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Essays in Macroeconomics and Political Economy

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Resumo

Esta tese possui três capítulos independentes. O primeiro capítulo mostra que territórios étnicos ligados à resistência escrava, chamados quilombos, estão correlacionados com níveis mais altos de desenvolvimento econômico no Brasil. Para entender como os quilombos podem afetar a atividade econômica a longo prazo, proponho um novo mecanismo no qual as crenças religiosas iniciais e o trabalho com ferro africano e outras habilidades de alto valor são perpetuadas no longo prazo através da transmissão intergeracional cultural-religiosa. Primeiro, divido o território brasileiro em células de municípios virtuais de aproximadamente 11 x 11 quilômetros, o que possibilita o uso extensivo de efeitos fixos, e mostro que células com mais quilombos têm mais atividade econômica indicada por luzes noturnas. Segundo, para analisar os mecanismos pelos quais os quilombos podem afetar o desenvolvimento econômico e melhorar a identificação, emprego uma abordagem de inferência de randomização com configurações espaciais alternativas de quilombos contrafactuais. Mostro então que a proximidade aos quilombos está relacionada a ocupações mais altamente qualificadas e relacionadas a metais e a uma ampla gama de resultados culturais e religiosos, como atividades culturais, confiança da comunidade e ação coletiva mais elevadas. O segundo capítulo é co-autorado com Joaquim Andrade e Pedro Cordeiro. Este capítulo analisa questões de identificação de um modelo comportamental Novo Keynesiano e o estima usando métodos de informação limitada e de verossimilhança com conjuntos de confiança robustos à identificação. O modelo apresenta algumas das mesmas dificuldades que existem nos modelos DSGE de benchmark simples, mas a solução analítica é capaz de indicar em quais condições o parâmetro de desconto cognitivo pode ser identificado e os métodos de estimação robustos confirmam sua importância na explicação do modelo comportamental. O terceiro capítulo é co-autorado com Eustáquio Reis. Aplicamos uma abordagem de equilíbrio espacial para entender a heterogeneidade inicial de preços, população ocupada e renda do Brasil entre os municípios no final do século XIX. Compreender o equilíbrio espacial no passado é importante para gerar novas compreensões sobre o caminho de desenvolvimento adotado posteriormente no século XX, que mostraria um desenvolvimento espacial muito desigual e um alto grau de atraso econômico em um país abundante em recursos naturais e com uma alta relação terra-trabalho. Resultados preliminares mostram que o equilíbrio espacial inicial, quando alterado por variáveis geográficas exógenas, como rugosidade do terreno, clima e adequação do solo a commodities e alimentos básicos, gera resultados perversos de produtividade e bem-estar que às vezes são amplificados pelo nível de escravidão como fator de produção em um município .

Palavras-chave: quilombos; persistência histórica; macroeconomia comportamental; equilíbrio espacial.

Abstract

This thesis has three independent chapters. The first chapter shows that ethnic territories connected to slave resistance, called quilombos, are correlated with higher levels of economic development in Brazil. To understand how quilombos can affect economic activity in the long run, I propose a new mechanism where initial religious beliefs and African iron-working and other high-valued skills are perpetuated in the long run through cultural-religious intergenerational transmission. First, I divide the Brazilian territory in virtual municipality cells of approximately 11 x 11 kilometers, which makes possible an extensive use of fixed effects, and show that cells with more quilombos have more economic activity proxied by nightlights. Second, in order to analyze the mechanisms through which quilombos can affect economic development and improve identification I employ a randomization inference approach with alternative spatial configurations of counterfactual quilombos. I then show that proximity to quilombos are related to more high-skilled and metal-related occupations and a wide array of cultural-religious outcomes, such as higher cultural activities, community trust, and collective action. The second chapter is co-authored with Joaquim Andrade and Pedro Cordeiro. This chapter analyzes identification issues of a behavioral New Keynesian model and estimates it using likelihood-based and limited-information methods with identification-robust confidence sets. The model presents some of the same difficulties that exist in simple benchmark DSGE models, but the analytical solution is able to indicate in what conditions the cognitive discounting parameter can be identified and the robust estimation methods confirm its importance for explaining the behavioral model. The third chapter is co-authored with Eustáquio Reis. We apply a spatial equilibrium approach to understanding Brazil's initial heterogeneity of prices, working population, and income across municipalities in the late XIX century. Understanding the spatial equilibrium in the past is important to generate new insights on the development path taken subsequently into the XX century that would show a very unequal spatial development and a high degree of economic backwardness in an otherwise natural resource abundant country with a high land-labor ratio. Preliminary results show that the initial spatial equilibrium when shifted by exogenous geographic variables, such as terrain ruggedness, climate, and soil suitability for commodities and staple foods generate perverse results for productivity and welfare that sometimes gets amplified by the factor share of slavery in a municipality.

