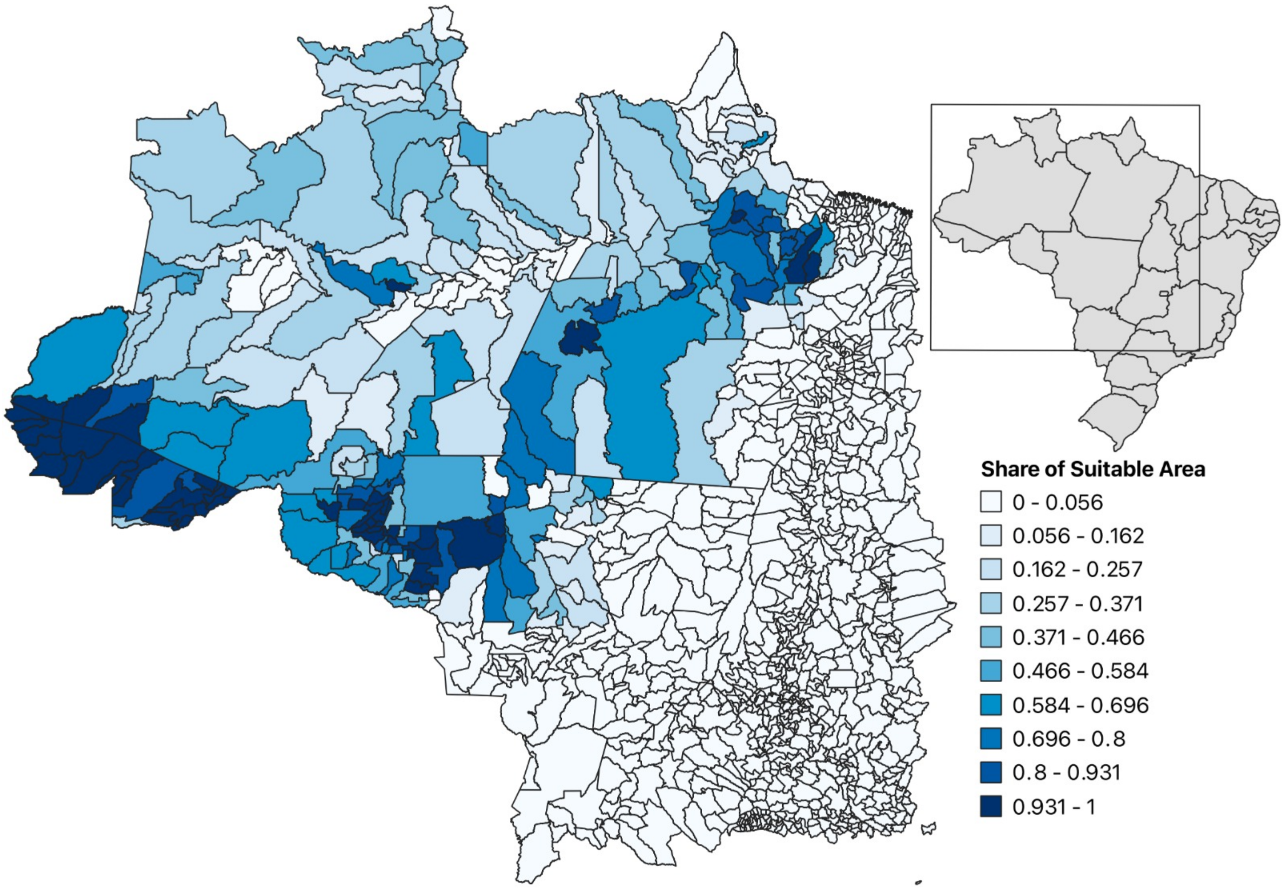


Notes: This graph shows the evolution of wild and plantation rubber production (on the left axis), and the value per ton in British pounds (on the right axis) from 1825 to 1925. The main sources of information are Schidrowitz and Dawson, eds (1952); Hotchkiss (1924); Benchimol (2010); Vayagool (1967).

Figure 2: Historical Rubber Suitability in 1925

Notes: Figure displays the historical rubber suitability map from Schurz et al. (1925). The darker shaded areas represent regions identified as suitable for rubber cultivation.

