Old But Gold: Historical Pathways and Path Dependence

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Abstract

We show that historical pathways from Brazil's gold rush era still impact today's population distribution. We find that these pathways generated road towns that shaped the initial urban configuration and population settlement in Brazil, contributing to the distinct evolution of impacted locations. We identify a causal relationship between the pathways and various demographic indicators, including population density, population growth via in-migration, urbanization, and structural change over time. The findings reveal patterns more consistent with path dependence rather than historical persistence. The empirical quantification of an economic geography model using our estimated agglomeration spillovers implies that the forces driving population dynamics have a path-dependent nature.

Keywords: Historical Roads, Geography, Multiple Equilibria, Path Dependence, Persistence, Population Density
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1 Introduction

What drives the spatial distribution of economic activity and population? The implications of location advantages and historical shocks for history dependence in economic geography are well documented in the literature. While many studies find location advantages to be the main driver of economic activity and population distribution at several spatial scales, such as cities, industries, and neighborhoods (Davis and Weinstein, 2002, 2008; Lee and Lin, 2017), others find historical persistence and path dependence with multiple equilibria to be more consistent with the empirical patterns (Bleakley and Lin, 2012, 2015; Redding, Sturm and Wolf, 2011; Jedwab and Moradi, 2016; Jedwab, Kerby and Moradi, 2017; Michaels and Rauch, 2017; Hanlon, 2017). The answer may also rest on a mix of location advantages and path dependence (Maloney and Valencia Caicedo, 2016). Overall, it appears that the emerging consensus is that "location fundamentals may be key when differences across locations are large, but other factors dominate as locations become more similar" (Hanlon and Heblich, 2022). In other words: "history matters only when it matters little" (Rauch, 1993).

The difference, however, between *persistence* and *path dependence* remains less clear. It is essential to clarify this difference, as persistence and path dependence can represent different types of historical dependence, although the terms are often used interchangeably, and their effects are many times conflated without an attempt of distinction. For example, a temporary historical episode might cause persistent effects on the location of economic activity both because the episode could affect institutions in the past, which then affects the current economy through modern institutions, or because the episode might cause agglomerations or other types of externalities that shift the economy's long-run equilibrium. Both effects could also be occurring simultaneously.[1] Allen and Donaldson (2020, 2022) model *persistence* as long-lived dependence of current outcomes on temporary historical episodes and *path dependence* as when temporary historical episodes permanently shape long-

[1] See Voth (2021) for a review of the literature on persistence of historical shocks. In particular, the author argues that one may expect *any* historical shock to fundamentals to cause geographically-delimited persistent impacts, thus it is necessary to tease out the transmission mechanism from the historical shock to the long-run outcome.

run outcomes in the presence of multiple equilibria. Still, distinguishing these two forces empirically is challenging, as they often lead to the same long-run outcome.

In this paper, we use an economic geography model and a historical episode that defined the very initial population settlement and urban configuration of an economy to demonstrate a case in which it is possible to have path dependence without persistence from the initial shock. With the sudden discovery of gold in Brazil around 1700, many "gold roads" were built connecting the population settlements on the coast to the then unpopulated interior. Progressively, the gold roads became a nationwide "mule road" network, since mules served as the main transportation system before railroads. These historical pathways gave birth to the "road town," a new type of population settlement featuring an urban configuration that contrasted with the sparsely populated rural estates that were most common at the time. The road town also attracted a distinct mix of initial settlers that were based on non-agricultural workers. Yet, as established in the Brazilian historiography, the gold and mule roads impacted the flow of people but not the flow of goods. With the advent of modern transportation, the gold and mule roads became obsolete, and the road towns and their populations became the seeds of a new economic geography.

We use two sources of data to build the gold and mule roads variables. We digitize the gold roads from historical maps in Simonsen (1977), which contain all the main routes created from the population settlements that already existed on the coast before 1700 to the gold mines discovered in various regions of the Brazilian hinterlands. For the mule roads, we build a unique historical origin and destination network database from 19th century archival documents and government reports depicting the transportation network before railroads. The main advantages of integrating the two sources are that we can have more options for our empirical strategy and that our findings hold broader external validity and are not solely contingent on some specific characteristic of the first gold roads or mining regions. With the georeferenced trails in hand, we compute road density in a region as the area of a 5-kilometer buffer around the road divided by the region's total area, following Dalgaard, Kaarsen, Olsson and Selaya (2022). This measure allows us to interpret the road's influence as a share of the region's area. We construct the outcome variables for population using data from all censuses conducted between 1920 and 2010.

Although the locations of gold deposits are randomly determined by nature, other determinants of historical pathways are nonrandom, such as the predetermined location of existing towns and cities and the strategic direction of exploration and road placement. Thus, to isolate the effects of the gold and mule roads from omitted variable bias, we use optimal least-cost paths combined with an inconsequential units approach (Redding and Turner, 2015). The least-cost paths, which serve as an instrument for the gold roads and directly represent the mule roads, are selected based solely on exogenous topography.[2] In addition, the inconsequential units approach leaves in the sample only *inconsequential* areas that are crossed because they are in a convenient path between the origins and destinations. The combination of these two strategies mitigates concerns about omitted variables that affect both road placement and outcome variables.[3]

Our findings indicate that historical pathways significantly impact the spatial distribution of population density in present-day municipalities. We observe that a 10 percentage points increase in the density of gold roads is associated with a 20% increase in a municipality's population density, a 14% increase in nightlight incidence as an alternative measure of population density, and a 23% increase in urban population density. Similarly, mule roads have a positive but slightly smaller effect on the same three measures. The results are robust to a large number of alternative specifications and a within-municipality analysis using grid cells.

Even if our approach using least-cost paths with inconsequential units is successful in removing the omitted variable bias from strategic road placement, there could exist omitted variable bias from some regions receiving systematically more

[2]The historical documents do not present the exact path of the mule roads but origins and destinations with the actual distances traveled, so we use the least-cost paths directly representing mule roads. This is a plausible assumption as animals typically follow paths of least resistance, which humans historically adopted for road construction. As we demonstrate, the predicted distances from the least-cost paths explain 92% of the variation in actual distances recorded in the historical documents that we use to build our origin and destination network database.

[3]We also employ two additional sample restrictions. First, we drop all pre-existing locations—either before the discovery of gold or before the description of mule roads in the historical documents—preventing any reverse causality from older settlements to road placement. Second, we only include the municipalities traversed by the gold and mule roads and their neighboring municipalities, ensuring a more compatible comparison group, although our results still hold in the full sample.

nonrandom exposure to the pathways than other regions because of their economic and geographic centrality, given the location of gold deposits. To address this challenge, we follow Borusyak and Hull (2023) and recenter the treatment with the expected treatment, purging the bias. The expected treatment is built by averaging the outcome of counterfactual shocks leveraged by the natural experiment aspect of our treatment given a shock assignment process.[4] The coefficients are similar when we re-center the treatment, suggesting that the this type of bias is not important in our setting.

We then analyze the short- and long-run factor dynamics to understand the drivers behind the contemporaneous effects on population density. We find no short-run effects of the gold and mule roads on population density but a long-run increase followed by a flattening out of the coefficient, suggesting convergence to a new steady state. Conversely, the coefficient on population growth starts off high and then converges to approximately zero. We find that in-migration, rather than fertility, is the primary driver of population growth. Additionally, we observe a positive effect on the urbanization rate, along with indications of structural change in the density of the working population. Modern transportation density (such as paved roads, highways, and railroads) appears to play a minimal role.

Subsequently, using the economic geography model proposed by Allen and Donaldson (2022), we estimate the strength of agglomeration forces using the gold and mule roads as instrumental variables, representing the agglomeration effects of areas with gold and mule road "compliance." The coefficients align with estimates found in the literature for other countries but are higher than previously estimated for Brazil. Drawing on our estimates and parameters from prior research, we derive the model's long-run dynamics. Our findings suggest an economy characterized by multiple steady states, indicating a "road town mechanism" that leads from initial

[4]For this exercise we need only to assume that gold *deposits*, given predetermined variables, are as good as random, and not that the *discovery* of gold is random. Nevertheless, Palma (2022) makes the case that the timing and location of gold discovery in Brazil was unexpected, which can be used for exogenous variation in certain settings. In our setting, we make a similar case only for the first gold discovery and the first gold road analyzed in Appendix J.

conditions to a new equilibrium characterized by higher population density through early structural transformation and urbanization driven by in-migration.[5]

Our paper contributes to the growing literature on the enduring effects of historical routes on the spatial distribution of economic activity mediated by population settlements (*e.g.* Dalgaard et al., 2022; Paik and Shahi, 2022). In particular, Barsanetti (2021) looks at historical *Peabirú* indigenous routes in Brazil and finds that their effects on contemporaneous population were mediated by railroads but not paved roads, while there could be a direct effect via early settlements. Also, Portugal and Barsanetti (2023) perform a local analysis of two gold roads, but in a complementary context of heterogeneity between roads given the flow of gold, not of people like in our paper.[6]

Our paper adds to this literature by conducting a more nuanced and comprehensive analysis of long-run dynamics, with more detailed historical data, including new archival sources. Moreover, we identify the extent of agglomeration effects with an empirical quantification of an economic geography model to provide more context into the nature of persistence and path dependence. In this respect, our paper adds to the literature on history dependence in spatial economics. See, for example, Lin and Rauch (2022) for a review.

We also contribute to the literature that estimates the effects of agglomerations on workers' wages in Brazil by proposing a new instrumental variable, whereas most papers in the literature estimate population density directly or instrument it with lagged population (*e.g.* Barufi, Haddad and Nijkamp, 2016; Chauvin, Glaeser, Ma and Tobio, 2017; Ehrl and Monasterio, 2021; Dingel, Miscio and Davis, 2021).

[5] Our results generalize anecdotal evidence accounting for the creation of population settlements in the country's hinterlands. For example, the following excerpt illustrates the creation of the municipality of Piracicaba: "In the heroic cycle of expeditions and explorations, the Piracicaba River began to be traversed and explored. The first known attempt dates back to 1693, when Pedro de Morais Cavalcanti requested a land grant, but it didn't lead to settlement. Following the discovery of the gold mines in Cuiabá in 1718, efforts were made to construct a road from São Paulo to that region for easier transportation of cattle and troops and to avoid the dangers of river navigation. This road, built in 1725 by Luís Pedroso de Barros, passed through the region that later became the municipality of Piracicaba, marking the beginning of settlement there. [Translated from Portuguese by the authors.]" (IBGE, 1957, p. 297).

[6] In addition, Barsanetti (2023) analyzes the so-called "railroad endpoints" in Brazil, the towns at the end points of railroads, which is a nice complement to our paper, which focuses on the road towns that are between end points.

A notable exception is Almeida, Neto and Rocha (2023) that use a shift-share IV to estimate the agglomeration coefficient, but with a focus on different outcomes.

2 Gold, early road infrastructure, and population settlements

Following initial contact in 1500, Portuguese colonizers established settlements along the Brazilian coast. For a long time, they refrained from exploring the hinterlands due to the challenges posed by the indigenous population, geographical obstacles, and transportation costs. In 1627, the Franciscan friar Vicente de Salvador famously described the Portuguese presence on the coast as akin to crabs scratching the shores (Salvador, 2010, p. 70). In the 1700s, the Benedictine friar Gaspar da Madre de Deus observed that the essential reason why the Portuguese had decided to settle only on the coast were transportation costs: King John III (1502–1557) knew that all goods produced along the sea could be easily transported to Europe, while those of the hinterland would never get to the ports and if they did the costs would be such that the farmers would not sell for the prices offered to them at the ports (Deus, 1920, p. 179). Particularly, in the late 16th century, Brazil had three towns and fourteen villages scattered across the coastal line; São Paulo, established in 1554, was the only exception (Azevedo, 1956). The city of São Paulo was established at great costs of expeditions venturing further into the country's interior, carving pathways through dense rainforests and the coastal mountain range, amid conflict and negotiation with the indigenous population.[7]

These pathways were not exactly new, explorers would take advantage of indigenous trails connecting native villages, called *Apés* (Kok, 2009). According to Holanda (1975), these trails were primitive—no better than tracks left by tapirs—such that wheeled carts were prohibitive. The main expeditions into the Brazilian hinterlands were composed of Jesuit missions and slave raiders—named *Bandeirantes*—who mainly followed these indigenous trails using enslaved people as porters (Abreu, 1998).

[7] For example, an enslaved porter with a 30 kilogram load took four or five days to complete the round trip from the port city of Santos to São Paulo, a mere 70 kilometers but which had to cross the imposing *Serra do Mar* mountain range (Reis, 2023).

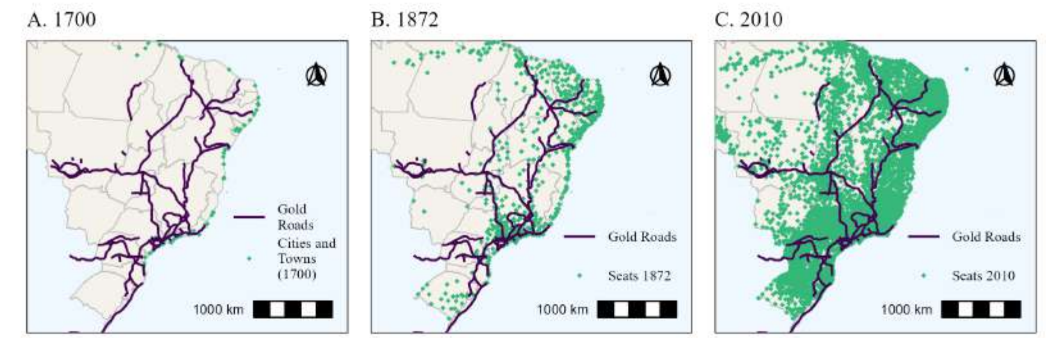

Figure 1: Gold Roads and Population Settlements

Notes: The evolution of cities in Brazil since 1700 and its relationship with Gold Roads. In 1700, cities are defined as cities or towns. In 1872 and 2010, cities are the municipal seats.

The missions and *bandeirante* expeditions, however, did not shift the distribution of population away from the coast (Deffontaines, 1938; Morse, 1974). Azevedo (1956) points out that by end of the 17th century, the Brazilian urban system had 51 villages and seven towns; only six were located away from the coast and considered entry points to the hinterlands. Panel A of Figure 1 depicts the spatial distribution of these urban areas in 1700.

Even if there were settlements, the lack of significant population density away from the coast is attributed to the large tracts of land allocated to the colonizers. As argued by Deffontaines (1938), the basic unit of settlement in Brazil was the large estate (the *fazenda*) and even when the estates were small, it did not foster agglomerations. This changed with the discovery of gold mines around 1700 in the interior of Brazil, first in Minas Gerais in large quantities and later in Goiás, Mato Grosso, and other regions in smaller quantities.

With the discovery of gold, the economy shifted from the sugar cane plantations on the coast to the mining regions of the interior. Several pathways were created to connect the mines with the population settlements on the coast. The mining economy demanded agricultural provisions and other goods from the coast, while the precious metals were transported back along the same roads, where the Crown collected taxes and controlled the flow of gold at certain checkpoints (Morais, 2010). The main transportation system was the *mule train*. The large-scale usage of mules was an important innovation in this period, lasting until the modern age and becoming obsolete only by new transportation technologies.[8] At the same time, fostered by the gold economy, a complementary cattle economy developed, connecting the interior regions to the coast, especially in the Northeast (Arraes, 2017). Thus, over time, the gold roads grew into a nationwide mule road system, especially after the 1830s when the number of pathways increased rapidly (Morais, 2010). Figure 1, Panel B displays a snapshot of the Brazilian urban distribution in 1872, which was connected by Mule roads.

The increasing inter-regional flow of people, cattle, and mule-train commodities created a new type of population settlement: *the road town*. These new settlements, born out of roads, are more numerous and more widespread than before, representing a new urban configuration. While the estate-based settlement was dispersed without a discernible urban center, the road town featured a main street with shops, cattle ranches, fairs, inns, and hotels. Naturally, the road towns attracted a different type of settler than the agriculture-based towns, such as craftsmen, workmen, merchants, and innkeepers, resulting also in a different mix of initial population (Deffontaines, 1938; Morse, 1974).[9]

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[8]The mule—a hybrid animal resulting from the crossing of a donkey with a mare—proved an excellent option to trail irregular pathways: stable, resistant to climatic, and elevation variations (Borges, 2016). Over long distances, it was more resilient and faster than horses. Relative to enslaved porters, the mule was faster, traveling three to four leagues a day, and had a load capacity of three to five times greater. Mules also had more advantageous biological characteristics for transport than other animal species, requiring less water and being more energy-efficient. The mules were first brought from the mining regions of the Spanish Empire and later raised on farms in the far south of Brazil, then transported by land to the interior of São Paulo, where they would be traded in large livestock markets. From 1730 to 1875, mule troops dominated long-distance inland transport in Brazil, and their contribution to the country's economic development is recognized by several scholars (Milet, 1881; Silva, 1947; Goulart, 1959; Furtado, 1968; Klein, 1990; Summerhill, 1997; Abreu, 1998; Suprinyak, 2008).