Keywords: quilombos; historical persistence; behavioral macroeconomics; spatial equilibrium.

Slave resistance, cultural transmission, and Brazil's long-run economic development*

Contents

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Os brasileiros devem, sem dúvida, alguma coisa a seus escravos, aos quais se misturam tão freqüentemente, e que talvez lhes tenham ensinado o sistema de agricultura que adotam e a maneira de extrair o ouro dos córregos. Além do mais, foram os seus mestres de dança.

[*Brazilians undoubtedly owe something to their slaves, whom they mix so often, and who may have taught them the farming system they adopt and how to extract gold from the rivers. Moreover, they were their dance masters.*]

Auguste de Saint-Hilaire, 1847[1]

1 Introduction

Slavery and labor resistance are usually associated with negative impacts on a variety of outcomes in the short and long run.[2] In this article, I show that ethnic territories with slave resistance, on the contrary, are systematically correlated with higher levels of long-run development in Brazil.[3] I explore historical episodes that generated ethnic territories with a concentration of run-away slaves, known as *quilombos*, which were commonplace across the Brazilian territory during the advent of slavery. More than 130 years after the abolition many of these resistance sites still exist today, which leads us to investigate why these places persist and how they affect economic activity.[4]

I show that a probable mechanism of how ethnic territories connected to slave resistance persist and transform economic activity in their proximity is the cultural transmission of occupational activities, specially those derived from African iron-making technology, and higher levels of trust and collective action possibly connected to cultural identity created

[1]Quoted in Versiani (2000).

[2]For example, at the sending side of the trans-Atlantic slave trade, there are negative effects in Africa on long-run development (Nunn 2008b) and trust (Nunn and Wantchekon 2011). At the receiving side, there are negative effects in the United States on human capital and occupations (Sacerdote 2005, Bertocchi and Dimico 2012), black labor wage and postbellum economic development (Hornbeck and Naidu 2014), political attitudes (Acharya, Blackwell, and Sen 2016), and fertility (Allen 2015). In Colombia, on income, human capital, health and public goods provision (Acemoglu, García-Jimeno, and Robinson 2012), and inequality and crime (Buonanno and Vargas 2019). In Brazil, on inequality, human capital, and public institutions (Fujiwara, Laudares, and Valencia Caicedo 2019). In the Americas in general, on current economic performance in a test of the Engerman-Sokoloff hypothesis (Nunn 2008a). And world wide, on inequality (Soares, Assunção, and Goulart 2012). In relation to labor resistance, it cam have negative impacts, for example, on technology adoption, capital investment, and labor productivity (*e.g.*, Galenson and Leibenstein 1955, Phillips 1963, Coomes and Barham 1994).

[3]Another paper that shows a unintended consequence of slavery that is not entirely negative is Teso (2018) that documents how the slave-trade demographic shock leads women today to participate more in the labor force, have lower levels of fertility, and be more empowered in household decisions.