Figure 3: Historical Rubber Suitability in Brazilian Municipalities

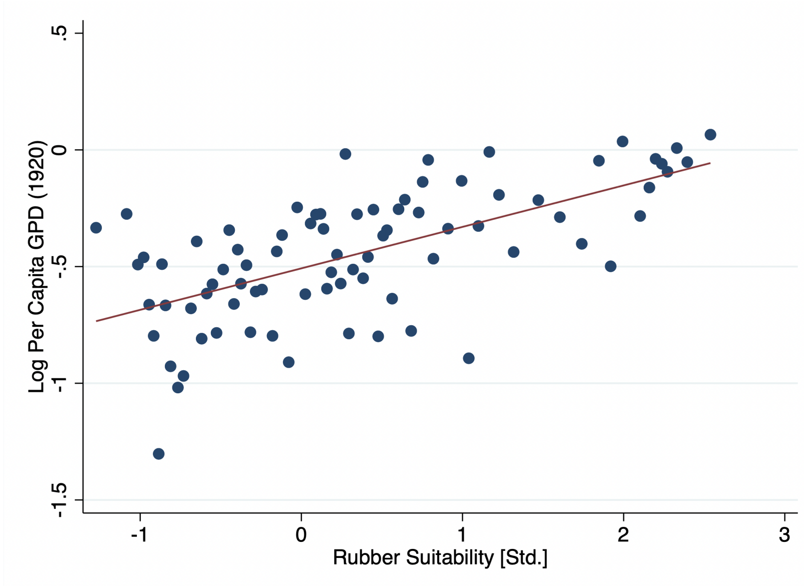


Notes: Figure displays the mean of the historical rubber suitability map from Schurz et al. (1925) by municipalities in Brazil. The share of land suitable in each grid is presented in shades of blue.

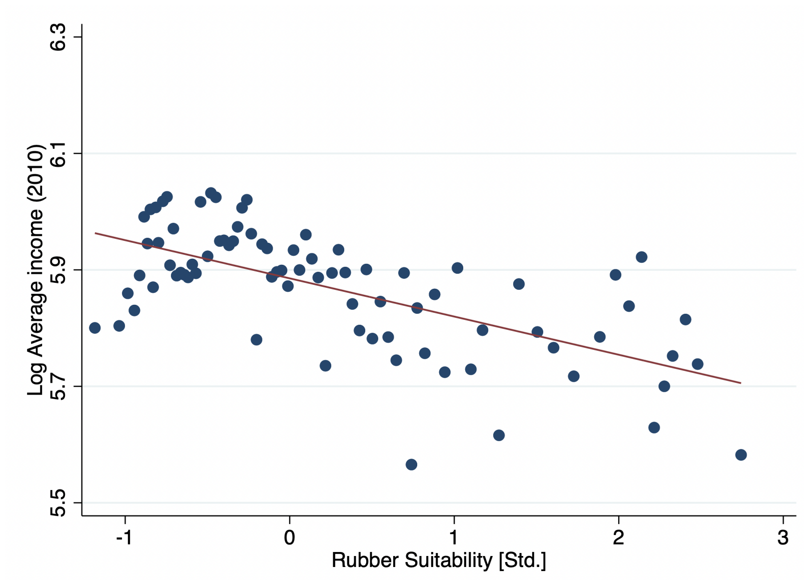
Figure 4: Casa Arana: Demarcation, Extraction Camps, and Trading Routes (1913)

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: Income Reversal in Rubber-Suitable Areas