[9]Deffontaines (1938) also argues that the road towns are more stable than the mine towns themselves, because "mining colonization left only a devastated country strewn with dead or lethargic towns."

The problem, however, of high transportation costs did not change; what changed and enabled the settlement of the hinterlands in the 18th century was the high value to weight of gold and precious minerals, which then implied negligible transportation costs for commodity outflows but not for the inflow of goods for the local populations. For instance, prohibitive transportation costs would often lead to speculative crisis in the supply of foodstuffs: The prices of foodstuffs in Ouro Preto, the mining center, were 10 to 30 times higher than in São Paulo in the beginning of the 18th century (Reis, 2023). The new road towns were not woven into commercial networks with one another or within a functional urban hierarchy. The mule roads linked each town independently to the provincial capital or the county (*comarca*) seat and even the county seats had a short commercial radius. This is because usually the mule roads were the "highways" of the time, connecting the county seats and provincial capitals, while the road towns would emerge within this hierarchy of cities (Morse, 1974).

With the depletion of gold towards the end of the 18th century, the problem of high transportation costs became more salient and it is often said that Brazil evolved into an archipelago of self-sufficient islands without integration (*e.g.* Deutsch (1996)). During the second half of the 19th century and the early 20th century, the Brazilian central government promoted a railroad system, yet it was not successful in promoting national integration. Simonsen (1977) highlights that, even at the time of his original writings in 1937, mules continued to play a vital role in connecting cities across Brazil, although the freight rates of mule troops were on the order of three to eight times higher than the freight rates of railroads in the period between 1860 and 1915, as shown in Reis (2023).

In 1951, the central government began to prioritize roads for motorized vehicles as the primary national integration strategy, but with a significant expansion only in the second half of the 1960s and in the 1970s. The expansion of paved roads and highways has minimal overlap with the gold and mule roads, only in places which would clearly be the best path for any mode of transportation, but overall they were not on paths suitable for modern transportation. Even the "royal road," the most famous of the historical pathways, which connected the mine regions in Minas Gerais to the court in Rio de Janeiro, today has minimal overlap with paved roads: Only 20% of it is paved, while 74% are dirt roads and 6% are trails.[10] In Panel C of Figure 1, we show the distribution of municipalities in 2010, when the gold and mule roads became obsolete technologies and were substituted by the highway system.

The history described above summarizes the introduction of primitive transport infrastructure in unpopulated areas due to the discovery of gold. The gold and mule roads served as the primary means for the flow of people in the Brazilian hinterland until the early 20th century, although, as shown below, no economic advantage would come from their presence in the short run, likely due to high transportation costs as we described in this section. As a testament to the prohibitively high transportation costs of gold and mule roads, Brazil never developed long-distance wheeled transportation until railroads were built. The evidence presented in this paper suggests instead that it was the contribution of the road towns to population settlement, with their distinct urban configuration and initial mix of settlers, the main mechanism which led to a long-run equilibrium with higher population density in regions where the gold and mule roads used to exist.

3 Pathways of the colony: Gold roads

We start by investigating the gold roads that interconnected the first gold regions, discovered around 1700, and the initial population settlements along Brazil's coastline. Information about the routes taken by these roads was georeferenced from Simonsen (1977), and the resulting map is displayed in Figure 2, Panel A. We conduct the study at the municipality level, assessing the impact of gold roads on local economies using road density, defined as the area spanning five kilometers around roads within a municipality over the municipality's area. Figure 2, Panel B illustrates the gold road density in municipalities traversed by gold roads and neighboring areas. For a detailed explanation of variable construction and the procedures involved in creating the georeferenced dataset used in this section, refer to Appendix B.1.

[10] We consider a total of 1,780 kilometers of the *caminhos novo*, *velho*, *diamante*, and *sabarabuçu*. See https://institutoestradareal.com.br/en/ for maps and pictures.

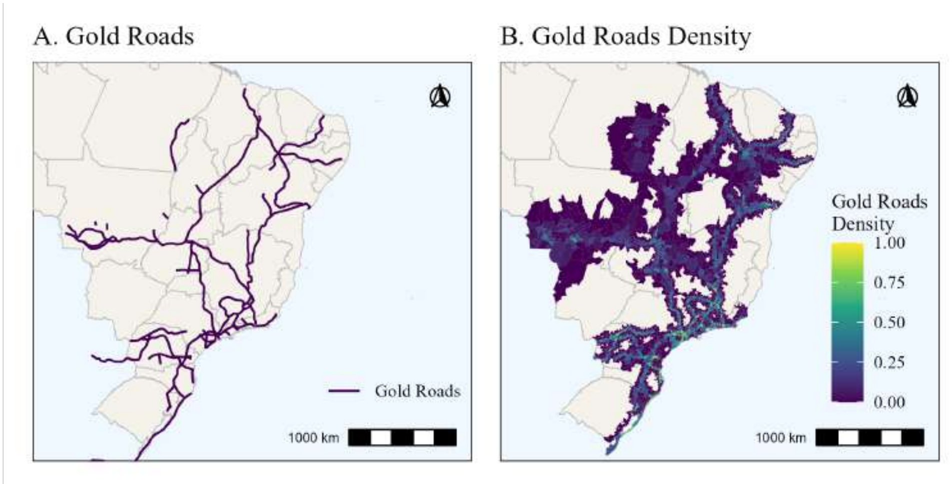

Figure 2: Gold Roads and their Densities in 2010 Municipalities

Notes: Panel A depicts the georeferenced Gold roads from Simonsen (1977). Panel B depicts the spatial distribution of Gold road densities.

We model the relationship between gold roads and economic activity using the following linear regression equation:

$$y_i = \alpha_s + \beta \text{Road Density}_i + \mathbf{X}_i' \boldsymbol{\gamma} + \epsilon_i, \tag{1}$$

where y_i represents a measure of agglomerations at municipality i in 2010. Specifically, y_i denotes population density, nightlight incidence, or urban population density. The variable Road Density_i captures the influence of gold roads measured as road density. The column vector $\mathbf{X}_i$ contains additional geographical covariates, α_s represents the fixed effects for state s, and ϵ_i denotes the error term.

A simple Ordinary Least Squares (OLS) interpretation of the β coefficient using a full sample of municipalities would be biased due to traditional problems such as omitted variables, reverse causality, and measurement error: there could be omitted variables influencing both the decision to create roads and the initial placement of population settlements. Additionally, initial population settlements could drive road placement, and since population settlements tend to be persistent, they would correlate with current settlements, leading to reverse causality. Moreover, there is likely some degree of measurement error in the georeferenced map.

To solve these problems and ensure a causal interpretation of β, we combine an instrumental variables approach with least-cost paths and a variant of the inconsequential units approach (Redding and Turner, 2015), restricting the sample to exclude end points where there were already pre-established population settlements and include only the municipalities traversed by gold roads and their neighbors. The optimal least-cost path strategy uses the exogenous variation in the topography of a region to create the instrument and is not affected by the existing economy. In addition, we remove the pre-existing settlements along the roads, making the remaining areas *inconsequential* for the choice of the route and will be traversed only because they lie on a convenient path. We also exclude municipalities that existed before 1700—even if not traversed by the road—in the form of cities, towns, or villages to ensure we are not selecting on pre-existing population settlements.[11] As shown in Figure 1, in 1700, practically all cities and towns were located by the coast, and none yet existed in the interior along the gold roads. In addition, looking at regions traversed by the gold roads and their adjacent neighbors ensures comparability among geographically similar areas, and we exclude northern-state municipalities in the Amazon Forest where the Amazon basin plays a significant transportation role and was still mostly unexplored. We also control for observable geography and climate (temperature, precipitation, elevation, ruggedness, distance to the coast, distance to rivers, and a latitude-longitude polynomial) which likely affected the choice of the path and ensure the least-cost paths are capturing only the topography relevant to the paths, conditional on the overall elevation and ruggedness of the region.

The sample comprises 2,092 observations, with population density ranging from 0.23 to 12,998 individuals per square kilometer and colonial road density varying

[11] This means we drop a location even if it was not yet emancipated to the category of the municipality by 1700 and existed only in the form of a town or village within another municipality. While it is conceivable that some routes were constructed after the discovery of mines, we provide separate results for the *caminho velho* in Appendix J, where historical accounts support that the road was built before the population settlements in between. In this case, the OLS estimates are similar to the Two-Stage Least Squares estimates, suggesting minimal bias from OLS estimates. Moreover, estimated coefficients in Table J.2 are somewhat close to the estimates presented in Table 1 in this section.

from zero to one. On average, municipalities exhibit a gold road density of 14%. Detailed descriptive statistics are provided in Table B.1 in Appendix B.2.

The main results are displayed in Table 1. Panel A presents the Two-Stage Least Squares (2SLS) estimates with population density as the variable of interest. Panel B shows the 2SLS estimates with nightlight incidence as the dependent variable, and Panel C pertains to urban population density. All dependent variables are presented in logarithmic form. In Column (1), we present a simple 2SLS estimation without covariates or fixed effects. Moving to Column (2), state fixed effects are added to the model. In Column (3), geographic controls are included, and in Column (4), a second-order polynomial of latitude and longitude is added. Standard errors are clustered at 1872 minimum comparable areas (1872 MCAs) as defined by Reis, Pimentel, Alvarenga and Santos (2011) to address spatial correlation between units. 1872 MCAs are areas with stable boundaries associated with 1872 municipalities, which groups geographical locations in 2010 that previously shared common administrative borders.

Overall, the findings suggest a positive association between access to gold roads and population concentration, as indicated by population density, nightlights, and urban population density. While the effect somewhat diminishes with the inclusion of state fixed effects and geographic controls, the results remain statistically and economically significant. Based on the specification in Column (4), an increase of ten percentage points in road density corresponds to a 20% increase in population density, a 14% increase in nightlight incidence, and a 23.4% increase in urban population density.

As our model is just identified, the Kleibergen-Paap F statistic is equivalent to the effective first-stage F statistic proposed by Montiel-Olea and Pflueger (2013). In Table 1, we observe that our F statistic far exceeds the critical value (37.42) associated with a 5% 2SLS bias (Montiel-Olea and Pflueger, 2013). Hence, we can confidently employ the conventional 2SLS method without concerns about a weak instrument problem, as highlighted by Andrews, Stock and Sun (2019).

Moreover, the bias introduced by the OLS estimation is significant and underestimates the effect of historical roads. OLS estimates equivalent to the specification in Column (4), panels A, B, and C, respectively, are 0.89 (0.21), 0.52 (0.12), and

Table 1: Gold roads and current population density

	(1)	(2)	(3)	(4)
Panel A - Dep. Var.: Population Density:				
Gold Road Density	5.27***	3.62***	1.97***	2.01***
	(0.954)	(0.747)	(0.602)	(0.632)
Observations	2,092	2,092	2,092	2,092
Cluster Groups	260	260	260	260
Panel B - Dep. Var.: Nightlights:				
Gold Road Density	4.32***	2.65***	1.45***	1.40***
	(0.519)	(0.392)	(0.386)	(0.412)
Observations	2,092	2,092	2,092	2,092
Cluster Groups	260	260	260	260
Panel C - Dep. Var.: Urban Population Density				
Gold Road Density	6.03***	4.12***	2.34***	2.34***
	(1.04)	(0.805)	(0.665)	(0.699)
Observations	2,091	2,091	2,091	2,091
Cluster Groups	260	260	260	260
Kleibergen-Paap F:	83.159	87.724	82.966	82.869
Fixed-Effects:		State	State	State
Geography Controls			✓	✓
Lati-Longi Polynomial:				✓

Notes: Standard errors clustered at the level of 1872 Minimum Comparable Areas in parentheses. Geography variables are the ones presented in Table B.1. Lati-Longi Polynomial refers to a second-order latitude-longitude polynomial. The sample excludes municipalities that already existed in 1700. $^{*}p < 0.1, ^{**}p < 0.05, ^{***}p < 0.01$

1.05 (0.23), with clustered standard errors in parentheses. The larger IV estimates compared to the OLS estimates might indicate the presence of measurement error in the historical map we used to build the gold roads, explaining the downward bias in the OLS results. Given that our instrument captures the relevant topographical features, it is likely that measurement error on the digitized gold roads leads to the naive OLS estimates understating the true impact of the roads.

Robustness analysis In Appendix D, we demonstrate the robustness of our results through various extensions and alternative specifications. Specifically, we show that the results remain unchanged when we extend the sample to include all municipalities (not only neighbors but still excluding historical cities) and when we reduce the sample to exclude municipalities where the seat is located within 100 kilometers from the coast. The latter case addresses concerns that the dynamics of coastal cities, which were the main population settlements before 1700, may drive our results. In this scenario, estimates are smaller but still statistically and economically significant. We also demonstrate that our results are robust when using the inverse hyperbolic sine transformation in our variable of interest. This transformation alleviates concerns related to the right-skewness of road density, which may include zero-valued observations.

Moreover, the effect remains positive and significant when our explanatory variable indicates whether road density is positive. Again, this mitigates concerns about the choice of measures for gold roads.[12] The results are similar but somewhat weaker within 1872 MCAs. We acknowledge there can be a potential presence of spatial correlation among the units. Thus, we also calculate spatially robust standard errors (Conley, 1999). Importantly, Conley standard errors are similar to the ones clustered at the level of 1872 MCAs, suggesting that clustered standard errors at this level already accounts for spatial correlation.

[12]One point of concern may be that a large gold road density reflects more rugged terrain, leading to spurious interpretations. Although we control for terrain ruggedness, it is essential to show that the effects are still positive when using this alternative measure of gold road influence.

4 Pathways of the empire: Mule roads

In this section, we broaden our analysis to incorporate information on *all documented connections* between municipality pairs in 1872 (the year of the first national census). With this nationwide exercise, we address the possibility that our previous findings may only apply to some contexts or maybe contingent on some specific characteristic, as our focus was solely on a specific set of historical roads and regions associated with the gold rush during the colonial period in Brazil. We expand the scope of our analysis to encompass the entire transportation network in the late 19th century, covering a larger geographical area.

The data used in this analysis come from manuscripts and official documents issued by the Brazilian imperial government in 1863 and 1873 (see Appendix A for the sources). These documents contain information regarding distances between municipality pairs traveled primarily by ground transportation, where mules were predominant. Consequently, we refer to this network of routes as "mule roads."[13] As the precise routes taken are not specified in the documents, but only the actual distance traveled between municipality pairs, we construct the least-cost paths for all the municipality-pair connections that appear in the documents. In this regard, our estimates are analogous to the reduced-form estimates of a 2SLS approach if we had access to the exact paths as in a map. For a comprehensive account of the data construction, including the data sources, consult Appendix B.

Although a direct comparison between the estimated and actual pathways is not possible, we can assess the accuracy of our estimated pathways by examining the information on the distance traveled along each route. Figure 3 Panel A depicts the relationship between effective distances and estimated distances. It is evident that our estimates closely align with the 45-degree line. To further evaluate the goodness of fit, we calculate the coefficient of determination, denoted as $R^2 = 1 - \frac{\sum_i (x_i - y_i)^2}{\sum_i (y_i - \bar{y})^2}$, where x_i represents the estimated distance of pathway i, y_i represents the effective distance, and $\bar{y}$ denotes the mean value of y_i. The calculated R^2 value of 92%

[13] Some of the municipality-pair connections were reported in a report by the imperial government's Post Office. We do not find any differences in the main regressions if we add an indicator for the roads that were official mail routes.

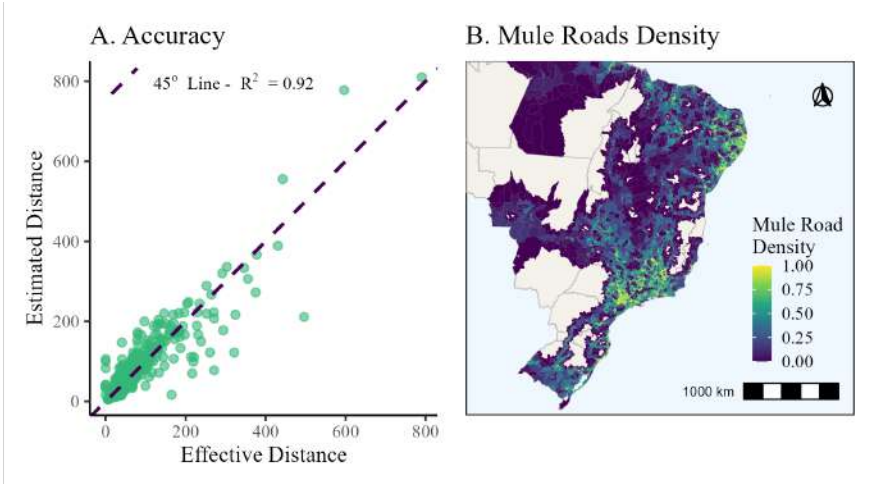

Figure 3: Mule Road

Notes: Panel A compares the estimated distances using our constructed least-coast path and the effective distance reported in historical documents. The measure of goodness of fit is defined as $R^2 = 1 - \frac{\sum_i (x_i - y_i)^2}{\sum_i (y_i - \bar{y})^2}$. Panel B depicts the density of Mule roads per 2010 municipalities.

indicates that only 8% of the variance in the effective distances remains unexplained by the variance in the estimated distances.