[4]Fujiwara, Laudares, and Valencia Caicedo (2019) and Papadia (2019) also use quilombos in their analysis–to measure the intensity of slavery in the first case and as a general proxy for slavery in the second base–both approaches are very different from the focus of this article.

through the Ogun belief system. I use the Ogun belief system broadly defined as encompassing those African-based religions that have beliefs in Orisha spirits, considered to be African ancestors recognized as deities. Ogun, specifically, is the deity of iron, warfare, hunting and agriculture, and technology; he is responsible for introducing iron instruments to civilization. Fundamentally, I propose a novel channel of transmission in which initial beliefs causes the local economy to move towards skill-intensive occupations, but without any shock in formal schooling. These beliefs and occupations are then sustained through the intergenerational transmission of culture and religion. This mechanism complements another related strand of literature, in which only the migration of Europeans to the Americas (or other continents) is usually connected to the transmission of human capital, knowledge, know-how, and technology.[5]

The findings in this article is in line with a long-standing hypothesis and body of evidence brought forward by historians, anthropologists, and archaeologists that slave-based New World economic endeavors were entirely dependent on African iron-making technology and other high-valued skills. These skills were directly related to the Ogun belief system that, in turn, was connected to slave resistance. I not only find evidence to support this hypothesis but also show that it plausibly transformed economic activity through cultural and occupational mechanisms of transmission. This mechanism also complements the economic literature on religion that show positive economic effects mostly for Protestantism, Catholicism, or Judaism, although recently there is some evidence on the benefits of specific African rituals and other religions.[6]

To address the issue that historical changes in municipal political boundaries are endogenous to the location of quilombos and economic activity, I divide the country into arbitrary cells of approximately 11 × 11 kilometers each (0.1 × 0.1 degree), called virtual municipalities. I combine this gridcell with a geo-coded data set on the exact location of more than one thousand quilombos. In this setting it is possible to include real municipality and district (one level bellow the municipality) fixed effects. I show in Figure 1 a detail of Brazil's Northeast region with quilombos assigned to the virtual municipality cells overlaid by nightlights and in Figure 2 a zoom of the gridcell with real municipality borders.

I find that virtual municipalities with quilombos have higher levels of economic activity

[5] See, for example, Glaeser et al. (2004), Carvalho Filho and Monasterio (2012), Easterly and Levine (2016), Rocha, Ferraz, and Soares (2017), Droller (2018), and Sequeira, Nunn, and Qian (2020). In contrast, Sacerdote (2005) shows that slave descendants can catch up with free blacks in a variety of outcomes through intermarriage and intergenerational transmission of human capital.

[6] For example, see Botticini and Eckstein (2005), Botticini and Eckstein (2007), Becker and Woessmann (2009) for a view on Judaism and Protestantism and Valencia Caicedo (2019) for a survey of Catholic missionaries in Latin America and Asia. In addition, see Clingingsmith, Khwaja, and Kremer (2009) and Campante and Yanagizawa-Drott (2015) about Islamic rituals, and Nunn and Sierra (2017) and Nunn, Sierra, and Winkler (2019) about African rituals.

proxied by the number of nightlight pixels lit in the virtual municipality.[7] Quilombos are related to more nightlight pixels in a virtual municipality over two decades: taking the average of nightlights in 1992 and 1993, 2002 and 2003, and 2012 and 2013. For example, a 10% increase in the number of quilombos in a virtual municipality increases the number of lit pixels in 4.67% in 2012-2013.

An extra feature of the virtual municipality analysis is that I pair neighboring virtual municipalities, that is, each cell with its eight adjacent cells, similar to Michalopoulos (2012). This allows for the inclusion of neighbor-pair fixed effects eliminating any bias introduced by unobservables that are common across the arbitrary virtual boundaries. I then use two more specifications, one with the difference in the number of quilombos and lit nightlight pixels that exist between the two neighboring virtual municipalities and the other with the sum of common quilombos and nightlights. This dyadic analysis furthers alleviates concerns that unobservables might be driving the results. The results are highly robust to these specifications. A difference of one quilombo between neighbor-pairs is correlated with a difference of 2.9 pixels between them and an increase in 10% of common quilombos between neighbor-pairs is correlated with an 1.8% increase of common lit pixels.