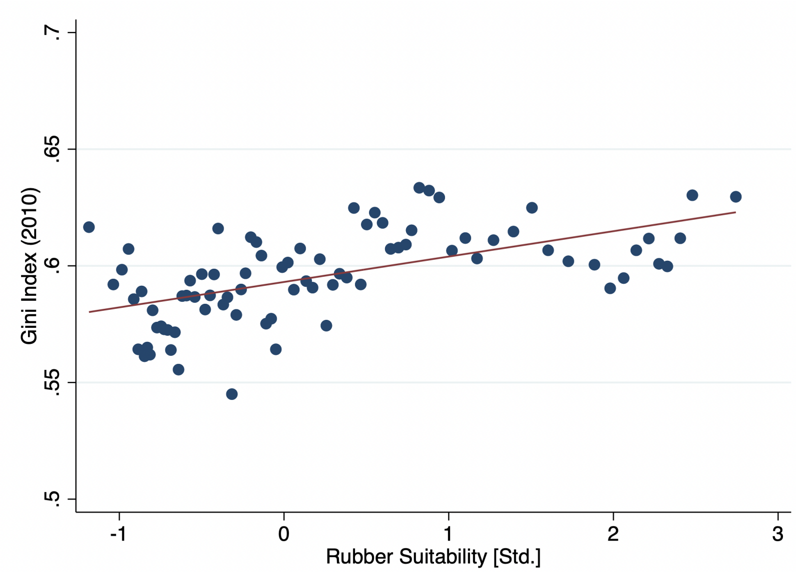
(a) Log Per Capita GPD in 1920



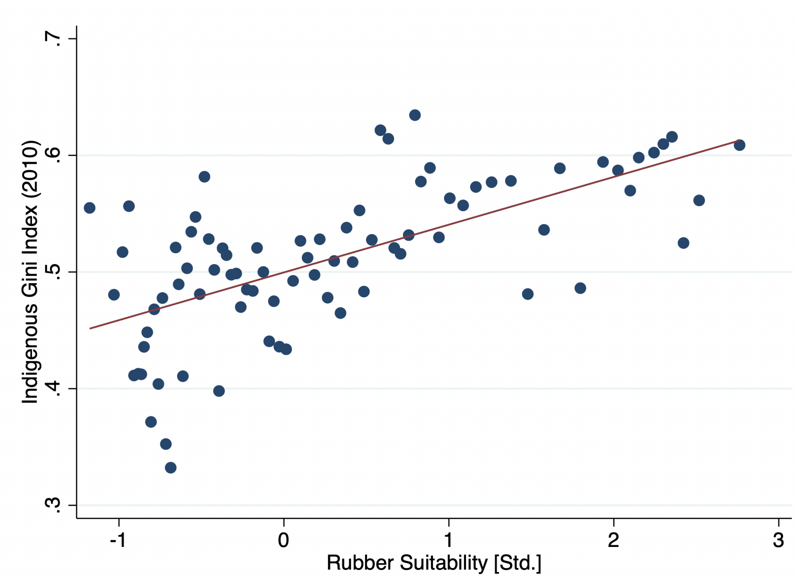
(b) Log Average income in 2010

Notes: Panel A presents the relation between the log. per capita GDP in the 1920 Brazilian Census and the rubber suitability 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 6: Rubber Cultivation and the Increase of Inequality