Table 2 provides further insights into the relationship between the two analyses, revealing a robust and positive association between the gold roads and the broader mule transportation network. This finding shows that the gold pathways are intimately connected to the extensive historical mule road network and population settlement dynamics that evolved over two centuries, as we suggested in Section 2.

We assume a linear relationship between a dependent variable y and the density of pathways, akin to Equation (1). Once again, y_i represents the logarithm transformation of either population density, nightlight incidence, or urban population density. Our strategy is exactly the same as described in Section 3, with an inconsequential units approach with additional sample restriction and geographical covariates. Our primary sample consists of municipalities intersected by mule roads and their immediate neighboring municipalities, as depicted in Figure 3 Panel B. In this case, we also exclude municipalities that already existed up to 1872, instead of only up to 1700, as with the gold roads.

Table 2: Gold roads and mule roads

	(1)	(2)	(3)	(4)
Dep. Var.: Mule Road Density				
Gold Road Density	1.42***	1.25***	1.21***	1.18***
	(0.180)	(0.133)	(0.148)	(0.154)
Observations	2,092	2,092	2,092	2,092
Cluster Groups	260	260	260	260
Kleibergen-Paap F:	83.159	87.724	82.966	82.869
Fixed-Effects:		State	State	State
Geography Controls			✓	✓
Lati-Longi Polynomial:				✓

Notes: Standard errors clustered at the level of 1872 Minimum Comparable Areas in parentheses. Geography variables are the ones presented in Table B.1. Lati-Longi Polynomial refers to a second-order latitude-longitude polynomial. The sample excludes municipalities that already existed in 1700. $^{*}p < 0.1, ^{**}p < 0.05, ^{***}p < 0.01$

We present the estimated coefficients in Table 3. Standard errors are clustered at the 1872 MCA level for all columns. Column (1) shows the OLS estimates of β. Column (2) reports the fixed effect estimate of β without controls. Column (3) adds the geographic covariates, and Column (4) includes a second-order latitude-longitude polynomial. Consistent with the previous section, Panel A reveals a positive relationship between mule roads and population density. Panels B and C reach similar conclusions when nightlights and urban population density are the dependent variables, respectively.

Although the coefficients are significantly smaller than in the previous analysis, the two analyses are not directly comparable as Table 3 shows the effect of least-cost path densities rather than actual road densities. When we compare the coefficients in Table 3 with the reduced-form coefficients from the Gold road analysis, we find similar numbers, with the Gold road coefficients being slightly larger.[14] The combined results of the gold and mule roads experiments provide strong evidence of

[14]Using least-cost paths for gold roads, the coefficients equivalent to the ones in Column (4) for panels A, B, and C are 0.626 (0.197), 0.435 (0.13), and 0.726 (0.22), respectively, with standard errors in parentheses.

Table 3: Mule roads and population density

	(1)	(2)	(3)	(4)
Panel A - Dep. Var.: Population Density:				
Mule Road Density	1.91***	1.28***	0.453***	0.425***
	(0.221)	(0.118)	(0.083)	(0.082)
Observations	3,347	3,347	3,347	3,347
Cluster Groups	367	367	367	367
Panel B - Dep. Var.: Nightlights:				
Mule Road Density	1.64***	1.18***	0.533***	0.468***
	(0.138)	(0.109)	(0.083)	(0.084)
Observations	3,347	3,347	3,347	3,347
Cluster Groups	367	367	367	367
Panel C - Dep. Var.: Urban Population Density				
Mule Road Density	2.22***	1.51***	0.597***	0.549***
	(0.226)	(0.134)	(0.099)	(0.099)
Observations	3,346	3,346	3,346	3,346
Cluster Groups	367	367	367	367
Fixed-Effects:		State	State	State
Geography Controls			✓	✓
Lati-Longi Polynomial:				✓

Notes: Standard errors clustered at the level of 1872 Minimum Comparable Areas in parentheses. Geography variables are the ones presented in Table B.1. Lati-Longi Polynomial refers to a second-order latitude-longitude polynomial. The sample excludes municipalities that already existed in 1872. $^{*}p < 0.1, ^{**}p < 0.05, ^{***}p < 0.01$

a positive relationship between historical pathways and the spatial distribution of population density and urban population.

In the online appendix, we expand the Mule Roads analysis in several directions. First, we show that our results are robust to expected Mule Road density based on the centrality of municipalities, following the approach of Borusyak and Hull (2023). Next, we perform a placebo analysis to test whether connections that did not have official roads have positive effects on current population density. We find that this is not the case, dismissing the possibility that our results are solely driven by the construction of least-cost path connections between previously developed areas. Finally, we demonstrate that Mule Roads are positively associated with population density within municipalities in grid-level regressions. This result also holds true for the Gold Roads analysis.

5 Short- and long-run dynamics

In the previous sections, we established a robust causal relationship between the gold and mule roads and current population density. In this section, we look into the short- and long-run dynamics of population and investigate forms of location-specific capital.

5.1 Short-run factor densities

As a first step, we use the earliest available census data to study the short-run effects of the historical pathways on population density. We also investigate whether historical pathways are related to early investments in durable capital, as investments that may not yet have depreciated could be a key factor underlying the association between historical pathways and population density in the long run. Examples of sunk capital include human capital, the development of railroads, schools, factories, and other infrastructure.

In what follows, we focus on the gold roads because, in this case, we know the actual paths traversed, allowing for a two-stage least square estimation. Analogous results for the mule roads are presented in Appendix G and are similar to the gold roads. The units of observation for this analysis are 1920 MCAs. In Appendix B, we show a map with the density of the roads according to the 1920–2010 MCA consistent-boundary division. It is noteworthy that these areas are significantly larger than the areas analyzed in the previous sections. Thus, although we still keep only areas traversed by roads and their immediate neighbors, the sample covers a larger part of the Brazilian territory. It is reassuring that the estimates using 1920 MCAs as observation units are similar to the ones in Table 1 (compared with the first column of Panel B in Table 4).[15]

[15] The necessity of consistent boundaries is the reason why we do not carry out the analysis using the 1872 census. In this case, 1872–2010 consistent boundaries give too few MCAs to arrive at meaningful results.

We modify the regression model Equation (1) by replacing the dependent variable y_i with the density of historical factors in 1920. In this analysis, we control for geographic variables, including a second-order latitude and longitude polynomial, and exclude municipalities that existed already in 1700. The historical factors we consider as proxies for investments in sunk capital are railroad stations, railroad length, literate men, teachers, and workers in the agriculture, manufacturing, services, and transportation sectors. All measures are divided by the area to capture the density of these quantities in a given region. Literate men, workers in agriculture, workers in manufacturing, and workers in services, whose observations do not contain zeros, are transformed using the logarithm. We transform the other variables using the inverse hyperbolic sine.[16]

The estimated effects of gold roads on historical factors are shown in Table 4. We employ a 2SLS estimation, using least-cost paths as an instrument for the gold roads. In all estimates, the Kleibergen-Paap F statistic stays around 40. Panel A of Table 4 presents the marginal effects of gold roads on various historical factors in 1920. Column (2) shows the effects on population density in 1920. The estimated coefficient is approximately zero and statistically insignificant. The coefficients associated with railroads and human capital are positive but small and statistically insignificant. With respect to workers' density columns, the coefficients are also statistically insignificant, but in a direction consistent with the history of road towns outlined in Section 2. Places with gold roads have an initial mix of working population which is less agricultural and more related to the manufacturing and services sector, but still with no significant investments to achieve disproportionately larger sectors.

[16]We rescale all variables x using the inverse hyperbolic sine so that $\bar{x}/\sqrt{\bar{x}^2+1}$ is close to one, where $\bar{x}$ is the average of x. Thus, we can interpret the coefficients as semi-elasticities (Bellemare and Wichman, 2020).

Table 4: Gold roads and factor densities in 1920

	Baseline	Popul.	Stations	Railroad	Literate	Teachers	Agric	Manuf.	Services	Transp.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Panel A - Dependent Variable: Factor Densities / Kleibergen-Paap F: 40.1										
Gold Road Density		-0.217	1.38	0.972	0.119	0.788	-0.671	0.594	0.546	0.430
		(0.450)	(2.13)	(1.86)	(0.459)	(0.660)	(0.466)	(0.660)	(0.537)	(0.857)
Panel B - Dependent Variable: log(Population Density)										
Gold Road Density	2.17***	2.34***	2.03***	2.07***	2.08***	1.80***	2.62***	1.91***	1.84***	2.04***
	(0.795)	(0.643)	(0.747)	(0.759)	(0.633)	(0.664)	(0.673)	(0.672)	(0.644)	(0.725)
Factor Density		0.7698***	0.101***	0.103***	0.725***	0.474***	0.679***	0.438***	0.607***	0.302***
		(0.0715)	(0.017)	(0.017)	(0.063)	(0.056)	(0.077)	(0.044)	(0.049)	(0.034)
Kleibergen-Paap F:	40.984	41.110	39.999	40.440	41.027	40.879	40.661	40.922	40.723	41.257
Observations	620	620	620	620	620	620	620	620	620	620

Notes: 2SLS estimates using least-cost paths as an instrument. Robust standard errors in parentheses. Dependent variables in Panel A and Factor Densities in Panel B are the log of quantities over area, except in columns (3), (4), (6), and (10) where it is the inverse hyperbolic sine of quantities over area. All columns control for state fixed effects, geography variables presented in Table B.1, a latitude-longitude second-order polynomial, and exclude MCAs that already existed in 1700. $^{*}p < 0.1, ^{**}p < 0.05, ^{***}p < 0.01$

In Panel B, we examine the relationship between gold roads and current population density while controlling for the historical factor density in each column. If the historical factors are mediating the effects between gold roads and current population density, controlling for these factors should result in significant reductions in the direct marginal effect of the gold roads on current variables. We observe that, while the factor density coefficients are positive and significant, the gold road coefficient is highly stable and virtually unaffected in relation to the baseline by the inclusion of any of the historical factors.

In general, the results presented in this section show that there is no relationship between the gold roads and population density in the initial years of the past century, suggesting that these roads did not translate into economic development in early periods. These findings are consistent with the Brazilian historiography discussed in Section 2 which supports the idea that the gold and mule roads were mainly for the flow of people and not the flow of goods due to extremely high transportation costs. We also find no support for the sunk investments hypothesis since areas with higher gold road densities are not disproportionately associated with higher investments in early infrastructure or human capital. Nonetheless, there seems to exist a positive relationship between the non-agricultural composition of the initial working population in areas with gold road density, supporting the idea of road towns discussed in Section 2.

5.2 Long-run factor densities

Now, we shift our focus to the long-run dynamics of population, aiming to understand how historical roads affected population density, population growth, migration, urbanization, workforce composition, and the evolution of modern transportation densities. The hypothesis that the gold and mule road effects are mediated through modern transportation such as paved roads, highways, and railroads is valid given that it is plausible that historical roads could have paved the way for railroads or modern roads, as exemplified by the indigenous *Peabirú* trails in southern Brazil detailed in Barsanetti (2021).

In this analysis, we utilize all censuses from 1940 to 2010 and estimate Equation (1) using the density of least-cost paths as the instrumental variable for gold road density. Once again, 1920–2010 MCAs are the unit of observation to allow for comparability over time, and the usual sample restrictions apply. In the figures below, we present summarized results, while the full tables are provided in Appendix F. Results for the mule roads are similar and available in Appendix G.

Panel A in Figure 4 illustrates the impact of gold roads on population density across different years from 1940 to 2010. Notably, there's negligible effect in 1940, consistent with the null finding observed in 1920 as discussed in Table 4. However, the influence gradually intensifies from 1950 onwards, reaching a peak around 1990 before stabilizing by 2010. This trend differs from what one might expect from persistent historical events, where significant effects would gradually diminish over time.

The increasing effect on population density stems from higher population growth rates, as depicted in Panel B. A higher density of gold roads is associated with accelerated population growth, particularly during the decades between 1940 and 1970.[17] To gain deeper insights into this trend, we examine the effects of gold roads on net migration, which is measured as the difference between population growth and the natural rate of increase, itself calculated as the difference between crude birth rates and crude death rates. Unfortunately, we can only construct this variable starting from the 1970 census. However, across all years, the effect on net migration mirrors that of population growth, suggesting that the majority of population growth is due to in-migration. Indeed, if we use the natural rate of increase (crude birth rates minus crude death rates) as the dependent variable, the coefficients associated with gold road density are positive and significant but close to zero, ranging from 0.002 to 0.013. Although we can only speculate about the effect on net migration before 1970, given the pattern observed from 1970 to 2010, it is plausible that in-migration drove population growth from 1940 to 1960.

Panel C in Figure 4 illustrates the effects on the change in urbanization rates, controlling for the initial urbanization rate. There is a substantial positive effect in the 1960s and 1970s, whereas in other years, the coefficients are approximately zero, suggesting that gold roads are associated with faster urbanization rates during these decades. Finally, Panel D in Figure 4 depicts the effect of gold roads on the

[17] These regression models also include controls for initial population density.

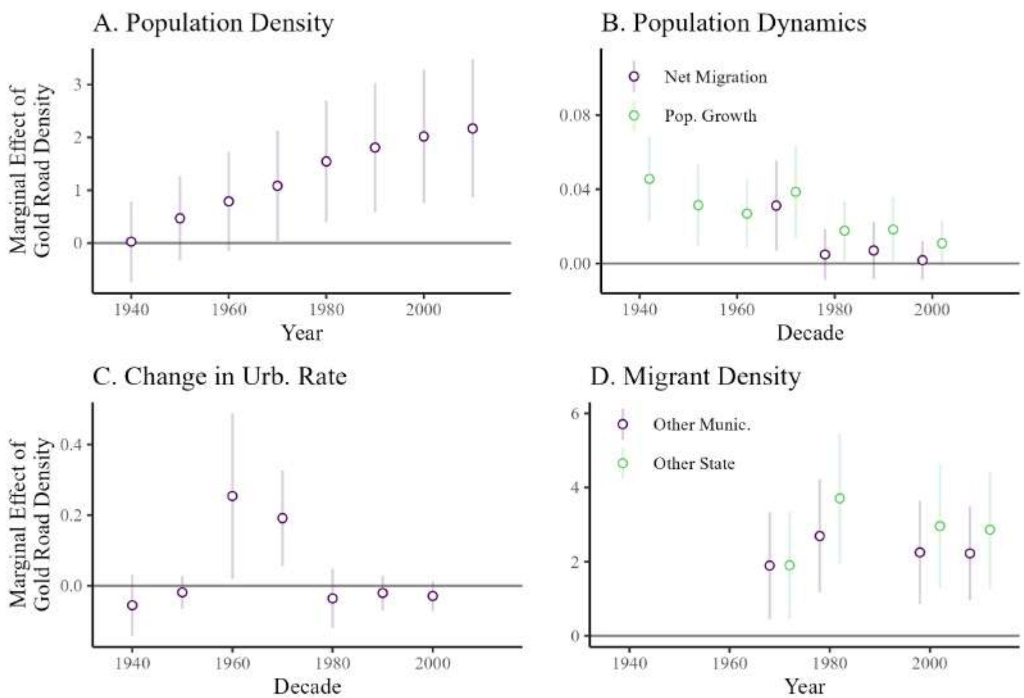

Figure 4: Population dynamics

Notes: The figure above illustrates the marginal effects of gold roads on the dynamics of population across different years. Population density and migrant densities represent measures of stock, referring to the year indicated on the horizontal axis. There are two measures of migrants: individuals who moved from another municipality per squared kilometer and individuals who moved from another state per squared kilometer. Population growth, net migration, and the change in urbanization rate are measures of flow, referring to the decade starting from the year on the horizontal axis. Net migration is computed as the difference between population growth and the natural rate of increase (crude birth rate minus crude death rates) using census information. All estimates control for geography, a second-order latitude-longitude polynomial, and state fixed effects. In the case of flow variables, we also control for initial population density in Panel B and initial urbanization rate in Panel C. Circles represent point estimates, and the lines denote 95% robust confidence intervals. Exact values are displayed in Table F.9.

stock of migrants. Specifically, we quantify the number of migrants as individuals who were not born in the municipality and moved from either another municipality or another state. The figure reveals that the effects on both variables are consistently positive, with little difference between them. Additionally, a specific question in the 1970 census allows us to identify whether the person had migrated from a rural or urban area. The coefficients presented in Table F.9 of the Appendix show that the coefficients are positive in both cases, but the effect on migration from other urban areas is larger. Taken together, we interpret these results as indications that the positive increasing effects on population density were driven by deferentially higher effects on in-migration rates, accompanied by increasing urbanization rates.