Despite the extensive use of fixed effects, there are still two problems with the virtual municipality analysis. One is that the choice of places by running-away slaves is not random, thus the virtual municipality results could be simply capturing the effect of some unobservable that causes both the establishment of quilombos and higher level of nightlights in the long run. The other issue is that the variables that can be used to investigate the persistence mechanisms are mostly at the real municipality level, hence it is impractical to continue with the virtual municipality analysis.

I thus employ an additional empirical strategy to better examine the impact of quilombos: a randomization inference-type approach with historical narrative evidence that enables the construction of counterfactual spatial configurations of quilombos, similar to Dell and Olken (2020). I use the fact that a broad array of the literature on the history and the geography of quilombos describe them as always close to rivers and close to themselves.

Quilombos are described to be close to rivers first because a source of fresh water is essential to survival, even more before the abolition when seeking other sources of water would mean exposure to risk. Second, rivers would provide a safe escape route when needed. Third, rivers were very useful as a means for everyday transport, considering that transportation costs were very high in Brazil. And fourth, rivers would provide a source of food and income with fishery and mangrove firewood. In addition, quilombos would form one close to

[7] This result is robust to using other measures of nightlights such as the sum of light density in the virtual municipality.

another, but not too close. This effect, similar to an agglomeration with dispersion effect in the spatial economics literature, exists because of a trade-off between scale economies and transportation costs (Proost and Thisse 2019). The general concentration of slaves in a specific area producer of commodities would naturally cause more concentration of run-away slaves in specific regions. High transportation costs would then geographically constrain the running-away slaves to this region; in addition, quilombos would provide scale economies to run-away slaves, generating quilombo agglomerations. A dispersion force would also be present because of the desire of run-away slaves to avoid competition in the attention of slave hunters, which would lead quilombos not locating, say, right next to each other. This generates a spatial configuration with many suitable locations, but once a quilombo was formed it constrained the formation of other quilombos. Shifting a quilombo would change the spatial configuration, but most likely all the municipalities would remain the same.

I compare the impact of proximity to an actual quilombo to the average effect of 1,000 alternative feasible spatial configurations of counterfactual quilombos. The p-values are computed by comparing the effect of the actual quilombo to the distribution of the effects of the counterfactual quilombos. A feasible spatial configuration for the counterfactual quilombos has to satisfy three constraints: (1) be relatively close to a rive because of the demand for fresh water, (2) be relatively close to one another and to a real quilombo due to the agglomeration effect, but (3) not right next to each other or an actual quilombo as a result of the dispersion effect. Figure 3 depicts this approach showing one example of the location of real and counterfactual quilombos in constrained areas. Figure 4 demonstrates all actual quilombos and one random alternative spatial configuration.

Using this randomization approach I document that proximity to quilombos predicts more cultural initiatives supported by the local government for quilombo communities and Afro-religious communities, that is, any religous variant of the Ogun belief system, and more *capoeira* groups, which is a form of dancing and martial arts with a strong connection to resistance. Proximity to quilombos predicts more community trust and collective action, although I do not find any effects for generalized trust. I also document that proximity to quilombos cause an increase in the supply of craft and related trades and skilled agriculture and fishery occupations, which include high-skilled occupations. Finally, proximity to quilombos increase the probability that handcraft activities (*artesanato*) with metal are among the top handcraft activities developed in the municipality. Furthermore, I track skilled occupations related to slave resistance through time and document that proximity to quilombos increases the number of people engaged in these occupations both in 1980 and 2010, which shows that this effect is not an artifact of recent economic development.

To further alleviate the concerns on the potential endogeneity of quilombo placement, I conduct a placebo-type test using the location of quilombos that were destroyed in the XVIII and XIX centuries. Provided that the placement choice of the run-away slaves of the destroyed quilombos and the current quilombos are not systematically different along some dimension or that the slave hunting expeditions followed some systematic pattern, then we can expect destroyed quilombos to be valid placebos. I do not find any significant effect of the placebo quilombos on cultural-religious or occupational outcomes, which suggests that what matters in the long run is associated to the actual quilombos and not to some variation driven by systematic selection of places by run-away slaves.