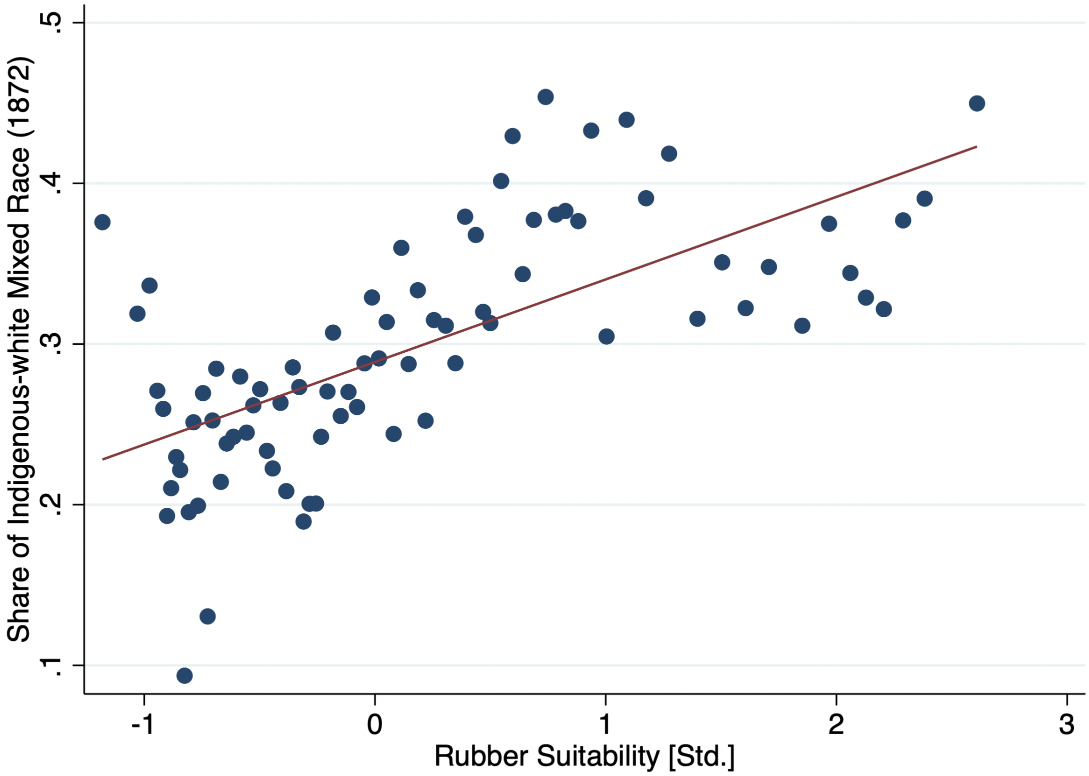
(a) General Gini Index in 2010



(b) Indigenous Gini Index in 2010

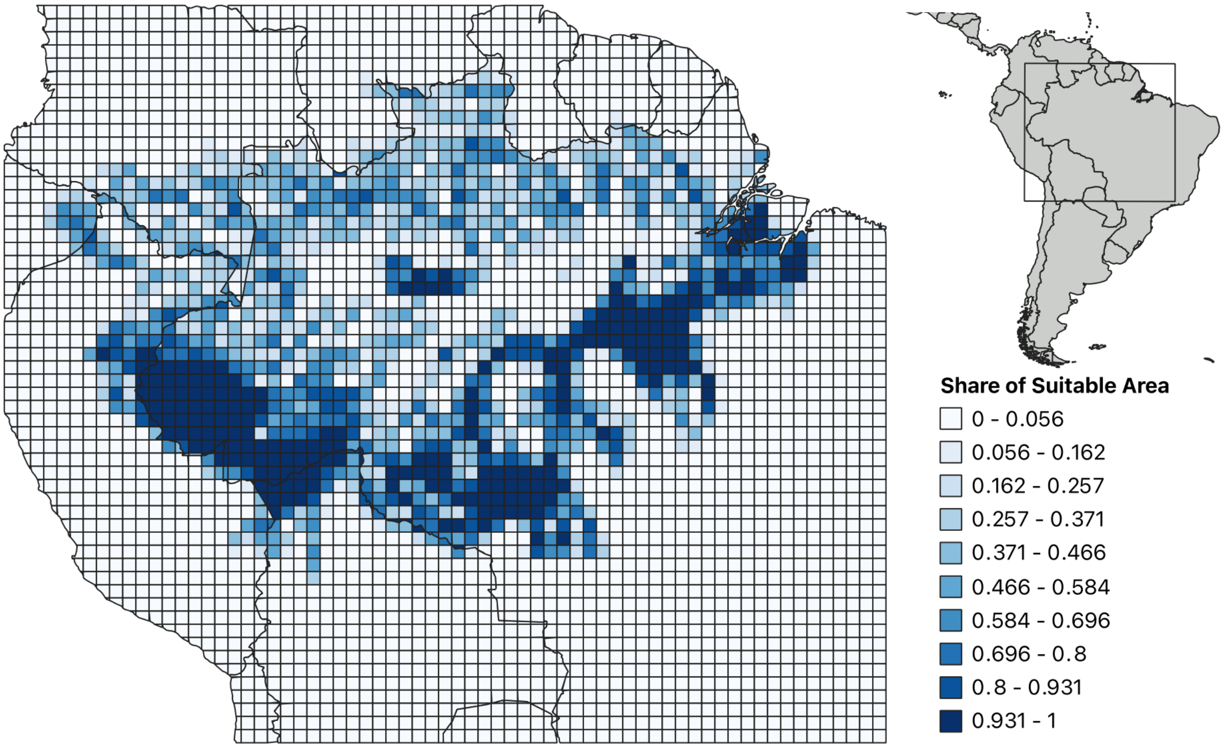
Notes: Panel A presents the relation between the general Gini Index in the Brazilian 2010 Census and the rubber suitability in Brazilian municipalities [Std.]. Panel B presents the relation between the Indigenous Gini Index in the Brazilian 2010 Census and the rubber suitability in Brazilian municipalities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

Figure 7: Historical Miscegenation in Rubber-Suitable Areas



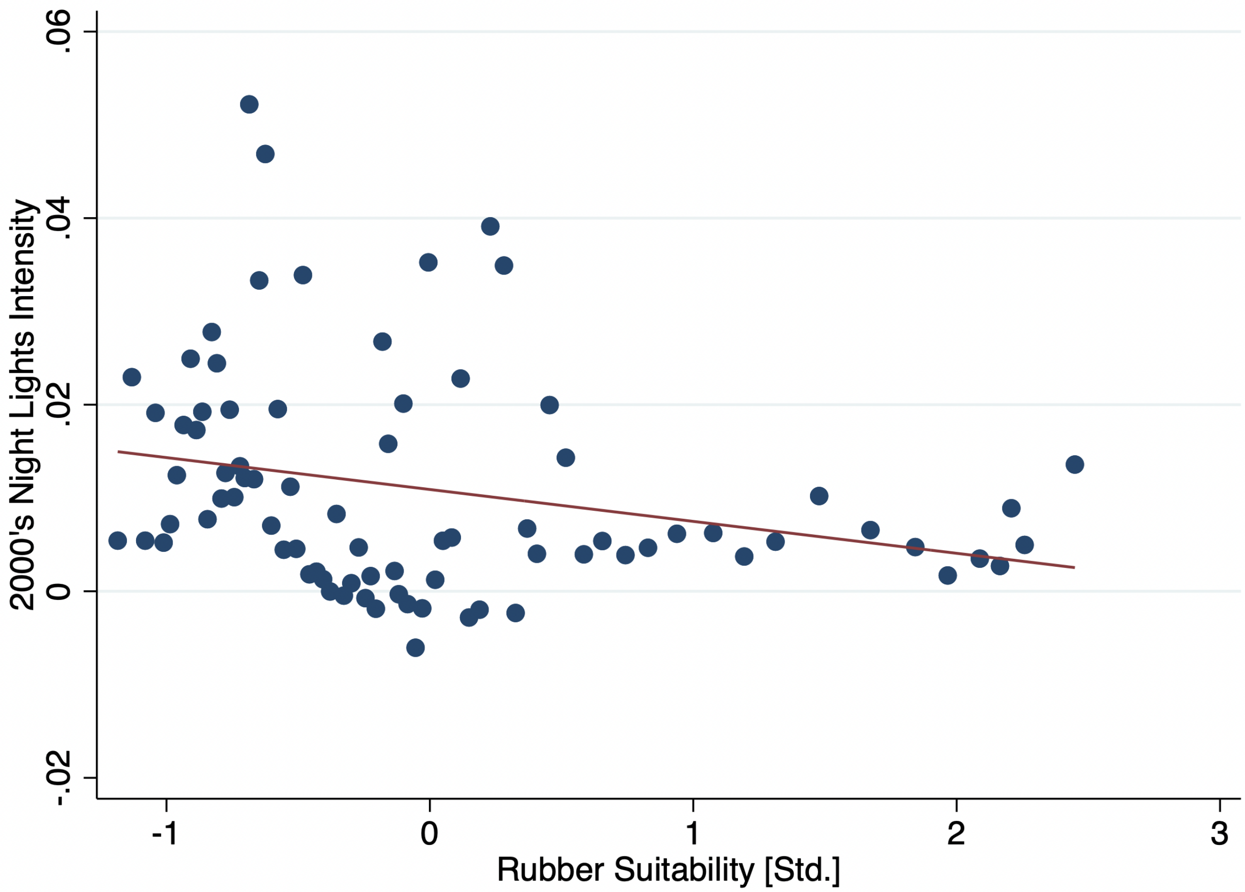
Notes: Figure 7 displays the relation between the share of Indigenous-white mixed race in the 1872 Brazilian Census and the rubber suitability in Brazilian municipalities [Std.].