Moreover, the combination of Panel A and Panel B in Figure 4 rules out migration frictions as the driver of our results. If that were the case, larger gold road densities would likely be associated with higher population density initially, as subsequent increases in density could indicate limitations in people's ability to move out. However, population density is not initially higher in areas with more gold road density, indicating that people likely have the ability to move out given their ability to move in, as shown.

In Figure 5, we turn our attention to the workforce composition, which also provides a picture of the structural transformation of local economies in the 20th century. The effect of gold roads on the density of agricultural workers is always negative and statistically significant, while the effect on the density of manufacturing workers is large and positive in the first two decades, approximately zero in the following three decades, and negative in the last two decades. The effect on service worker density is positive in the first three decades and, with the exception of a negative drop in 1970, is approximately zero in the following decades. In all regression models, we control for population density. In general, these results highlight the different sectoral compositions of the economies influenced by the historical pathways, reflecting the characteristics of the road towns previously outlined.

In Figure 6, we show the effect of the gold roads on modern transportation density. Panels A and B show that the effect on railroad and station density is

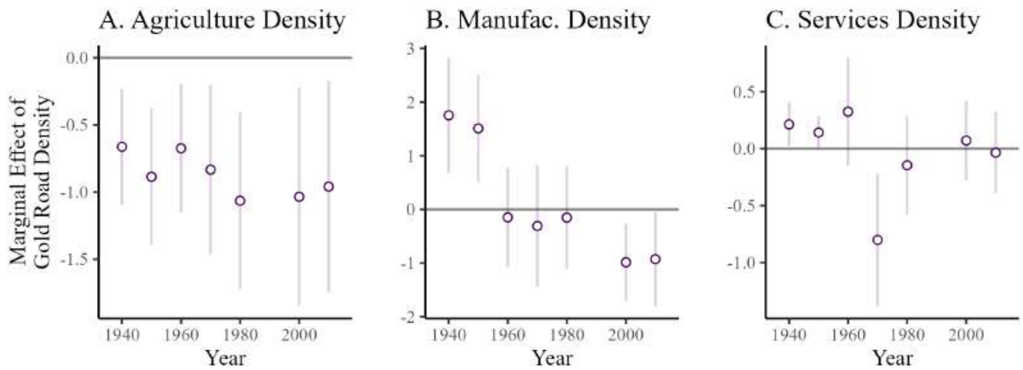

Figure 5: Sector density

Notes: Marginal effects of gold roads on sector density in different years. All densities are measured as the number of workers in a sector per municipality area. The dependent variables are log-transformed in all cases. We exclude the 1991 census due to a significantly smaller number of observations. All estimates control for geography, a second-order latitude-longitude polynomial, state fixed effects, and the logarithm of population density in that year. Circles represent point estimates, and the lines indicate 95% robust confidence intervals. Exact values are displayed in Table F.10. Sectors conform to the International Standard Industrial Classification following Ruggles et al. (2024), see Appendix B.1 for details.

approximately zero in all years.[18] Panel C shows, however, that there is an effect on paved roads only in 1960. This decade marks the beginning of the expansion of paved road infrastructure in Brazil, which was initially heavily concentrated in the state of São Paulo (see Reis (2014), for example). The gold roads display a high degree of density São Paulo, as shown in the Panel B of Figure 2, which could account for the effect in this decade, while in the following decades the expansion of the paved road and highway system did not bear any correlation with the paths of the gold roads.[19]

To summarize, the general patterns presented in this section are more consistent with a theory wherein areas with larger gold and mule road density converge to a new long-run equilibrium characterized by higher population density, increased urbanization rates, and a increased reliance on non-agricultural workers. This pattern

[18]For mule roads, however, Tables G.1 and G.4 of the Appendix show in all years a positive effect on railroads, which we take into account in the next section.

[19]The same argument is valid for the effects of mule roads on paved roads and highways shown in Table G.5 of the Appendix.

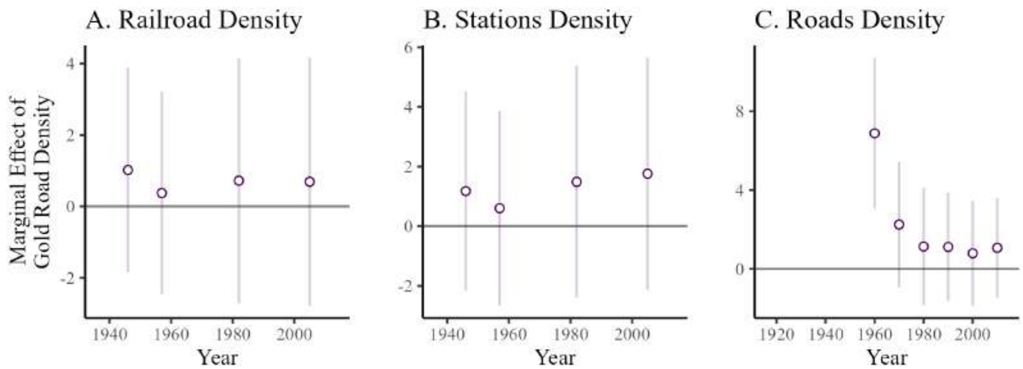

Figure 6: Modern transportation density

Notes: Marginal effects of gold roads on modern transportation infrastructure across different years. Railroad and road densities refer to the area within a 5-kilometer radius from the pathway over the total municipality area. Station density represents the number of train stations per municipality area. In all cases, we apply the inverse hyperbolic sine transformation to the dependent variables. All estimates control for geography, a second-order latitude-longitude polynomial, state fixed effects, and the logarithm of population density in that year. Circles represent point estimates, and the lines indicate 95% robust confidence intervals. For exact values, refer to Tables F.11 and F.12.

contradicts a theory positing that historical roads caused the persistence of these characteristics through short-run effects. Additionally, the influence of gold and mule roads primarily affects the population equilibrium rather than location-specific capital investments. While there is an association between historical roads and the development of modern transportation infrastructure, the effect is limited. Specifically, for gold roads, there is only a non-zero effect on paved roads and highways in 1960, likely resulting from the expansion of the system in the state of São Paulo, which shows as high density of both historical roads and modern transportation.

6 A model of economic geography with history dynamics

In this section, we provide additional evidence on the path-dependent nature of the population spatial distribution. We use the framework developed in Allen and Donaldson (2022) to model the long-run population dynamics and agglomeration forces. This enables us to distinguish whether the evolution of population in each locality is primarily driven by persistence and/or path dependence and how the population equilibrium of the system behaves.

The model bridges two traditional strands of literature in spatial economics: one focuses on path-dependent geographies, agglomeration forces, and forward-looking behavior but in low-dimensional settings (*e.g.* Krugman, 1991; Matsuyama, 1991; Rauch, 1993), while the other involves high-dimensional models with realistic geographies but often lacks both forward-looking agents and local agglomeration spillovers (*e.g.* Roback, 1982; Glaeser, 2008; Desmet, Nagy and Rossi-Hansberg, 2018). Most importantly, the model in Allen and Donaldson (2022) arrives at a labor supply and demand system that can be estimated in the Rosen-Roback-Glaeser spatial equilibrium tradition. In this setting, we can use the gold and mule roads as excluded instruments to estimate the agglomeration spillover coefficients. With the estimations of the agglomeration coefficients at hand, we can then interpret the evidence in light of the model's dynamic properties.

6.1 Model setup

Below, we present the features of the model and the equations that are important for our purposes. There are many regions indexed by i with exogenous time-varying productivity A_{it} and amenities fundamentals u_{it}, where t denotes time. Regions trade a homogeneous numeraire good produced using a linear production function with local labor as the single input represented by $Y_{it} = A_{it}L_{it}$, where L is the total working population. The key assumption is that the productivity term is composed of intrinsic productivity $\bar{A}_{it}$ and agglomeration spillovers such that $A_{it} = \bar{A}_{it}L_t^{\alpha_1}L_{t-1}^{\alpha_2}$, where α_1 and α_2 denote the strength of contemporaneous and historical productivity spillovers. Since firms pay workers their marginal product, the log of the inverse labor demand equation is

$$\ln w_{it} = \alpha_1 \ln L_{it} + \alpha_2 \ln L_{i,t-1} + \ln \bar{A}_{it}, \tag{2}$$

where w_{it} denotes nominal and real wages.

Individuals in the model choose where to live based on idiosyncratic preferences drawn from a Fréchet distribution with a shape parameter $\theta > 1$, a proportional mobility cost $\mu \geqslant 1$, and the amenity-adjusted real wage $W_{it} = w_{it}u_{it}$. Similar to productivity, amenities are determined by the intrinsic amenity $\bar{u}_{it}$ and amenity spillovers such that $u_{it} = \bar{u}_{it}L_t^{\beta_1}L_{t-1}^{\beta_2}$, where β_1 and β_2 denote the strength of contemporaneous and historical amenity spillovers. Individuals' optimization yields the following log of inverse labor supply:

$$\ln w_{it} = \left(\frac{1}{\theta} - \beta_1\right)\ln L_{it} + (-\beta_2)\ln L_{i,t-1} + \frac{1}{\theta}\ln IMMA_{it} - \ln \bar{u}_{it}, \qquad (3)$$

where IMA_{it} is the "inward migration access," which is a function of mobility costs, historical population, and individual preferences over locations.[20]

6.2 Estimating agglomeration spillovers

Next, we use the gold and mule roads as instruments for population density in a regression on hourly wages to estimate the coefficient of agglomeration spillovers from labor demand (Equation (2)). The gold and mule roads can be thought of as excluded instruments, as we shown in previous sections that they plausibly affect the inward migration access term by influencing the flow of people but are excluded from the labor demand equation by not having an direct effect on the productivity of the regions. Since we only use one instrument at a time, we are estimating α_1 and α_2 together, which is irrelevant for our conclusions.[21]

Consistent with the literature (*e.g.*, Bleakley and Lin (2012); Chauvin et al. (2017)), we utilize individual-level census data on male workers aged between 25 and 65 years old and population density on the right-hand side. Hourly wages are set as the dependent variable, and we include individual-level and modern transportation controls (paved roads, highways, and railroads). Table 5 presents the estimated agglomeration coefficients for the 2SLS regressions, ranging from 0.05 to 0.10, depending on whether gold roads or mule roads are used as instruments. In Appendix H, we present similar results while controlling for contemporaneous paved

[20]Refer to Allen and Donaldson (2022) for details.

[21]The underlying assumption is that we are studying the steady state of the system, where $L_{it} = L_{ut+1}$ for all regions, such that the estimated coefficient is $\alpha_1 + \alpha_2$.

road and highway density to rule out the possibility that historical roads are influencing current population density through modern transportation infrastructure.

These estimates are consistent with the typical range found in the literature, which falls between 0.03 and 0.08 in the reviews by Rosenthal and Strange (2004) and Combes and Gobillon (2015), equals 0.09 in Bleakley and Lin (2012), and 0.15 in Allen and Donaldson (2020). However, our estimates are somewhat higher than those from other papers studying Brazil; for example, Chauvin et al. (2017) estimate it at 0.026, while Ehrl and Monasterio (2021) finds it equal to 0.01. One possible reason for our higher estimates is related to the instrument capturing the influence of road towns that were comparatively more likely to develop urban and non-agricultural agglomerations throughout the 20$^{\text{th}}$ century, which generated larger agglomeration effects in a country where historically the unit of settlement was dispersed agricultural estates.

6.3 Interpreting the evidence as path dependence

To analyze the dynamic properties of the model, we can rewrite Equations (2) and (3) with the population at time t and place i related to the population in the previous period and exogenous amenities, productivity, and mobility costs:

$$L_{it}^{1-\theta(\alpha_1+\beta_1)} = (\bar{A}_{it}\bar{u}_{it})^{\theta} \times L_{i,t-1}^{\theta(\alpha_2+\beta_2)} \times \sum_j \mu_{jit}^{-\theta} L_{j,t-1}. \tag{4}$$

Equation (4) stands as the central dynamic equilibrium relationship in the model. Given a trajectory for the exogenous fundamentals $\{A_{it}, u_{it}, \mu_{ijt}\}$, and the initial population distribution $\{L_{i0}\}$, this equation yields the dynamic path of population in all locations in any period.

At the steady state, both the exogenous and endogenous variables must be constant. Thus, Equation (4) yields $L_{it}^{1-\theta(\alpha_1+\beta_1+\alpha_2+\beta_2)} = \sum_j \mu_{ji}^{-\theta}(\bar{A}_i\bar{u}_i)^{\theta} L_j$, from which we can conclude that if the absolute value of $[1-\theta(\alpha_1+\beta_1+\alpha_2+\beta_2)]^{-1}$ is greater than one, there exist many geographies for which there are multiple steady states at each geography and consequently the possibility of path dependence, as stressed in Proposition 3 in Allen and Donaldson (2022).

Table 5: Population density and hourly wages

	Gold Roads		Mule Roads	
	(1)	(2)	(3)	(4)
Panel A - Dep. Var.: log(Hourly Wage 2010)				
log(Pop. Density 2010)	0.0667***	0.0609***	0.0644***	0.0502***
	(0.0126)	(0.0218)	(0.0071)	(0.0145)
Observations	4,354,596	4,354,596	1,827,946	1,827,946
Cluster Groups	620	620	422	422
Kleibergen-Paap F:	31.959	16.134	36.746	30.673
Panel B - Dep. Var.: log(Hourly Wage 2000)				
log(Pop. Density 2000)	0.0896***	0.0863***	0.0805***	0.0668***
	(0.0143)	(0.0215)	(0.0091)	(0.0153)
Observations	3,217,096	3,217,096	1,335,997	1,335,997
Cluster Groups	620	620	422	422
Kleibergen-Paap F:	40.344	14.495	53.148	45.832
Panel C - Dep. Var.: log(Hourly Wage 1980)				
log(Pop. Density 1980)	0.1049***	0.1035***	0.1017***	0.0660***
	(0.0156)	(0.0228)	(0.0121)	(0.0243)
Observations	2,414,501	2,414,501	961,316	961,316
Cluster Groups	614	614	421	421
Kleibergen-Paap F:	32.774	14.202	34.599	42.873
Fixed-Effects:	State	State	State	State
Individual Controls	✓	✓	✓	✓
Modern Transportation		✓		✓

Notes: Clustered standard errors at the 1920 MCA level in parentheses. 2SLS instruments population density using either gold road LCP or mule road LCP density. The sample excludes municipalities where historical cities were located. Individual controls include age, squared age, and indicators of race, sex, education attainment, marital status. Modern transportation refers to 1960 road densities in column (2) in all panels, and 1970 road density and 2005 (1982) railroad density in column (4), panels A and B (panel C). $^{*}p < 0.1, ^{**}p < 0.05, ^{***}p < 0.01$

Taking the logarithms of Equation (4), one can see the equilibrium relationship as an AR(1) process for the log population at each location, providing insights into persistence. The nature of the convergence process to the steady state is determined by the strength of the AR(1) coefficients for the endogenous population processes. If $(\alpha_1+\beta_1+\alpha_2+\beta_2) < \frac{1}{\theta}$, there is partial equilibrium convergence, where the speed of convergence of each location towards the steady state does not depend on the other locations, whereas if $\theta(\alpha_1+\beta_1+\alpha_2+\beta_2) < 0$, there is uniform convergence in the general equilibrium sense.

In Figure 7, we relate our estimates of agglomeration spillovers, $\alpha_1+\alpha_2$, to the qualitative implications outlined in the model. The estimated values in Table 5 yield a range for the agglomeration spillovers, varying from 0.05 to 0.10, depending on the year and whether gold roads or mule roads are used. Additionally, we require values for the amenity spillovers and the dispersion effect, which we derive from the literature. The contemporaneous amenity spillovers from housing, denoted by β_1, represent 15% of household expenditure in Brazil; thus, it is set to -0.15 (Chauvin et al., 2017). The historical amenity spillovers, which also stem from the housing stock and denoted by β_2, are assumed to remain relatively stable over the lagged period in the model, resulting in a value of 0.15.[22] The dispersion effect, or migration to wage elasticity, denoted by θ, is set to be 4 as in Allen and Donaldson (2020).

Given the parameter values discussed above, Figure 7 illustrates that plausible values of $[1-\theta(\alpha_1+\beta_1+\alpha_2+\beta_2)]^{-1}$ fall within the region characterized by possible multiple steady states, partial equilibrium convergence, and general equilibrium divergence. The intuition behind this observation is evident from Equation (4), where the current population is determined by the initial population and exogenous geography. The historical pathways determine the initial distribution and spatial configuration of the population, thereby setting the economy on the path towards the new steady state.[23]

[22] All our conclusions remain valid if one assumes an increase in the housing stock, for example, with $\beta_1=-0.26$ and $\beta_2=0.31$ as found for the United States in Allen and Donaldson (2020).