A related alternative explanation for these results could be simply that run-away slaves picked the best places back in the XIX century to establish quilombos. These quilombos then benefited from growth spillovers in the long run. Using the 1872 census and 1875 data on wages I show that this is probably not the case. There is no significant relationship between current quilombos and human capital stock of the free population and slaves in 1872 or income levels in 1875.

Other channel that could be affecting the results is related to institutions and public goods, in which colonial institutions or public goods put in place to explore commodities or investments made towards the colonial elite spillover to the rest of the population in the long run (*e.g.*, Huillery 2009, Feyrer and Sacerdote 2009, Bruhn and Gallego 2012, Naritomi, Soares, and Assunção 2012, Jedwab, Kerby, and Moradi 2017, Dupraz 2019, and Dell and Olken 2020). I show that the relationship between quilombos and institutions and public goods is mostly null. If anything, the results sway on the side of Naritomi, Soares, and Assunção (2012), which show how different colonial institutions in Brazil have different negative effects on a variety of outcomes in the long run; in some specifications, proximity to quilombos point towards a more unequal land distribution and a worse public good provision.

Finally, I show a map with selected quilombos that are driving the proximity results and what African ethnic groups where brought as slaves to each region. The selected quilombos are in areas where Africans from the Yoruba-Nago and Jeje Mina ethnic groups were brought as slaves. Reassuringly, these ethnic groups are exactly the ones that the literature describes as having well developed iron-working and related skills. This ties back the discussion to our main mechanism.

This article is related to the literature on historical persistence with interactions between culture and institutions. This literature postulates that the effects of historical shocks can persist until the present through a variety of channels, *e.g.*, geography, climate and natural endowments, institutions, legal origins, culture, ethnolinguist traits, and human capital.[8]

[8]Some seminal and recent contributions include Engerman and Sokoloff (1994), Sachs and Warner (1995), Diamond (1997), Landes (1998), Porta et al. (1998), Acemoglu, Johnson, and Robinson (2001), Glaeser et al. (2004), Michalopoulos (2012), Voigtländer and Voth (2012), Maloney and Valencia Caicedo (2016), Guiso,

And also to the spatial persistence literature, in which economic activity is shown to be stable in certain locations, even following large shocks. Recent contributions have pointed, more importantly, to the role of agglomerations in driving spatial persistence over the long run (Bleakley and Lin 2012, Ehrl and Monasterio 2019).

More closely related are Botticini and Eckstein (2007) and Valencia Caicedo (2018) that have specific mechanisms of occupational transmission. Botticini and Eckstein (2007) shows how Jewish religious norms led to investments in human capital and a transition to skilled occupations. Valencia Caicedo (2018) documents that Jesuit missions in Brazil, Argentina, and Paraguay invested heavily in education and crafts training, causing the population in proximity of the missions to have higher levels of human capital even after 250 years. The mechanism of persistence in the Jesuit's case is the structural transformation of the economy towards skill-intensive occupations and the adoption of agricultural technologies. My mechanism, in contrast, does not hinge on an initial schooling or training shock. It also lends support to theoretical models of intergenerational transmission of cultural and religious traits (Boyd and Richardson 1985, Bisin and Verdier 2000, Bisin and Verdier 2001).

This paper is organized as follows. In section 2, I present all the necessary historical background on quilombo ethnic territories and their relation to culture, skills, and occupations. In section 3, I present the current institutional framework regulating quilombos in the Brazilian territory and the derived data set. In section 4, I present the virtual municipality analysis, in section 5 the analysis with counterfactual quilombos, and in section 6 the conclusion.

2 Historical Background

The historical argument proceeds in three steps. First, I present the formation of quilombos in historical perspective, which leads to ask what caused the necessity of quilombos in the first place. In the second section I answer this question by arguing how the necessities of colonial trade cycles led to a slave trade that was not random but rather one that sought for specific occupation skills. In the last section, I show how these high-valued skills are connected to the Ogun belief system and to slave resistance.