Figure 8: Historical Rubber Suitability by Grid Cells



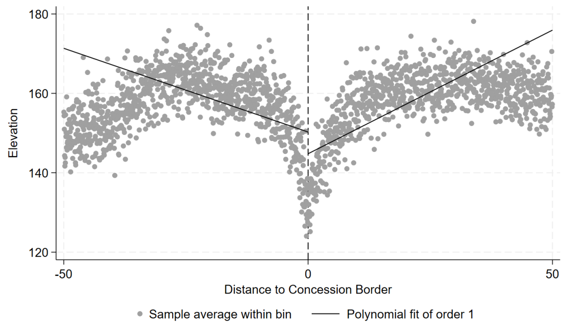
Notes: Figure displays the mean of the historical rubber suitability map from Schurz et al. (1925) by 0.5 × 0.5 degree grid cells. The share of land suitable in each grid is presented in shades of blue.

Figure 9: 2000's Night Lights Intensity in Rubber-Suitable Areas

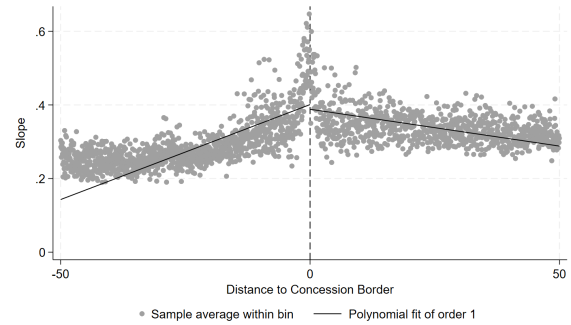


Notes: Figure 9 displays the relation between the 2000's night lights intensity and the rubber suitability in Brazilian 0.5 × 0.5 degree grid-level data [Std.].

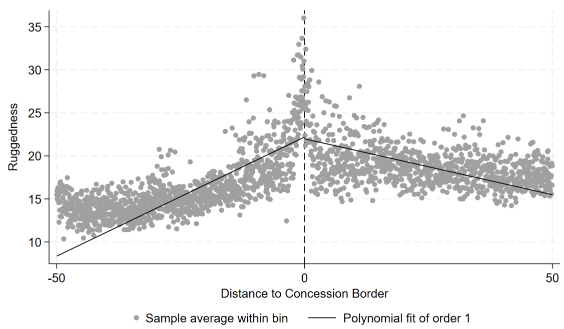
Figure 10: RD Plots for Geographic and Environmental Covariates



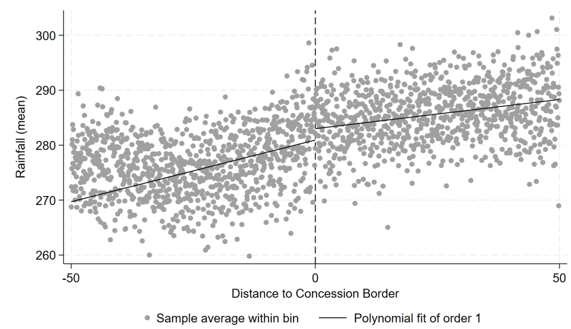
(a) Elevation



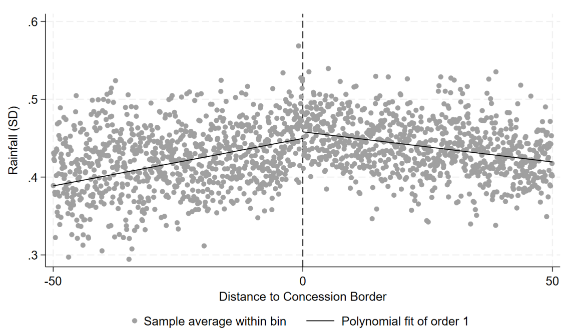
(b) Slope



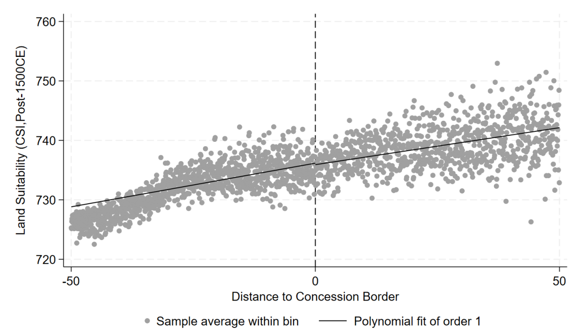
(c) Ruggedness



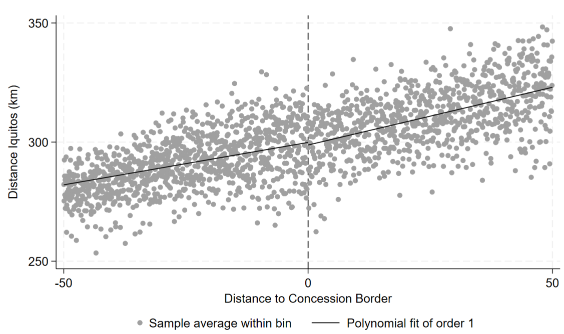
(d) Mean Rainfall (2003)