[23] The intuition for convergence in partial equilibrium and divergence in general equilibrium arises from our observation of convergence over time in the rate of population growth between places with and without pathway density. However, there is no uniform convergence because we cannot rule out

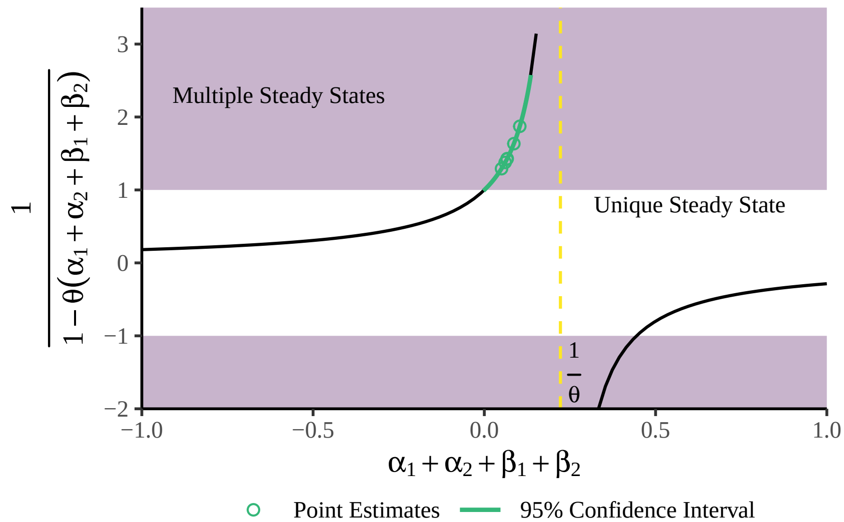

Figure 7: Steady states and convergence

Notes: Visual representation of Proposition 3 in Allen and Donaldson (2022) when $\theta = 4$. The shaded areas represent values of the term on the y-axis, $[1-\theta(\alpha_1+\beta_1+\alpha_2+\beta_2)]^{-1}$, greater than one, indicating the possibility of multiple steady states, while the white area indicates when this term is less than one, suggesting a unique steady state. Point estimates are the values of the term on the y-axis associated with the coefficients in Columns (2) and (4) of Table 5. Each coefficient represents $\alpha_1+\alpha_2$, and we assume $\beta_1+\beta_2=0$. Confidence intervals are computed using the delta method. The dashed line represents θ^{-1}. On the left of the dashed line are steady states with partial equilibrium convergence, and on the right are steady states with partial equilibrium divergence (historical persistence). The region with negative values on the x-axis indicates uniform convergence. While the dashed line does not represent the exact boundary between stable and unstable equilibria, extreme values to the right of the line tend to be associated with unstable equilibria.

We can also draw connections between the insights derived from the model and the evidence presented in Section 5. In 1940, only 15% of the Brazilian population lived in urban areas; by 1970, the majority of the population was residing in cities. At the national level, this increase is attributed equally to natural population growth and internal migration (Wagner and Ward, 1980). In contrast, our findings reveal that in areas with gold and mule roads almost all of the population growth was driven by in-migration. Internal migration gained momentum in the 1930s,

the possibility that the difference in the location with the highest rate of population change relative to the location with the lowest rate is decreasing over time. This is partly because, as we have shown, historical pathways have little relevance to the flow of goods in a location relative to other locations. For evidence of transportation costs and general equilibrium divergence at the national level, refer to Reis (2014).

making the early dislocations associated with sugar and gold economies seem comparatively modest in scope (Furtado, 1968), which was precipitated by structural transformation that began during the Great Depression years (Wagner and Ward, 1980).

The road towns created along gold and mule roads were historically well positioned to take part in the process of structural transformation and attract migrants, boasting a non-agricultural mix of initial population and a town configuration that already included an urban center with a history of catering and accommodation services. Since industry and services are urban-oriented activities, urban sites naturally attracted firms (Wagner and Ward, 1980). Structural transformation subsequently spurred population growth at higher densities with a lower share of agricultural workers, thereby driving increasing urbanization (Michaels, Rauch and Redding, 2012). This process led the economy towards the basin of attraction of the long-run equilibrium, where places with historical pathways have higher population density. The agglomeration effects estimated in Section 6.2, generated by higher densities, then solidified the economy's trajectory towards the new steady state.

The results above depend on the values of θ and $\beta_1 + \beta_2$. As there are no specific estimates of historical and contemporaneous amenity spillovers for Brazil, we use a plausible assumption commonly found in the literature and also adopt θ from existing studies. Nonetheless, due to the substantial value of $\alpha_1 + \alpha_2$ associated with the historical roads, our main conclusions remain robust to reasonable parameter choices. Figure I.1 demonstrates that with $\alpha_1 + \alpha_2 = 0.06$, partial divergence occurs only at extremely high values of θ. Furthermore, a unique steady state is achieved only if (1) $\beta_1 + \beta_2$ is very low (less than $-\alpha_1 - \alpha_2$) or (2) $\beta_1 + \beta_2$ and θ are both very large. For example, using the preferred estimate of $\beta_1 + \beta_2$ for the United States in Allen and Donaldson (2020) of 0.05 places our results far from the unique steady state region unless θ exceeds 15, which is highly unlikely.

7 Conclusion

In this paper, we investigate the effects of historical pathways on the long-run population dynamics in Brazil. We show, through two sets of historical roads, evidence that the population distribution of municipalities is path dependent on these roads. The first set of roads provides us with the exact gold roads created due to the discovery of gold, initiating a new era of population settlement in Brazil with the road towns. The second set of roads reconstructs, from new archival sources, the mule transportation network that evolved from the gold roads.

We study population dynamics in the long run to understand the mechanisms that generate the path-dependent nature of the spatial economy. We demonstrate that gold and mule roads had a positive effect on population growth in the mid-20$^{\text{th}}$ century. Consequently, population density disparities between areas traversed by historical pathways and other regions increased during the 20$^{\text{th}}$ century. In addition, we observe that areas with historical pathways and road towns experienced higher levels of in-migration, earlier urbanization, and structural change.

Finally, we employ our estimates to empirically quantify the long-run population dynamics model in Allen and Donaldson (2022) and demonstrate that agglomeration spillovers are robust enough to imply the presence of multiple steady states and path dependence. Overall, the evidence suggests that the road towns created along the gold and mule roads led in urbanization and structural transformation away from agriculture and served as population attractors when rapid migration began after 1930. This conclusion is further supported by the historiography of urban development in Brazil and anecdotal evidence describing the presence of road towns along the gold and mule roads with an urban configuration that would facilitate the attraction of individuals from other more sparsely populated municipalities when the country began the process of urbanization and structural transformation in the 1930s.

Our findings have important implications for policymakers and urban planners, highlighting the significance of history dependence in shaping current regional economic development. As highlighted by Lin and Rauch (2022), by recognizing the existence of path dependence, policymakers can design temporary policies that can cause permanent effects and influence the geographic distribution of economic activity.

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Online Appendix to

Old But Gold: Historical Pathways and Path Dependence

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- *Ao Illm. e Exm. Sr. Pedro D'Alcantara Bellegarde Ministro e Secretário de Estado dos Negócios da Agricultura, Comércio e Obras Públicas pelo Director da Directoria Geral dos Correios Dr. Thomaz Jozé Pinto Serqueira.* Typographia Perseverança. 1863. Rio de Janeiro, Brasil.

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B Data details

B.1 Variables and procedures

Units of observations The analysis was conducted at three primary levels: municipalities, grid cells, and minimum comparable areas. Municipalities are defined as administrative boundaries established by each state legislature. We utilized municipal boundaries from 2010. To ensure consistency when comparing different years, we employed 1920 Minimum Comparable Areas (MCAs) as defined by Reis et al. (2011), Figure B.1 shows historical road densities in these regions. The shapes and seat locations of each municipality in 2010 were obtained from Pereira, Goncalves, Carabetta and Furtado (2019), and the MCAs are aggregations of these shapes. For grid-cell data, we collected information at the 1x1 kilometer level and aggregated it to the 5x5 kilometer level by extracting the median value for each variable of interest.

Historical roads The gold roads were georeferenced using a map compiled by Simonsen (1977). The *caminho velho*[24] was georeferenced using a map compiled by Costa (2005). In both cases, we utilized ArcMap to accurately represent the roads using linestrings.

[24] See Appendix J below.

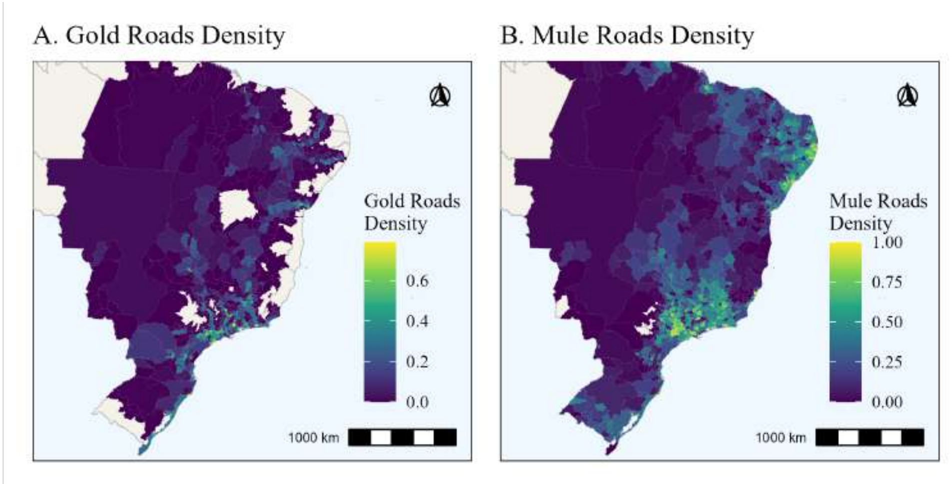
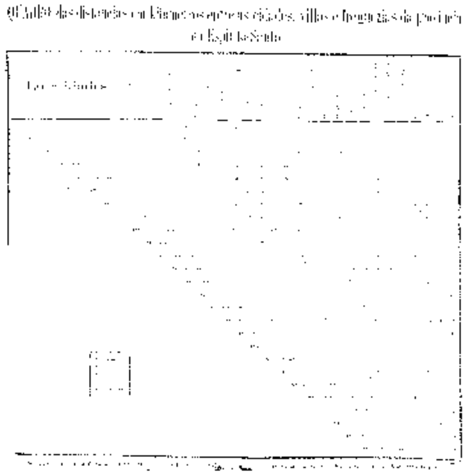


Figure B.1: Road Density in Minimum Comparable Areas

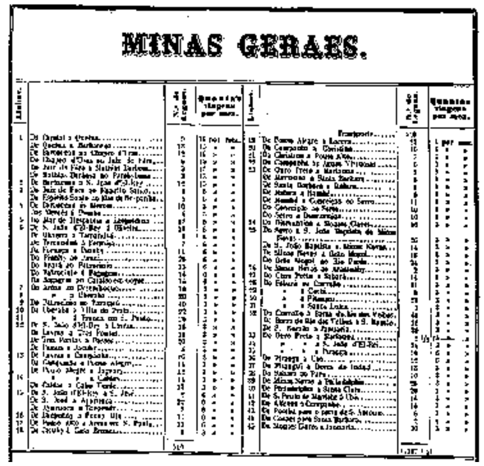
Notes: Panel A displays the spatial distribution of Gold roads in 1920 MCAs. Panel B displays the spatial distribution of Mule roads in 1920 MCAs.

The network data used in this study is derived from historical statistical reports produced in 1863 and 1873. These reports contain information about the municipalities that were connected by the transport network, as well as the actual distances covered between these locations. The provincial governments were responsible for preparing and reporting the data on effective distances, following instructions from the Empire's Business Secretariat. Examples of these historical reports are presented in Figure B.2, which displays a sample of the matrices available in the statistical reports for the province of *Espírito Santo* and the post office report for the province of *Minas Gerais*, respectively.

After digitizing the reports, several steps and verification processes were undertaken before the data could be utilized. Firstly, it was crucial to identify the municipalities by their old names and georeference them to determine the geographic coordinates of their headquarters. Subsequently, we converted the distances initially measured in leagues to kilometers for consistency. Finally, we constructed the distance matrices between the municipal seats based on the 1872 administrative division, utilizing both the historical pathways and the postal routes. To fill in any missing information, we digitized additional historical official records from provincial governments, which allowed us to capture distances between locations in different provinces. This complementary data enabled us to establish interconnections between paths, resulting in an origin and destination matrix that covered a significant portion of the national territory.



(a) 1873 Statistical Report, Distance between the locations of the province of *Espŕito Santo*



(b) 1863 Post office Report, Distance between the locations of the province of *Minas Gerais*

Figure B.2: Historical Documents

Least-cost paths For the gold roads, we calculate least-cost paths between the connecting population centers of the paths in the Simonsen map. For the mule roads, we calculate least-cost paths between each pair of municipal seats that appear connected in the documents described above. We adopt an approach employed in several studies investigating the causal impact of transportation systems on economic development. Specifically, we utilized the reciprocal of the terrain ruggedness index (TRI) as a transition matrix to construct the least-cost paths using Dijkstra's method. These paths allowed for connections through all eight adjacent cells. It is important to note that the TRI does not directly consider elevation; rather, it captures the variation in elevation between neighboring areas. Consequently, areas with higher variation in elevation are indicative of more challenging terrains for transportation.

Economic activity Our primary indicators of economic activity consist of population density, nightlight incidence, and urban population density. At the municipality and MCA levels, (urban) population density is derived by dividing the (urban) population data obtained from the Brazilian census between 1920 and 2010 by the corresponding area. Nightlight incidence is determined by calculating the median intensity of nighttime lights in cloudless skies using satellite data provided by the Earth Observation Group. For grid-level population data, we utilized rasters generated by the Center for International Earth Science Information Network, which incorporated 2010 census tract data. This approach was preferred over using census tracts directly, as the size and shape of census tracts are directly influenced by population density. Additionally, we employed nighttime lights in cloudless skies as an supplementary metric to gauge levels of development.

Economic Sectors Following the International Standard Industrial Classification (ISIC) as in Ruggles et al. (2024), in our classification "Agriculture" equals "Agriculture, fishing, and forestry" (code 010 in IPUMS), "Manufacturing" equals "Manufacturing" (code 030 in IPUMS), and "Services" aggregates "Hotels and restaurants" (code 070 in IPUMS), "Financial services and insurance" (090), "Services, not specified" (110), "Business services and real estate" (111), "Education" (112), "Health and social work" (113), "Other services" (114), and "Private household services" (115).

Geography Geographical variables, including temperature, precipitation, and elevation, were acquired through satellite data sourced from the National Institute for Space Research. These variables represent the median values within each municipality, MCA, or grid cell. Furthermore, we calculated the distances to the coast and rivers based on data from the same sources. All distances were measured in kilometers.

Modern transportation Information about the location of railway, train stations, and roadways are from shapefiles provided by the Brazilian Ministry of Transportation.

Population dynamics Information regarding urbanization is collected from the census. Net migration is computed as the difference between population growth and the natural rate of increase, which, in turn, is the difference between crude birth rate and crude death rates. Crude birth rates are computed applying the Brass P/F method to census data regarding fertility. Crude death rates are computed using information about life expectancy per municipality and the age distribution of the population. See Baerlocher, Parente and Rios-Neto (2019) for details.

Modern and historical factors Information regarding education, sectoral composition, and wages in different decades is from the Brazilian censuses.

Spatial operations Most spatial operations were computed using R's simple features package (Pebesma, 2018). Areas where constructed using South America Albers Equal Area Conic projection, whereas distances where computed using South

America Albers Equidistant Conic projection. Least-coast paths were constructed using the geopandas library for Python.

B.2 Summary statistics

Below we present descriptive statistics for the main variables at municipality, grid cells, and MCA level. Table B.1 refers to the gold roads sample, whereas Table B.2 refers to the mule roads sample. These numbers reflect the samples we used in the estimation. For municipalities and MCAs, we keep only those that are traversed by historical roads and their neighbors. For grid cells, we keep only cells within a 30-kilometer radius from the historical road. In all cases, we exclude municipalities and MCAs where historical cities were located. In the case of grid cells, there is a small number of grid cells with zero population (0.009%) and zero nightlight incidence (2.64%). We drop these observations from the sample.