Sapienza, and Zingales (2016), Lowes et al. (2017), Valencia Caicedo (2018), Lowes and Montero (2018b), Lowes and Montero (2018a), and Giuliano and Nunn (2019).

2.1 The formation of quilombos in historical perspective

The Portuguese-Brazilian slave trade was responsible for approximately half of all slaves transported across the Atlantic in the 400 years between 1500 and 1900.[9] Historical records indicate slaves accounted for at least half of the population or more of most places that had slavery. Of 100 persons that entered Brazil from 1550 to 1850, 86 were slaves (Alencastro 2018).

A great concentration of slaves invariably led to a large number of them escaping and forming community-based ethnic territories, denominated firstly *mocambos* and later *quilombos*, with the former remaining in use only for temporary hideouts.[10] This distinction reflects different etymological origins. *Mocambo* was the name given to housing made in a craft fashion, most of the time with fragile material, such as various forms of straw and ready available wood, but sometimes with more robust clay techniques that are still in use today. Whereas *quilombo* comes from African Bantu etymology in the region of Angola, where there was a city with this name. The word takes on a shape-shifting meaning, first of resting place for nomad people, and later came to signify more broadly as union, warrior camp, and village. In Brazil, coming to rest on the notion of slave resistance locations where culture and tradition replicate and communal property rights are established.

Quilombos in Brazil, however, have a distinctive feature from all other places in the Americas. These ethnic territories proliferated as nowhere else, mostly because of their capacity of integration with the economy of each region where they were present (Gomes 2015). Quilombos play a dominant role in Brazilian history and over three thousand of them continue to exist today. From over five thousand municipalities currently existent in Brazil there are quilombos in 14% of them.[11]

The first mocambo formed in Brazil dates from 1575 in Bahia, but only in 1740 the colonial legislation through the Ultramarine Council officially defined a quilombo as: "all dwellings of runaway blacks that go beyond five, partly unpopulated, even if they have no raised ranches or pestles are found in them" (Gomes 2018). Aside from the formal definition, there was a great variety of quilombos. A tentative typology would include: "ancient and populous"[12];

[9]From a total of 12.5 million slaves that embarked in Africa, 5.5 million were headed to Brazil. In comparison, 472 thousand embarked for Mainland North America. In leeway of a timeline, embarkations per century to Brazil from Africa are in the order of 35 thousand slaves in the XVI century, 910 thousand in the XVII century, 2.2 million in the XVIII century, and 2.3 million in the XIX century (The Trans-Atlantic Slavetrade Database, www.slavevoyages.org).

[10]These communities also known as *cumbes* in Venezuela, *palenques* in Colombia, *bush negroes* in Guiana and Suriname, *maronage* in the French Caribbean, *cimaronaje* in the Spanish-speaking Caribbean (especially Cuba and Porto Rico), and *maroons* in the English-speaking Caribbean and North America.

[11]According to Anjos (2009), which is probably the most complete published source there are currently 3,231 quilombos distributed among 5,565 municipalities.

[12]Here I include Palmares (in the captaincy of Pernambuco, now Alagoas), perhaps the most famous

"mobile and dissoluble", these are temporary groups that would practice robberies; "protest and negotiation", which would form to gain bargaining power with their masters and public authorities; "open frontier", those on the fringes of civilization; and "urban and suburban", those near urban centers. There is evidence of *petit marronage* (quilombos on the smaller scale) and suburban quilombos in many urban centers, such as Salvador, Recife, Vila Rica, Rio de Janeiro, Belém, and Villa Boa (*e.g*, Carvalho 1991, Gomes 2010, and chapters in Reis and Gomes 2012). To illustrate what a quilombo was like in the colonial period, Figure 5 shows a depiction of the São Gonçalo quilombo in Minas Gerais in 1796. Note that the edification indicated with the number one is a blacksmith's house.