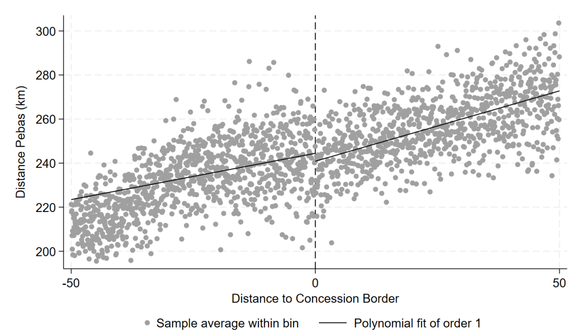
(e) Rainfall SD (2003)



(f) Land Suitability



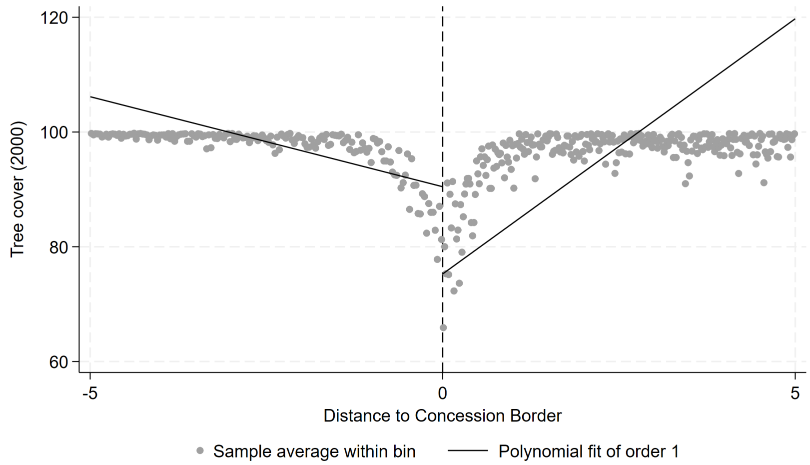
(g) Distance to Iquitos



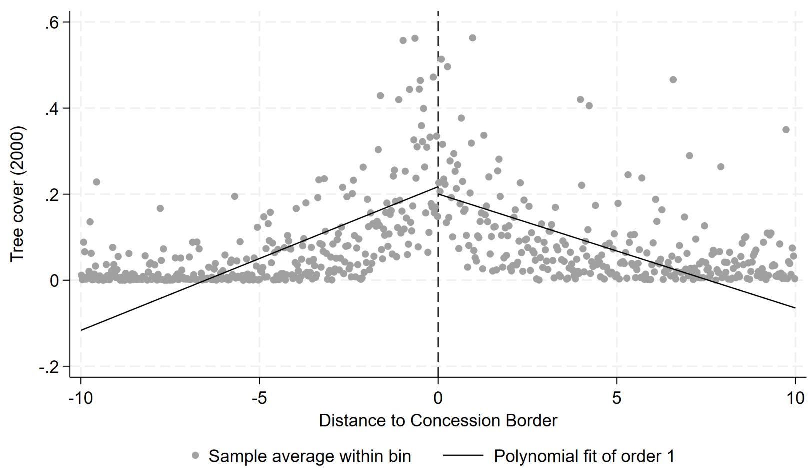
(h) Distance to Pebas

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 11: RD Plots for Deforestation



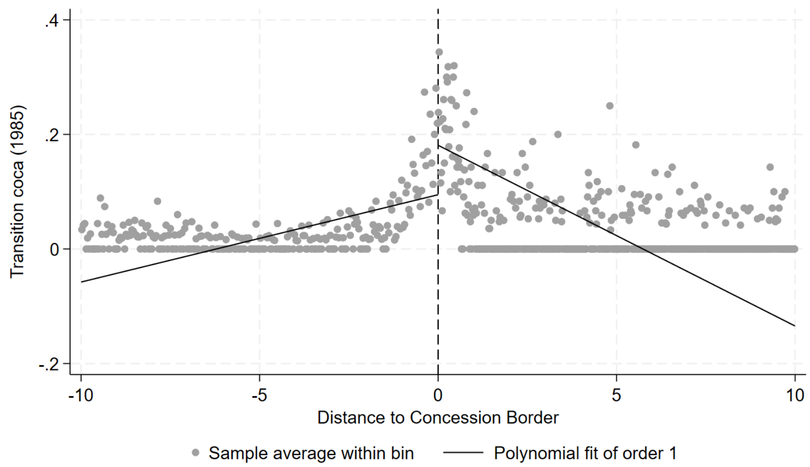
(a) Tree cover 2000 (% per 1km × 1km)