Table B.1: Descriptive statistics – Gold Roads

Variables	Count	Mean	Std. Dev.	Min	Max
Panel A - Municipality:					
Population Density	2092	159.27	800.34	0.23	12998.98
Log(Nightlights)	2092	1.95	1.15	0.06	4.61
Urbanization Rate	2091	0.68	0.21	0.08	1
Gold Roads Density	2092	0.14	0.22	0	1
Ruggedness	2092	45.06	30.36	2.19	187.45
Elevation	2092	548	305.78	1.86	1640.35
Precipitation	2092	1341.77	358.15	429.27	2789.36
Temperature	2092	21.73	3	13.75	27.64
Area	2092	1211.91	3107.77	3.57	84215.61
Distance to River	2092	85944.02	63842.44	20	328388.78
Distance to Coast	2092	355580.7	330336.6	50	1719448.9
Panel B - Grid Cell:					
Population Density	47420	1.88	19.15	9×10^{-5}	700.55
Log(Nightlights)	47780	1.69	1.18	-0.04	4.61
I(Dist. to Gold $<$ 5km)	47780	0.19	0.39	0	1
Ruggedness	47778	42.64	34.71	0	297.23
Elevation	47780	561.5	312.76	0.04	2377.03
Precipitation	47780	1332.35	375.33	382.17	3423.59
Temperature	47780	22.19	3.13	10.64	28.06
Distance to River	47780	99699.91	73581.65	0	364918.84
Distance to Coast	47780	496486.4	416205.5	0	1689078.3
Panel C - 1920 MCA					
Population Density	620	19.65	31.93	0.1	642.73
Gold Roads Density	620	0.1	0.15	0	0.79
Ruggedness	620	46.54	31.57	3.32	187.45
Elevation	620	553.57	302.2	5.98	1446.15
Precipitation	620	1285.05	376.84	448.97	2725.15
Temperature	620	219.16	28.96	151.31	277.83
Area	620	8733.74	49361.63	86.58	1056852.6
Distance to River	620	77797.3	59088.73	20	364392.78
Distance to Coast	620	265294.9	241486.4	50	1826661

Table B.2: Descriptive statistics – Mule Roads

Variables	Count	Mean	Std. Dev.	Min	Max
Panel A - Municipality:					
Population Density	3347	122.83	646.93	0.13	12999
Log(Nightlights)	3347	1.87	1.15	-0.01	4.61
Urbanization Rate	3346	0.62	0.22	0.04	1
Gold Density	3347	0.23	0.29	0	1
Ruggedness	3347	43.34	31.67	0.02	184.33
Elevation	3347	459.09	310.26	1.86	1640.35
Precipitation	3347	1299.26	436.51	367.23	3435.17
Temperature	3347	22.71	2.97	13.75	27.8
Area	3347	1206.31	5131.39	3.57	159537
Distance to River	3347	95272.1	72174.8	20	473149
Distance to Coast	3347	302421	307347	50	1915376
Panel B - Grid Cell:					
Population Density	69837	1.14	13.29	0.0001	700.55
Log(Nightlights)	67344	1.6	1.14	-0.04	4.61
I(Dist. to Gold $<$ 5km)	71054	0.24	0.43	0	1
Ruggedness	70480	38.58	33.57	0	305.58
Elevation	70485	474.92	316.66	0.03	2154.14
Precipitation	70560	1292.67	443.53	354.49	3659.8
Temperature	70560	22.97	3.01	11.38	27.92
Distance to River	71054	95272.6	73316.5	0	348558
Distance to Coast	71054	391230	342327	0	1617072
Panel C - 1920 MCA					
Population Density	422	21.79	22.42	0.04	189.67
Gold Density	422	0.22	0.24	0	0.97
Ruggedness	422	49.47	34.57	3.32	161.08
Elevation	422	533.04	299.88	6.06	1318.15
Precipitation	422	1295.02	389.94	449.76	3139.62
Temperature	422	219.85	27.32	153.18	277.83
Area	422	5493.31	21214.8	99.16	237590
Distance to River	422	81759.3	62152	20	381318
Distance to Coast	422	267726	321143	531.43	2646395

C First-Stage Regressions

Table C.3: Gold roads and current population density - First Stage

	(1)	(2)	(3)	(4)
Dep. Var.: Gold Road Density:				
Least-Cost Path Density	0.3959***	0.3743***	0.3150***	0.3110***
	(0.0434)	(0.0400)	(0.0346)	(0.0342)
Observations	2,092	2,092	2,092	2,092
Cluster Groups	260	260	260	260
Kleibergen-Paap F:	83.159	87.724	82.966	82.869
Fixed-Effects:		State	State	State
Geography Controls			✓	✓
Lati-Longi Polynomial:				✓

Notes: Standard errors clustered at the level of 1872 Minimum Comparable Areas in parentheses. Geography variables are the ones presented in Table B.1. Lati-Longi Polynomial refers to a second-order latitude-longitude polynomial. The sample excludes municipalities that already existed in 1700. $^{*}p < 0.1, ^{**}p < 0.05, ^{***}p < 0.01$

D Robustness

In this section, we present the main results in Sections 3 and 4 using alternative specifications. Table D.4 refers to the gold roads sample, whereas Table D.5 refers to the mule roads sample. Both contain six columns. In column (1), the sample is expanded to include all municipalities except those in the state in the Amazon Basin (all Northern states, except Pará and Tocantins) and those where historical cities existed. In column (2), we exclude from the main sample municipalities in which the seat is within 100km of the coast to test if the results are driven by the dynamics of the population settlements on the coast. In column (3), we apply the inverse hyperbolic transformation to the measure of road density to deal with right-skewness of the data in the presence of zero values. In column (4), we apply an indicator if road density is more than zero as the independent variable to alleviate concerns about measurement error in the road density variables. In column (5), we test if the results hold within 1872 MCAs and, in column (6), we present spatially robust standard errors suggested by Conley (1999).

Table D.4: Gold roads and economic activity – Alternative Specifications

	Full Sample	No-Coast Sample	IHS	Dummy	MCA FE	Conley (160km)
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A - Dep. Var.: Population Density:						
Gold Road Density	2.09***	1.51**	2.14***	0.813***	1.46**	2.01***
	(0.592)	(0.763)	(0.664)	(0.232)	(0.658)	(0.626)
Observations	5,503	1,614	2,092	2,092	2,092	2,092
Cluster Groups	438	174	260	260	260	2,058
Kleibergen-Paap F:	80.435	26.478	81.437	58.346	43.504	73.713
Panel B - Dep. Var.: Nightlights:						
Gold Road Density	1.45***	1.60**	1.51***	0.724***	1.03***	1.40***
	(0.369)	(0.649)	(0.447)	(0.184)	(0.353)	(0.257)
Observations	5,503	1,614	2,092	2,092	2,092	2,092
Cluster Groups	438	174	260	260	260	2,058
Kleibergen-Paap F:	80.435	26.478	81.437	58.346	43.504	73.713
Panel C - Dep. Var.: Urban Population Density						
Gold Road Density	2.42***	2.02**	2.50***	0.889***	1.80**	2.34***
	(0.653)	(0.891)	(0.737)	(0.282)	(0.777)	(0.673)
Observations	5,502	1,613	2,091	2,091	2,091	2,091
Cluster Groups	438	174	260	260	260	2,057
Kleibergen-Paap F:	79.479	25.418	79.931	57.531	42.332	72.571

Notes: 2SLS estimates using least-cost paths as an instrument. Standard errors clustered at the MCA level in columns (1) to (5) in parentheses. In column (6) standard errors are clustered as in Conley (1999) with a 160km cutoff. Full sample only excludes municipalities in states in the Northern region, except Pará and Tocantins. No-Coast excludes municipalities in which the seat is within 100km of the coast. IHS applies the inverse hyperbolic transformation to the measure of road density. Dummy uses an variable indicating if road density is more than zero as independent variable. MCA includes MCA fixed effects. All columns control for state fixed effects, geography variables presented in Table B.1, a latitude-longitude second-order polynomial, and exclude municipalities that already existed in 1700. $^{*}p < 0.1, ^{**}p < 0.05, ^{***}p < 0.01$

Table D.5: Mule roads and economic activity – Alternative specifications

	Full Sample	Sample	No-Coast IHS	Dummy	MCA FE	Conley (210km)
	(1)	(2)	(3)	(4)	(5)	(6)
Panel A - Dep. Var.: Population Density:						
Gold Road Density	0.545***	0.387***	0.454***	0.193***	0.337***	0.425***
	(0.097)	(0.108)	(0.089)	(0.043)	(0.084)	(0.078)
Observations	4,932	2,401	3,347	3,347	3,347	3,347
Cluster Groups	390	241	367	367	367	3,309
Panel B - Dep. Var.: Nightlights:						
Gold Road Density	0.537***	0.392***	0.493***	0.151***	0.360***	0.468***
	(0.097)	(0.097)	(0.092)	(0.040)	(0.082)	(0.076)
Observations	4,932	2,401	3,347	3,347	3,346	3,347
Cluster Groups	390	241	367	367	367	3,309
Panel C - Dep. Var.: Urban Population Density						
Gold Road Density	0.662***	0.507***	0.589***	0.235***	0.461***	0.549***
	(0.111)	(0.127)	(0.108)	(0.051)	(0.101)	(0.087)
Observations	4,931	2,400	3,346	3,346	3,347	3,346
Cluster Groups	390	241	367	367	367	3,308

Notes: Standard errors clustered at the MCA level in columns (1) to (5) in parentheses. In column (6) standard errors are clustered as in Conley (1999) with a 210km cutoff. Full sample only excludes municipalities in states in the Northern region, except Pará and Tocantins. No-Coast excludes municipalities in which the seat is within 100km of the coast. IHS applies the inverse hyperbolic transformation to the measure of road density. Dummy uses an variable indicating if road density is more than zero as independent variable. MCA includes MCA fixed effects. All columns control for state fixed effects, geography variables presented in Table B.1, a latitude-longitude second-order polynomial, and exclude municipalities that already existed in 1700. $^{*}p < 0.1, ^{**} p < 0.05, ^{***} p < 0.01$

D.1 Recentering and randomization inference

Even if we were in the ideal situation where gold deposits *and* mule roads are completely random, there could still be an omitted variable bias because of the centrality of some regions. That is, the mule road treatment coefficient could be biased just because there are regions more exposed to the gold deposits, whether or not there was a historical pathway constructed there. To address this challenge, we implement the method from Borusyak and Hull (2023) and decompose the treatment into a random component that follows a shock assignment process and a nonrandom component composed of the spatial distribution of economic activity. The exogenous shocks counterfactual are used to build the expected treatment, which purges the bias of nonrandom exposure.

To define the shock assignment process, we assume that gold deposits are as good as random, given the geographic characteristics and the predetermined economic geography of the region. Using the mule roads, we identify the "missing" routes between municipality pairs in the late 19$^{\text{th}}$ century; they are missing because no mule roads between these municipality pairs were found in any of the historical documents, indicating that these municipalities were not connected. However, if gold deposits were assigned to different regions, it is likely that some of the "missing" routes would be realized, while others would remain the same, thus we randomize actual and "missing" mule roads to build our counterfactual shocks and the expected treatment. In addition, the counterfactual shock assignment process gives us robust confidence intervals via a randomization inference approach.

Simulating the exact shock assignment process of mule roads appearing in other regions of the country given a random redraw of gold deposits by nature is challenging since it would likely change the whole underlying economic geography and not just the mule roads. Still, our specification already yields a strong robustness check on our main specification. As a matter of fact, any specification could yield a robustness check if the shock is exogenous, as stressed by Borusyak and Hull (2023). Because the mule roads were usually built to connect municipality seats and provincial capitals, it is unlikely that if there were gold deposits in the Northeast, for example, the whole distribution of cities would completely change, but would instead increase the number of connections between the existing municipalities' seats and provincial capitals in the Northeast due to an increased flow of gold and people, generating more mule roads and consequently more road towns. As we can see in Panel A of Figure D.3, the number of possible connections would increase in areas where no gold was found but there were already many municipalities. Thus, by controlling for our expected density measure we are effectively comparing only places with more mule road density than expected with those places with less density than expected.[25]

We compute the expected mule road treatment by drawing random samples of mule roads and averaging their influence across draws. There are 1712 possible connections between the 1872 municipality seats, out of which 1064 existed (Panel A of Figure D.3).[26] We randomly draw 1000 samples mixing existing mule roads and unbuilt mule roads conditional on 1064 connections. The intuition is that in each resampling, we assign to each connection the same probability of being created. Then, for each draw, we compute the mule road density and average over all draws. The result is the expected mule road density shown in Panel B of Figure D.3.

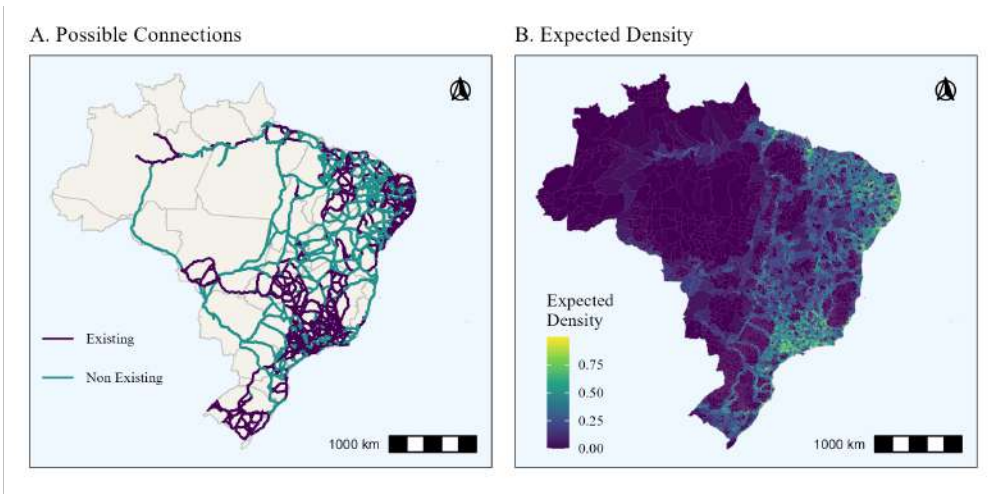


Figure D.3: Centrality and Expected Treatment

Notes: Panel A shows all possible connections between municipality seats in 1872 setting apart the existing and non existing routes. Panel B shows the spatial distribution of our measure of expected Mule Road density computed as in Borusyak and Hull (2023).

In Table D.6, we compare estimated coefficients by controlling for the "centrality" of municipalities in various ways. All models include state fixed effects, and errors are clustered at the 1872 MCA level. Column (1) does not control for

[25] Since the counterfactual shocks are not given by a randomization protocol (such as in a RCT), it is more efficient to control for the expected treatment instead of instrumenting the treatment, which also removes the residual variation in the outcome that is correlated with the expected treatment, as recommended by Borusyak and Hull (2023).

[26] We consider the connection of a municipality seat with their immediate neighbors and so on, following the actual observed topography of the spatial economy at this time in Brazil, as opposed to connecting each municipality with all other municipalities or directly with more distant municipalities, which was not realistic.

Table D.6: Mule roads and expected mule roads density

	(1)	(2)	(3)
Dep. Var.: Population Density			
Mule Road Density	1.281***	0.4246***	0.2995**
	(0.1180)	(0.0817)	(0.1319)
RI 95% CI		[0.005, 0.614]	[0.023, 0.61]
Observations	3,347	3,347	3,347
Cluster Groups	367	367	367
Other Geography Controls		✓	✓
Expected Mule Road Den.			✓

Notes: Standard errors clustered at the level of 1872 Minimum Comparable Areas in parentheses. All columns control for state fixed effects. Other Geography variables are the ones presented in Table B.1 and a second-order latitude-longitude polynomial. Expected Mule Road Den. controls for the expected treatment built from counterfactual shocks and RI 95% CI is the confidence interval given by randomization inference as proposed by Borusyak and Hull (2023). The sample excludes municipalities that already existed in 1872. $^{*}p < 0.1,^{**}p < 0.05,^{***}p < 0.01$

geography or location beyond the state fixed effects. In column (2), controlling for geographical variables and a second-order latitude-longitude polynomial significantly reduces the coefficient. Adding the expected mule road density as a control in column (3) further reduces the coefficient, but only slightly.

In the table, we also present the 95% confidence intervals from a random inference approach. At this level of confidence, we reject the null hypothesis that the effect of Mule Roads on population density in 2010 is zero. Importantly, both the coefficients in columns (2) and (3) are within the confidence interval. Therefore, we can conclude that our results in Table 3 are not significantly biased by centrality issues once we control for predetermined geography.