The quilombos today are mostly like reminiscent of the quilombos in the turn of the XVIII century with the decay of the gold cycle and of the XIX century when increasing manumissions, the 1850 Land Law, and abolition led quilombo ethnic territories to become the locus of resistance *per se*, where black populations could settle on land that they could call theirs (Anjos 2009, Gomes 2015). These sites did not function merely as hideouts, but became embedded in the economy and society as recent Brazilian historiography has come to establish. These communities show great longevity because they were never isolated, they developed trade with many sectors of colonial society, including taverns, markets, and fairs, with the likes of fishermen, farmers, miners, peasants, natives, and urban dwellers, free or enslaved. A representation of such argument is the painting by M. Rugendas in Figure 6 that shows products from quilombos do Iguaçu arriving at the Court market in Rio de Janeiro around 1825, at time the capital of the Empire of Brazil (Gomes 2012).

Most importantly, what the quilombos had in common is the organized reproduction of ethnic and religious traits tied to a specific territory. This reproduction is socially organized not just through the rituals and festivities, but also by the intergenerational development of crafts and trades for production of marketable surpluses and for labor supply in the vicinity. As Anjos (2009) has pointed out, quilombos are the most expressive territorial factor of colonial Brazil.

2.2 Colonial trade cycles, occupational skills, and the slave trade

African skills in ironworks were already know by the Portuguese before the establishment of the colony in Brazil. The following quote by Hieronymus Munzer from Portugal in 1493

quilombo in history, which was estimated to have between 20 and 30 thousand inhabitants and, as said with some alarmism by the Ultramarine Council, a greater circumference than the Reign of Portugal. Palmares was destroyed only after many incursions by the Colonial state in 1694. Approximately as large as Palmares, quilombo do Ambrósio and quilombo Grande in Minas Gerais was said to have between 10 to 20 thousand people, depending on which account, and was destroyed only after many incursions as well, in 1746 and again in 1759 (Moura 1981, Anjos 2009, Gomes 2015).

from the Archivo dos Açores (1878) attests that: "There were so many blacks working at the forges that you might believe them to be Cyclops and the shop the cave of the Vulcan" (quoted in Saunders (1982) and Libby (1992)). Much before, African craftsmen were already demanded for their skills since the Roman times (Yavetz 1988). The development of superior iron making in Africa date back to establishment of societal living in the Niger delta. It then spread across the continent with the mass movement of people in what is known as the 'Bantu Migration' (Shillington 1995). The process of ironmaking was both artifactual and religious. Smelting of gold and iron were often carried out by the same occupational clan and considered a sacred science (Richards 1981, Libby 1992). In addition to mining and metallurgy, African craftsmanship was also desired for cattle raising and agriculture, and other generally useful related crafts like woodworking. Thus it was not random that the slave trade was directed to certain parts of Africa (Klein 1971).

These skills were sought equally for gold mining and sugar plantation, the two main colonial cycles in Brazil. Mining required a wide range of skills–carpenters, masons, and smiths were essential. Russell-Wood (1977) makes the case for the gold mining areas: "The characterization of the average Portuguese migrant to Minas Gerais as a person who stopped in a port city only long enough to buy a horse contained more than an element of truth. For the most part, European migrants did not have any prior experience of gold mining. This was reflected in the absence of technical innovation in Minas Gerais and was especially serious insofar as the miners were unable to exploit the veins fully. In contrast, some "Mina" slaves had prior knowledge not only of gold mining, but of metallurgy." Mina salves originated from the "Costa da Mina" region in Africa, where mining and metallurgy was highly developed.

Russell-Wood (1977) adds that in the history of African contributions to the New World, the transfer of such technical skills was a major legacy. The introduction of the *cadinho* (crucible) technique, which is used until today for iron smelting in Brazil, is credited to be an African technology introduced in the XVI century. Freyre (2003) and Baer (1969) consider African iron technology as a fundamental shaper of iron mining and iron manufacturing in Brazil, citing as their source, among others, observations made by Wilhelm Ludwig von Eschwege, a German geologist and metallurgist hired by the Portuguese Crown to direct iron mining and smelting in Portugal and that later went with the Court to Brazil in 1808. Freyre (2003) also quotes Calógeras 1930, an early Brazilian historian, whose observation complements Russel-Wood's: "In one case, they [the slaves] were the guides of the Brazilians, their is the merit of the first direct iron preparation industry in the rudimentary forges of Minas Gerais, the natural fruit of the practical science infused in these native metallurgists who are the Africans". Additionally, there is evidence of slaves running entire iron factories in São Paulo (Florense 1996).[13]