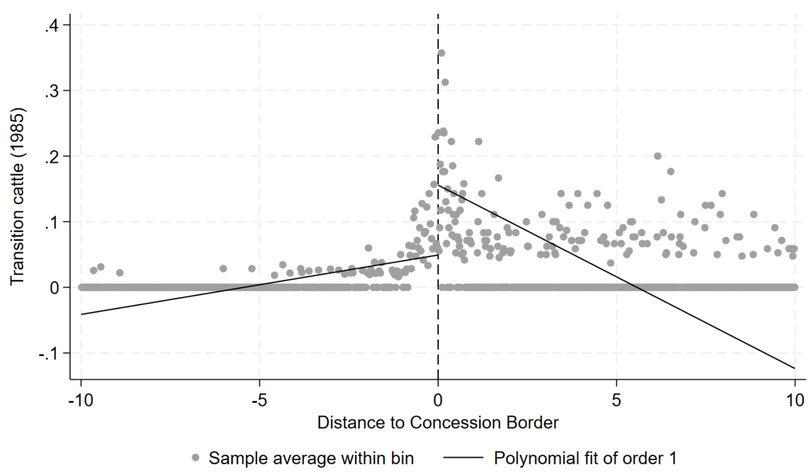
(b) Forest loss 2000–2023 (0–21, per 1km × 1km)

Notes: The figure presents RD plots for two deforestation outcomes along the running variable (distance to concession border), with positive distance values inside the concession boundaries. *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. *Forest loss* during the period 2000–2023 is defined as a stand-replacement disturbance, or a change from a forest to non-forest state. Encoded as either 0 (no loss) or else a value in the range 1–20, representing loss detected primarily in the years 2001–2023, 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).

Figure 12: 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 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 Rubber Suitability

	Nighttime Lights (2000) [Std.]		Population Density [Std.]	
	(1)	(2)	(3)	(4)
Rubber Suitability [Std.]	-0.0198	-0.0108	-0.0506	-0.0387
	[0.0030]***	[0.0027]***	[0.0062]***	[0.0061]***
# Grids	2,003	2,003	2,003	2,003
R-squared	0.0181	0.0827	0.0247	0.0642
Baseline controls	No	Yes	No	Yes

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

Table 2: Nighttime Lights in 2000 and Rubber Suitability by Country

	Nighttime Lights (2000) [Std.]					
	(1)	(2)	(3)	(4)	(5)	(6)
Rubber Suitability [Std.]	-0.0058	-0.0092	-0.0336	-0.0315	-0.0799	-0.0011
	[0.0031]*	[0.0023]***	[0.0134]**	[0.0182]*	[0.0685]	[0.0010]
# Grids	390	2017	359	63	464	155
R-squared	0.0015	0.0050	0.0035	0.0133	0.0007	0.0007
Country	Bolivia	Brazil	Colombia	Ecuador	Peru	Venezuela

Notes: OLS estimates in all columns. Our suitability variable is standardized. Standard errors shown in parentheses are clustered at the grid level. (***$p \leq 0.01$, **$p \leq 0.05$, *$p \leq 0.1$)

Table 3: Indigenous Extinction and Rubber Suitability

	Extinction of Indigenous Tribes			
	(1)	(2)	(3)	(4)
Rubber Suitability [Std.]	0.1235	0.0842	0.0686	0.0637
	[0.0185]***	[0.0183]***	[0.0304]**	[0.0303]**
# Grids	2,003	2,003	1,424	1,424
R-squared	0.0501	0.1209	0.0502	0.0787
Baseline controls	Yes	Yes	Yes	Yes
Country FE	No	Yes	No	Yes
Restriction to cells with at least one Precolonial tribe	No	No	Yes	Yes

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

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	-5.324	4.512	0.238	16543	20850
Slope	0.354	0.360	0.016	0.088	0.391	0.371	0.013	0.026	-0.040	0.037	0.282	30174	40660
Ruggedness	19.923	20.044	0.811	0.046	22.051	20.551	0.664	0.004	-1.205	1.890	0.524	27874	36988
Rainfall (mean)	278.949	283.994	1.292	0.117	280.743	283.491	0.731	0.105	0.087	1.266	0.945	16118	20305
Rainfall (SD)	0.438	0.450	0.010	0.237	0.447	0.454	0.008	0.285	-0.009	0.010	0.358	27992	37199
Land Suitability (CSI)	734.896	737.350	1.724	0.185	735.097	736.559	0.885	0.179	0.634	1.435	0.659	27724	36749
Distance Iquitos (km)	296.642	303.929	3.377	0.414	297.669	301.539	1.938	0.425	-0.030	2.872	0.992	16213	20370
Distance Pebas (km)	240.855	247.611	3.191	0.248	241.045	244.039	1.917	0.331	0.099	2.768	0.971	15615	19619
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