D.2 A most demanding placebo test

In this section, we take an extra measure to address the fundamental concern that our results may be driven by the pre-existing developed areas that serves as nodes for the least-cost paths or by a mechanical effect from the process of constructing optimal paths. The construction of optimal paths based on topography may be correlated with geographically advantageous areas or present advantages simply because they are located between already developed regions. The most demanding

Table D.7: Placebo roads and population density

	(1)	(2)	(3)	(4)
Panel A - Dep. Var.: Population Density:				
Placebo Density	1.36***	0.655***	0.169*	0.125
	(0.293)	(0.144)	(0.102)	(0.094)
Observations	3,240	3,240	3,240	3,240
Cluster Groups	347	347	347	347
Panel B - Dep. Var.: Nightlights:				
Placebo Density	1.64***	0.438***	0.121	0.014
	(0.089)	(0.116)	(0.094)	(0.086)
Observations	3,240	3,240	3,240	3,240
Cluster Groups	347	347	347	347
Panel C - Dep. Var.: Urban Population Density				
Placebo Density	2.30***	0.758***	0.232**	0.173
	(0.170)	(0.151)	(0.116)	(0.109)
Observations	3,239	3,239	3,239	3,239
Cluster Groups	347	347	347	347
Fixed-Effects:		State	State	State
Geography Controls			✓	✓
Lati-Longi Polynomial:				✓

Notes: Standard errors clustered at the level of 1872 Minimum Comparable Areas in parentheses. Geography variables are the ones presented in Table B.1. Lati-Longi Polynomial refers to a second-order latitude-longitude polynomial. The sample excludes municipalities that already existed in 1872. $^{*}p < 0.1, ^{**}p < 0.05, ^{***}p < 0.01$

placebo test we can conceive to alleviate these concerns is to estimate the effects of least-cost paths between *all* municipality pairs where mule roads did not exist, as shown the Panel A of Figure D.3, instead of a random redraw of some unbuilt roads along with existing roads as in the last section. Therefore, if we find similar effects from the "placebo roads", it would suggest that our results are driven by the construction of least-cost paths rather than the existence of historical roads. We follow the same strategy as before, with inconsequential units and restricting the sample to neighbors and dropping municipalities that already existed in 1872. The results are reassuring and presented in Table D.7.

In Columns (1) and (2), the coefficients in Tables 3 and D.7 are very similar, suggesting that natural least-cost paths imply a selection of geographically advantageous areas. However, when we control for geography in Columns (3) and (4), the coefficients associated with placebo roads are significantly smaller than those associated with mule roads and become statistically insignificant, suggesting that it is observed geography that is driving this selection. Since we always control for observed geography in our analysis, these results suggest the concerns discussed in this section cannot fully account for our findings.

E Within municipality effects

So far, we have established a positive association between historical roads and current distribution of population at the municipality level. In this section, we investigate whether this association holds within municipalities. Our approach uses grid-cell level data on population density and nightlight incidence to measure population concentration near historical roads. Specifically, our observations are at the level of 25-square-kilometer grid cells. We then keep only the cells within a 30km radius of the historical road and compare cells within a 5-kilometer radius with those further away. The results are presented in Table E.8.

Table E.8: Within Municipality Effects

	Gold Roads		Mule Roads	
	Population	Lights	Population	Lights
	(1)	(2)	(3)	(4)
Dist. to Roads < 5km	0.604	0.573**	0.070**	0.098***
	(0.391)	(0.277)	(0.035)	(0.028)
Observations	42,415	42,730	29,630	29,160
Clusters	1,734	1,735	1,376	1,375
Kleibergen-Paap F:	31.427	31.535		
Fixed-Effects:	Munic.	Munic.	Munic.	Munic.
Geography Controls	✓	✓	✓	✓
Lati-Longi Polynomial:	✓	✓	✓	✓

Notes: Standard errors clustered at the municipality level. Geography variables are the ones presented in Table B.1. Lati-Longi Polynomial refers to a second-order latitude-longitude polynomial. The sample excludes municipalities that already existed in 1700 for the gold roads and 1872 for the mule roads. $^{*}p < 0.1, ^{**}p < 0.05, ^{***}p < 0.01$

Columns (1) and (2) pertain to the effects of gold roads, while Columns (3) and (4) pertain to the effects of mule roads. The dependent variables are the logarithm transformation of population density in Columns (1) and (3) and the logarithm transformation of nightlight incidence in Columns (2) and (4). The estimation approach for both types of roads is the same as in Sections 3 and 4, where the effect of gold roads is measured through a 2SLS model and the effect of mule roads through a reduced-form model. All columns add geographical controls and municipality fixed effects, excluding pre-1700 municipalities for gold roads and pre-1872 municipalities for mule roads. Standard errors are clustered at the municipality level.

The findings suggest that historical roads are influential even within municipalities. In general, grid cells closer to historical roads present a higher incidence of nightlights and, in the case of mule roads, higher population density. The effect of gold roads on population density is not statistically significant at a 10% level. However, the coefficient is similar to the one corresponding to the effect of gold roads on nightlights. We attribute the large standard errors from the estimation in Column (1) to large measurement errors in assigning the measure of population density, which is made at the census-tract level, to the grid-cell level. Again, details about the data sources and procedures are available in the Appendix B.

F Gold roads long-run dynamics tables

In this section we present the regression tables associated with the figures presented in the Section 5.2. Specifically, Panels A-F in Table F.9 are associated with Figure 4, while Panels G and H present estimations for variables only included in the 1970 census. Table F.10 is associated with Figure 5 and Tables F.11 and F.12 are associated with Figure 6.

Table F.9: Gold roads and population dynamics

	Year								
	1920 (1)	1940 (2)	1950 (3)	1960 (4)	1970 (5)	1980 (6)	1991 (7)	2000 (8)	2010 (9)
Panel A - Dependent Variable: Population Density / Kleibergen-Paap F: 40.984									
Gold Road Density	-0.217	0.025	0.468	0.789	1.08*	1.55**	1.81**	2.02***	2.17***
	(0.450)	(0.465)	(0.486)	(0.571)	(0.634)	(0.699)	(0.745)	(0.768)	(0.795)
Panel B - Dependent Variable: Population Growth / Conditional on Population Density									
Gold Road Density	0.011	0.046***	0.031**	0.027**	0.039**	0.018*	0.018*	0.011	
	(0.012)	(0.014)	(0.013)	(0.011)	(0.015)	(0.010)	(0.011)	(0.007)	
Kleibergen-Paap F:	41.110	41.203	40.774	40.242	39.640	38.641	38.281	38.052	
Panel C - Dependent Variable: Net Migration / Conditional on Population Density									
Gold Road Density					0.031**	0.005	0.007	0.002	
					(0.015)	(0.008)	(0.009)	(0.006)	
Kleibergen-Paap F:					39.640	38.641	38.281	38.052	
Panel D - Dependent Variable: Change in Urb. Rate / Conditional on Population Density									
Gold Road Density		-0.056	-0.019	0.254*	0.191**	-0.036	-0.021	-0.029	
		(0.053)	(0.028)	(0.142)	(0.082)	(0.051)	(0.030)	(0.026)	
Kleibergen-Paap F:		37.576	39.531	40.895	39.475	38.321	38.630	39.387	
Panel E - Dependent Variable: Population Not Born in Municipality / Kleibergen-Paap F: 40.984									
Gold Road Density					1.89**	2.69***		2.25***	2.22***
					(0.877)	(0.928)		(0.847)	(0.767)
Panel F - Dependent Variable: Population Not Born in State / Kleibergen-Paap F: 40.984									
Gold Road Density					1.90**	3.71***		2.96***	2.86***
					(0.877)	(1.07)		(1.02)	(0.964)
Panel G - Dependent Variable: Population that Migrated from Another City / Kleibergen-Paap F: 40.984									
Gold Road Density					2.58***				
					(0.984)				
Panel H - Dependent Variable: Population that Migrated from Rural Areas / Kleibergen-Paap F: 40.984									
Gold Road Density					0.955				
					(0.831)				
Observations	620	620	620	620	620	620	620	620	620

Notes: 2SLS estimates using least-cost paths as an instrument. Robust standard errors in parentheses. In panels B, C and D, Year indicates the decade. All columns control for state fixed effects, geography variables presented in Table B.1, a latitude-longitude second-order polynomial, and exclude MCAs that already existed in 1700. $^{*}p < 0.1, ^{**}p < 0.05, ^{***}p < 0.01$

Table F.10: Gold roads and sector density

	Year							
	1940 (1)	1950 (2)	1960 (3)	1970 (4)	1980 (5)	1991 (6)	2000 (7)	2010 (8)
Panel A - Dependent Variable: Agriculture Density								
Gold Road Density	-0.662**	-0.885***	-0.674**	-0.832**	-1.06***	-0.103	-1.04**	-0.959**
	(0.262)	(0.309)	(0.292)	(0.383)	(0.400)	(0.571)	(0.494)	(0.480)
Panel B - Dependent Variable: Manufacturing Density								
Gold Road Density	1.75***	1.51**	-0.148	-0.308	-0.153	0.263	-0.984**	-0.926*
	(0.652)	(0.611)	(0.563)	(0.687)	(0.580)	(0.740)	(0.441)	(0.532)
Panel C - Dependent Variable: Services Density								
Gold Road Density	0.213*	0.142	0.325	-0.801**	-0.145	0.453	0.071	-0.035
	(0.116)	(0.088)	(0.288)	(0.353)	(0.264)	(0.519)	(0.210)	(0.217)
Observations	620	620	620	620	614	472	620	620
Kleibergen-Paap F:	41.203	40.774	40.242	39.640	38.550	21.380	38.052	37.889

Notes: 2SLS estimates using least-cost paths as an instrument. Robust standard errors in parentheses. All columns control for state fixed effects, geography variables presented in Table B.1, a latitude-longitude second-order polynomial, and exclude MCAs that already existed in 1700. $^{*}p < 0.1, ^{**}p < 0.05, ^{***}p < 0.01$

Table F.11: Gold roads and modern transportation density (railroads)

	Year			
	1946 (1)	1957 (2)	1982 (3)	2005 (4)
Panel A - Dependent Variable: Railroad Density				
Gold Road Density	1.02	0.376	0.723	0.694
	(1.74)	(1.72)	(2.09)	(2.11)
Panel B - Dependent Variable: Stations Density				
Gold Road Density	1.18	0.600	1.49	1.76
	(2.03)	(1.99)	(2.36)	(2.36)
Observations	620	620	620	620
Kleibergen-Paap F:	41.203	40.774	38.641	38.052

Notes: 2SLS estimates using least-cost paths as an instrument. Robust standard errors in parentheses. All columns control for state fixed effects, geography variables presented in Table B.1, a latitude-longitude second-order polynomial, and exclude MCAs that already existed in 1700. $^{*}p < 0.1, ^{**}p < 0.05, ^{***}p < 0.01$

Table F.12: Gold roads and modern transportation density (paved roads)

	Year					
	1960 (1)	1970 (2)	1980 (3)	1990 (4)	2000 (5)	2010 (6)
Gold Road Density	6.88***	2.25	1.14	1.11	0.790	1.07
	(2.34)	(1.94)	(1.82)	(1.67)	(1.62)	(1.54)
Observations	620	620	620	620	620	620
Kleibergen-Paap F:	40.242	39.640	38.641	38.281	38.052	37.889

Notes: 2SLS estimates using least-cost paths as an instrument. Robust standard errors in parentheses. All columns control for state fixed effects, geography variables presented in Table B.1, a latitude-longitude second-order polynomial, and exclude MCAs that already existed in 1700. $^{*}p < 0.1,^{**}p < 0.05,^{***}p < 0.01$

G Mule roads short- and long-run dynamics

In a similar vein to the main text, we study short and long-run factor and population dynamics resulting from the influence of mule roads. Table G.1 shows the short-run effect of mule roads on population density and historical factor densities in 1920 and the effect on population density in 2010 controlling for the various historical factor densities. Table G.2 shows the effects of mule roads on long-run population dynamics, including population density, population growth, net migration (migration net of fertility), the sources of migration, and the urbanization rate. Table G.3 shows the effects on the working population density by sector and Tables G.4 and G.5 on the density of modern transportation infrastructure.

Table G.1: Mule roads and factor densities in 1920

	Baseline	Popul.	Stations	Rail	Lit	Teachers	Agric.	Manuf.	Services	Transp.
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Panel A - Unconditional Effect:										
Mule Road Density		0.005	2.26***	1.77**	0.121	0.226	-0.120	0.393*	0.353**	0.827***
		(0.147)	(0.755)	(0.690)	(0.148)	(0.191)	(0.151)	(0.209)	(0.176)	(0.319)
Panel B - Current Development Conditional on Factor Density:										
Mule Road Density	0.817***	0.814***	0.660**	0.682**	0.738***	0.723***	0.876***	0.652***	0.598**	0.611**
	(0.270)	(0.252)	(0.271)	(0.275)	(0.245)	(0.251)	(0.261)	(0.239)	(0.240)	(0.260)
Factor Density		0.660***	0.070***	0.076***	0.653***	0.419***	0.492***	0.421***	0.623***	0.250***
		(0.093)	(0.017)	(0.018)	(0.090)	(0.083)	(0.089)	(0.057)	(0.067)	(0.037)
Observations	422	422	422	422	422	422	422	422	422	422

Notes: Robust standard errors in parentheses. Dependent variables in Panel A and Factor Densities in Panel B are the log of quantities over area, except in columns (3), (4), (6), and (10) where it is the inverse hyperbolic sine of quantities over area. All columns control for state fixed effects, geography variables presented in Table B.1, a latitude-longitude second-order polynomial, and exclude MCAs that already existed in 1700. $^{*}p < 0.1, ^{**}p < 0.05, ^{***}p < 0.01$

Table G.2: Mule roads and population dynamics

	Year								
	1920 (1)	1940 (2)	1950 (3)	1960 (4)	1970 (5)	1980 (6)	1991 (7)	2000 (8)	2010 (9)
Panel A - Dependent Variable: Population Density									
Mule Road Density	0.005 (0.147)	0.100 (0.148)	0.241 (0.163)	0.400** (0.192)	0.518** (0.220)	0.662*** (0.247)	0.740*** (0.259)	0.789*** (0.265)	0.817*** (0.270)
Panel B - Dependent Variable: Population Growth / Conditional on Population Density									
Mule Road Density	0.005 (0.004)	0.015** (0.006)	0.015** (0.006)	0.010** (0.005)	0.010** (0.004)	0.004 (0.003)	0.003 (0.003)	0.002 (0.002)	
Panel C - Dependent Variable: Net Migration / Conditional on Population Density									
Mule Road Density					0.010** (0.004)	0.004 (0.003)	0.002 (0.003)	0.001 (0.002)	
Panel D - Dependent Variable: Change in Urb. Rate / Conditional on Initial Urb. Rate									
Mule Road Density		0.005 (0.016)	0.006 (0.009)	0.154*** (0.050)	0.032 (0.023)	0.022 (0.016)	0.004 (0.010)	0.003 (0.010)	
Panel E - Dependent Variable: Population Not Born in Municipality									
Mule Road Density					0.778** (0.319)	0.996*** (0.331)		0.820*** (0.281)	0.731*** (0.249)
Panel F - Dependent Variable: Population Not Born in State									
Mule Road Density					0.772** (0.320)	1.10*** (0.397)		0.911** (0.352)	0.780** (0.326)
Panel G - Dependent Variable: Population that Migrated from Another City									
Mule Road Density					0.984*** (0.356)				
Panel H - Dependent Variable: Population that Migrated from Rural Areas									
Mule Road Density					0.585** (0.296)				
Observations	422	422	422	422	422	422	422	422	422

Notes: Robust standard errors in parentheses. In panels B, C and D, Year indicates the decade. All columns control for state fixed effects, geography variables presented in Table B.1, a latitude-longitude second-order polynomial, and exclude MCAs where historical cities were located. $^{*}p < 0.1,^{**}p < 0.05,^{***}p < 0.01$

Table G.3: Mule roads and sector density

	Year							
	1940 (1)	1950 (2)	1960 (3)	1970 (4)	1980 (5)	1991 (6)	2000 (7)	2010 (8)
Panel A - Dependent Variable: Agriculture Density								
Mule Road Density	-0.147* (0.085)	-0.158 (0.111)	-0.172 (0.107)	-0.187 (0.114)	-0.112 (0.139)	-0.026 (0.209)	-0.242 (0.171)	-0.398** (0.170)
Panel B - Dependent Variable: Manufacturing Density								
Mule Road Density	0.860*** (0.244)	0.900*** (0.229)	0.600*** (0.196)	0.333 (0.216)	0.170 (0.197)	0.538* (0.279)	0.029 (0.160)	-0.042 (0.177)
Panel C - Dependent Variable: Services Density								
Mule Road Density	0.099*** (0.036)	0.012 (0.031)	0.255** (0.106)	0.005 (0.112)	0.038 (0.095)	0.212 (0.201)	0.081 (0.079)	-0.012 (0.081)
Observations	422	422	422	422	421	287	422	422

Notes: Robust standard errors in parentheses. All columns control for state fixed effects, geography variables presented in Table B.1, a latitude-longitude second-order polynomial, and exclude MCAs where historical cities were located. $^{*}p < 0.1, ^{**}p < 0.05, ^{***}p < 0.01$

Table G.4: Mule roads and modern transportation density (railroads)

	Year			
	1946 (1)	1957 (2)	1982 (3)	2005 (4)
Panel A - Dependent Variable: Railroad Density				
Mule Road Density	1.75*** (0.621)	1.33** (0.597)	1.73** (0.715)	1.60** (0.717)
Panel B - Dependent Variable: Stations Density				
Mule Road Density	2.22*** (0.715)	2.04*** (0.690)	1.09 (0.834)	0.931 (0.829)
Observations	422	422	422	422

Notes: Robust standard errors in parentheses. All columns control for state fixed effects, geography variables presented in Table B.1, a latitude-longitude second-order polynomial, and exclude MCAs where historical cities were located. $^{*}p < 0.1, ^{**}p < 0.05, ^{***}p < 0.01$

Table G.5: Mule roads and modern transportation density (paved roads)

	Year					
	1960 (1)	1970 (2)	1980 (3)	1990 (4)	2000 (5)	2010 (6)
Mule Road Density	1.78***	1.38**	0.895	0.432	0.262	0.193
	(0.635)	(0.670)	(0.585)	(0.517)	(0.503)	(0.495)
Observations	422	422	422	422	422	422

Notes: Robust standard errors in parentheses. All columns control for state fixed effects, geography variables presented in Table B.1, a latitude-longitude second-order polynomial, and exclude MCAs where historical cities were located. $^{*}p < 0.1,^{**}p < 0.05,^{***}p < 0.01$

H Agglomeration spillovers OLS estimates

Table H.6: Population density and hourly wages

	Gold Roads			Mule Roads		
	1980	2000	2010	1980	2000	2010
	(1)	(2)	(3)	(4)	(5)	(6)
log(Pop. Density)	0.1066***	0.0941***	0.0685***	0.0869***	0.0764***	0.0588***
	(0.0179)	(0.0148)	(0.0148)	(0.0195)	(0.0140)	(0.0107)
Observations	2,414,501	3,217,096	4,354,596	961,316	1,335,997	1,827,946
Cluster Groups	614	620	620	421	422	422
Kleibergen-Paap F:	21.555	24.555	21.556	28.267	42.531	33.328

Notes: Clustered standard errors at the MCA level in parentheses. 2SLS instruments population density using either gold road or mule road density. The sample excludes municipalities that already existed in 1700 (Gold Roads) or in 1872 (Mule Roads). All columns controls for Individual age, squared age, and indicators of race, sex, education attainment, marital status, and road density in the correspondent year. $^{*}p < 0.1, ^{**}p < 0.05, ^{***}p < 0.01$

I Sensitivity of Multiple State Steady Equilibria

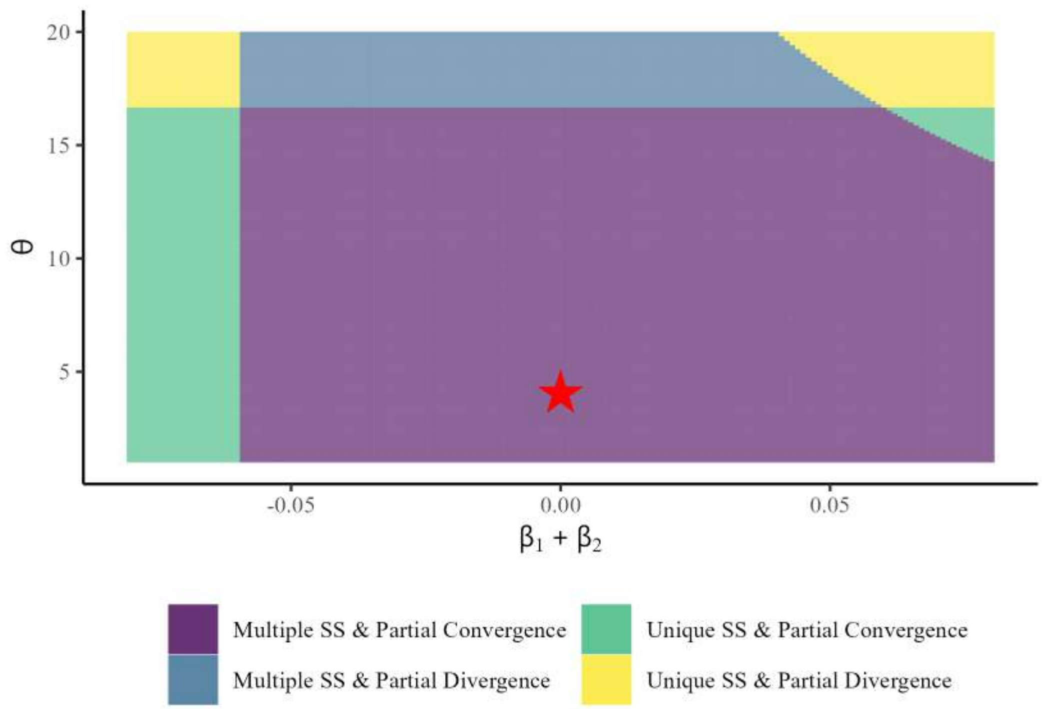


Figure I.1: Sensitivity of steady states and convergence

Notes: Visual representation of Proposition 3 in Allen and Donaldson (2022) when $\alpha_1 + \alpha_2 = 0.06$. The shaded areas indicate whether the values of the term $[1 - \theta(\alpha_1 + \beta_1 + \alpha_2 + \beta_2)]^{-1}$ imply a unique steady state (if it is between -1 and 1) or partial convergence (if it is below $1/\theta$) for different values of θ and $\beta_1 + \beta_2$. The star indicates the combination $\{\theta = 4, \beta_1 + \beta_2 = 0\}$ used the draw Figure 7.

J Special case: *Caminho Velho*

In this section, we study the effects of one specific and well-identified road, *caminho velho* (old road), linking the city of *Paraty*, in the southwest of the state of *Rio de Janeiro*, to the newly discovered gold mines in the city of *Ouro Preto* in the state of *Minas Gerais*, in the late 17^{th} century. The advantage of this analysis rest in the fact that this was the first route used to extract gold from the mines in Minas Gerais. Therefore, we can argue that this trail is plausibly exogenous, as we describe in the following paragraphs.

History In the latter half of the 17^{th} century, as the sugar industry declined, the Portuguese Crown incentivized the discovery of precious metals in Brazil by offering rewards and honors. This paved the way for a systematic search for gold and other minerals. The discovery of gold mines in Minas Gerais, Goiás, and Mato Grosso was a pivotal event in the economic history of the country. The shift in production focus from sugar cane plantations along the Northeast coast to the mining provinces in the countryside led to the creation of various pathways that connected the mines to Rio de Janeiro and Bahia on the coast. In this context, ground transportation became indispensable for collecting taxes on merchandise circulation and controlling the flow of gold (Morais, 2010, p. 22).

The *bandeiras* were small military forces launched in the state of São Paulo with the objective of exploring the country's hinterlands in search of valuable metals. Equipped with basic tools, these expeditions faced harsh conditions since the unsettled hinterlands of the country were largely uncharted. To navigate the unknown terrain, the *bandeiras* relied on existing indigenous paths and river routes and used the sun as their primary point of reference (Santos, 2001).

In the late 17^{th} century, Fernão Dias led a renowned expedition that discovered the first minerals in the province of Minas Gerais. The route taken by the expedition, known as the *caminho velho*, took over seven years to complete and eventually became the primary route used by miners to transport their goods. The pathway connected the gold mines to Paraty, located in the southwest of Rio de Janeiro state. From there, the gold was shipped by sea to Rio de Janeiro. Initially, the *caminho velho* intersected with the São Paulo pathway in Taubaté. However, the junction point later moved to Pindamonhangaba and then Guaratinguetá (see map in Figure J.1).

It is worth noting that the *caminho velho* was far from ideal. It was created by explorers who ventured into Brazil's hinterlands in search of gold, and they prioritized favorable geography over minimizing travel time to reach the ports in Rio. Consequently, in the early 18^{th} century, a new route called the *caminho novo* was established.

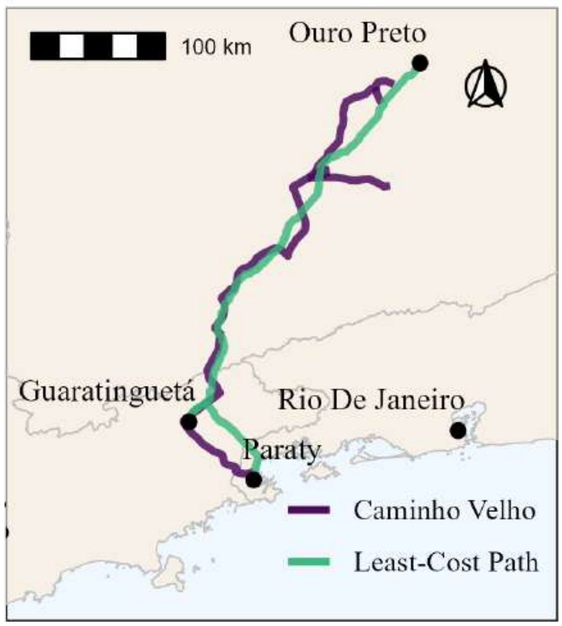


Figure J.1: Caminho Velho

Notes: Georeferenced *caminho velho* from Costa (2005) and the constructed least-coast path.

The historical episode detailed above provides us with a unique setting to estimate the long-run causal effect of historical pathways and local economic development, as the discovery of the mines happened fortuitously (Palma, 2022) and the treated units along the pathway connecting São Paulo, formerly an underdeveloped village with only 3,000 inhabitants, and the gold region in Minas Gerais are arguably exogenous, given the somewhat arbitrary nature of the paths trailed by the explorers following the initial expedition of Fernão Dias, in 1674 (Santos, 2001).

Data Historical maps are utilized to estimate distances to the historical pathway. The geographic location of the *caminho velho*, which serves as the primary source of data for this experiment, is obtained from historical maps compiled by Costa (2005), as illustrated in Figure J.1.

To ensure that the argument developed above holds, our main estimation considers only two sections of the *caminho velho*: the one connecting Paraty to Guaratinguetá and the one connecting Guaratinguetá to Ouro Preto. We also exclude Paraty and Guaratinguetá, given that these areas were previously developed, and Ouro Preto as the presence of gold mines may have prompted a specific path of development. None of these choices alter the main results significantly.[27] Figure J.1 depicts the resulting georeferenced pathway and four important seats highlighted: Paraty, Guaratinguetá, Ouro Preto and Rio de Janeiro. The *caminho velho* extends over 522.37 kilometers crossing three of the richest states in Brazil: São Paulo, Rio de Janeiro, and Minas Gerais.

The logarithm of the population (Panel A) and nightlights (Panel B) by 25km^2 grids are displayed in Figure J.2 along with the *caminho velho*. The images demonstrate a clear association between the *caminho velho* and higher population and nightlight density. Notably, in the stretch between Guaratinguetá and Ouro Preto, we observe areas with high economic development surrounded by areas with low development. It is worth mentioning the difference in variance between nightlights and population measures. The limited range of nightlights, between 0 and 100 per 1km^2 grids, results in less precision when comparing high-density areas.

The analysis is focused on municipalities touched by the pathway and their neighbors, excluding municipalities that existed before 1700 and Ouro Preto. Descriptive statistics for the variables mentioned earlier are presented in Table J.1. In our sample, there are 103 municipalities where population density ranges from 5.4 to 2,200 individuals per square kilometer, and the average road density is 17%.

[27] In fact, we exclude all municipalities in which pre-1700 cities where located. This excludes all nodes in the road, except Ouro Preto, which we also exclude.

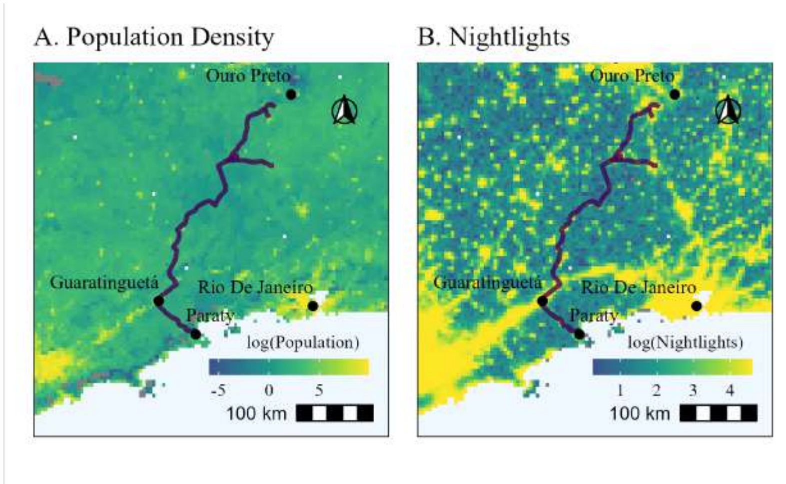


Figure J.2: Population Density and Nightlight Incidence in 25km^2 grid cells

Notes: Spatial distribution of population density (Panel A) and nightlights (Panel B) along the *caminho velho*. The unit of observation are 25 squared kilometer grid cells.

Table J.1: Descriptive Statistics – *Caminho Velho*

Variables	Count	Mean	Std. Dev.	Min	Max
Population Density	103	82.46	232.51	5.42	2200.29
Log(Nightlights)	103	2.11	0.78	1.14	4.59
Urbanization Rate	103	0.72	0.19	0.33	1
Gold Roads Density	103	0.17	0.27	0	1
Ruggedness	103	78.66	28.59	11.1	159.77
Elevation	103	987.94	204.88	545.4	1640.35
Precipitation	103	1515.5	105.42	1279.4	1856.02
Temperature	103	18.82	1.32	13.75	20.5
Area	103	361.77	278.41	3.57	1464.5
Distance to River	103	59200	34644	2208.39	187296
Distance to Coast	103	150491	74172	24278.3	292321

Results We establish a linear association between the distance to the *caminho velho* and current development indicators. In particular,

$$y_i = \alpha_s + \beta \text{Distance}_i + \mathbf{X}_i' \boldsymbol{\gamma} + \epsilon_i, \tag{J.1}$$

where y_i denotes the outcome variable at the geographical location i in 2010, Distance_i represents the distance from i to the *caminho velho*, $\mathbf{X}_i$ is a column vector containing covariates, α_s denotes the fixed effect of the state s, and ϵ_i is the error term.

Our identification assumption is based on the premise that, given the covariates $\mathbf{X}_i$ and state-invariant unobserved factors, the error term is uncorrelated with the distance to the *caminho velho*. This assumption is reasonable, even without conditioning on any specific factors, as the discovery of the mines was a chance occurrence, resulting from the explorers following a somewhat arbitrary path set by Fernão Dias in 1674 (Palma, 2022). Therefore, municipalities were treated based on their location between a port (Paraty) and a random point in space rather than any specific characteristic that could have caused long-term development. Nevertheless, our estimates account for geographical factors to address the possibility that the expedition may have traversed areas with "favorable" geography, such as proximity to rivers. The covariate vector $\mathbf{X}$ includes the logarithm of median elevation, median precipitation, median temperature, distance to the coast, distance to rivers, area, and median terrain ruggedness index (TRI).

To account for potential bias stemming from unobservable factors that may be associated with favorable geographic features of certain municipalities, we employ an instrumental variable approach. Specifically, we use the least-cost path between *Paraty* and *Guaratinguetá*, and then to *Ouro Preto*, as an instrument for the actual path taken by the *caminho velho*. The least-cost path is calculated by using the reciprocal of the terrain ruggedness index (TRI) as the transition matrix and employing Dijkstra's method to allow connections through all eight adjacent cells. The resulting path is displayed in Figure J.1.

The main results are presented in Table J.2. Panel A shows estimates where population density is the variable of interest, while Panel B shows estimates with nightlight incidence as the dependent variable. Columns (1), (3) and (5) show OLS estimates controlling for geography and state fixed effects. Standard errors are clustered at the level of 1872 minimum comparable areas (MCAs) to account for spatial correlation between units.

The results indicate that an increase in *caminho velho* road density is associated with higher population density, nightlight incidence, and urban population density. Specifically, a ten-percentage points increase in *Velho* road density is associated with a 17.5% increase in population density, a 11.7% increase in nightlights, and a

Table J.2: *Caminho Velho* access and current population density

	Pop. Density		Nightlights		Urban Pop. Density	
	OLS	2SLS	OLS	2SLS	OLS	2SLS
	(1)	(2)	(3)	(4)	(5)	(6)
Velho Road Density	1.75***	1.80*	1.17***	0.961**	2.12***	2.14*
	(0.247)	(0.909)	(0.320)	(0.364)	(0.342)	(1.13)
Kleibergen-Paap F:		15.262		15.262		15.262
Observations	103	103	103	103	103	103
Number of Clusters	26	26	26	26	26	26

Notes: Clustered standard errors at the level of 1872 MCA in parentheses. Geography variables are the ones present in Table J.1 and a latitude-longitude second-order polynomial. The sample excludes municipalities that already existed in 1700 and Ouro Preto. $^{*}p < 0.1, ^{**}p < 0.05, ^{***}p < 0.01$

21.2% increase in urban population density. Importantly, these values are similar to the ones found in Gold roads exercise in the main text.

The findings of the two-stage least squares (2SLS) estimation are presented in columns (2), (4) and (6). The first-stage F statistics indicate a somewhat strong relationship between the density of the least-cost path and the density of the *caminho velho*. The coefficients of the 2SLS estimates are similar in magnitude to those from the OLS estimates, suggesting that omitted variables in the OLS estimates might not be a first order factor.

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