	Tree cover 2000 (% per 1x1km)					*Forest loss 2000–2023 (0-21, per 1x1km)*				
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
	50km	20km	10km	Optimal	Optimal	50km	20km	10km	Optimal	Optimal
Inside Concession (Conventional)	-5.335***	-9.221***	-12.68***	-15.71***	-9.911***	0.0295***	0.00338	-0.0169	-0.0198	-0.00874
	(0.141)	(0.274)	(0.430)	(0.761)	(1.506)	(0.00625)	(0.0109)	(0.0159)	(0.0164)	(0.0424)
Inside Concession (Bias-corrected)	-7.964***	-12.69***	-14.99***	-15.66***	-11.10***	0.0101	-0.0172	-0.0546***	-0.0278	-0.0185
	(0.141)	(0.274)	(0.430)	(0.761)	(1.506)	(0.00625)	(0.0109)	(0.0159)	(0.0164)	(0.0424)
Inside Concession (Robust)	-7.964***	-12.69***	-14.99***	-15.66***	-11.10***	0.0101	-0.0172	-0.0546*	-0.0278	-0.0185
	(0.236)	(0.434)	(0.650)	(0.793)	(1.712)	(0.00987)	(0.0162)	(0.0227)	(0.0177)	(0.0490)
Controls	No	No	No	No	Yes	No	No	No	No	Yes
Segment FE (50km)	No	No	No	No	Yes	No	No	No	No	Yes
Observations	112,198	50,044	27,283	26,307	52,848	112,198	50,044	27,283	49,762	49,818
Bandwidth	50.00	20.00	10.00	3.69	13.15	50.00	20.00	10.00	9.46	13.64
Mean Dep. Var.	98.02	96.95	95.52	91.32	97.86	0.06	0.07	0.09	0.09	0.07
SD Dep. Var.	8.500	11.186	13.860	19.191	8.349	0.480	0.469	0.480	0.487	0.445

Notes: The unit of observation is 1km × 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. *Forest loss* during the period 2000–2023 is defined as a stand-replacement disturbance, or a change from a forest to non-forest state. Encoded as either 0 (no loss) or else a value in the range 1–20, representing loss detected primarily in the years 2001–2023, respectively. Columns (1) to (10) show RD coefficients estimated within 50km, 20km, 10km and optimal bandwidth ranges around the concession boundaries for each outcome; the fifth and tenth columns 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 Land-Use Transitions

	Transition coca (2000)		*Transition cattle (2000)*	
	(1)	(2)	(3)	(4)
Inside Concession (Conventional)	0.086***	0.068***	0.110***	0.084***
	(0.009)	(0.018)	(0.008)	(0.018)
Inside Concession (Bias-corrected)	0.081***	0.076***	0.111***	0.095***
	(0.009)	(0.018)	(0.008)	(0.018)
Inside Concession (Robust)	0.081***	0.076***	0.111***	0.095***
	(0.010)	(0.020)	(0.009)	(0.020)
Controls	No	Yes	No	Yes
Segment FE (50km)	No	Yes	No	Yes
Observations	29,336	46,679	26,987	43,214
Bandwidth	9.56	17.31	7.98	17.23
Mean Dep. Var.	0.05	0.03	0.04	0.01
SD Dep. Var.	0.226	0.168	0.198	0.118

Notes: The unit of observation is 1km × 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 7: 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	3km	4km	Base	3km	4km	Base	3km	4km
Conventional	-9.911***	-1.820*	-2.134**	0.068***	0.014	0.021	0.084***	0.025*	0.018
	(1.506)	(0.980)	(1.085)	(0.018)	(0.011)	(0.015)	(0.018)	(0.015)	(0.015)
Bias-corrected	-11.101***	-2.252**	-2.825***	0.076***	0.020*	0.034**	0.095***	0.028*	0.017
	(1.506)	(0.980)	(1.085)	(0.018)	(0.011)	(0.015)	(0.018)	(0.015)	(0.015)
Robust	-11.101***	-2.252*	-2.825*	0.076***	0.020	0.034*	0.095***	0.028	0.017
	(1.712)	(1.249)	(1.472)	(0.020)	(0.014)	(0.019)	(0.020)	(0.019)	(0.022)
Controls	No	No	No	No	No	No	No	No	No
Segment FE (50km)	No	No	No	No	No	No	No	No	No
Observations	52,848	42,853	40,262	46,679	38,245	36,180	43,214	34,780	32,715
Bandwidth	13.15	13.15	13.15	17.31	17.31	17.31	17.23	17.23	17.23
Mean Dep. Var.	97.86	97.86	97.86	0.03	0.03	0.03	0.01	0.01	0.01
SD Dep. Var.	8.349	8.349	8.349	0.168	0.168	0.168	0.118	0.118	0.118

Notes: The unit of observation is 1km $\times$ 1km grid cell. Columns (1), (4) and (7) show baseline RD estimates with optimal bandwidths, controls, and 50km-segment fixed effects. To mitigate river-bank discontinuities, the last two columns for each outcome implement a *donut RD* that excludes observations within 3km and 4km of the boundary on either side (approximate maximum width of Caqueta river), i.e., $|\text{distance}| \leq 1$ 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. 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. *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: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.