Despite popular thought of the production of sugar as low-tech business; like gold and iron mining and smelting, it requires a surprisingly wide array of skills. Schwartz (1978) documents that the transition from indian to African slave labor in sugar was, among other factors, a matter of superior productivity and skills of Africans workers. The occupational skills required in a sugar mill range from the sugar master, which was usually a high ranking employee, to the skimmer, kettleman, mill tender, presser, carpenter, and blacksmith that were occupations delegated to African slaves.[14]

African skills were, at the same time, sought-after for familiarity with long term agriculture and cattleherding (Schwartz 1978). Many of the practices connected to cattleranching were observed to be of African origin (Freyre 2003).[15] In fact, agricultural and ironworking skills are connected as smelting of iron ore needs large quantities of hardwood charcoal. Agricultural skills is also connected to cattleraising as Versiani (2000) reports that August Saint-Hilaire, a french naturalist that left numerous descriptions of his travels, saw slaves using a singular fertilizing technique in a corn field. August Saint-Hillary remarks that Brazilians should be indebted to their slaves, as the slaves thought agriculture and gold mining to them, in addition to being their dance masters.

2.3 Intergenerational transmission of African skills and the Ogun belief system, and their relationship to slave resistance

Dancing and other rituals had most of the time a religious meaning to the Africans in Brazil. The Ogun deity worked as the unifying Orisha for a number of African traditions that were adapted in the New World (Barnes 1997). Candomblé, Macumba, and Umbanda are the three most known traditions that flourished in Brazil. Others less known include Tambor de Mina, Xangô, Quimbanda, and Cabula. In addition, as Libby (1992) argues the slave trade forced many people into what "was not their original occupational caste. Ogun, as a belief system that underlay social development through ironmaking, carried across an internal stability, or self-congruity, to these traumatized individuals who needed to either give up, or take on, new roles. Africans in the Americas mentally survived these changes by altering the structure of the Ogun belief system: he became the God of resistance and revolution." Reis (2011) argues that the Nagô nation played a leading role in slave resistance in Bahia and was possibly inspired by Ogun, who became increasingly popular in Yorubaland in Africa in the most intense part of the Bahian slave trade from that African region in the period from

[13] See Libby (1992) for a discussion of the introduction of African technology in North American furnaces.
[14] Further consult Schwartz (1978) for a complete description of a sugar mill occupational structure.
[15] At which point Freyre (2003) adds one more superior African skill set to the list: cooking.

the 1820s throughout the 1840s. For many ethnic groups traveling across the Atlantic meant going from a Nation-state in Africa to a religious nation overseas (Anjos 2009).

Running away from slavery meant more than just an act of rebellion, notably in urban and suburban environments, it provided the foundation of evolving cultural and ethnic identities. Running away also meant more than just severing ties with the world of slavery, it meant that the boundaries of the institution of slavery itself could be reinvented (Gomes 2010).

As such, various expressions of African identity and cultural expression were outlawed and repressed by colonial authorities, even well into the Republic, such as capoeira groups, candomblé, and even gatherings at taverns. Chvaicer (2002) details how capoeira was persecuted throughout the whole colonial period. Candomblé persecution is even more persistent, as it is perpetuated until today, despite not being formally prohibited anymore.[16] Gomes (2005) details how taverns and other points of commerce were actively persecuted for even minor gatherings of black slaves, such legislation often included incentives for the population to turn against each other. One of such rulings took the form: "...the salesman or saleswoman that consent gambling and gatherings of black slaves will be sentenced in the first time to five thousand réis and after that in double and in such rulings half will be collected by the soldiers and other half will be given for the informer" (Office of the Governor Sebastião de Castro, 1695).

Reis (2011) shows the deep connection between candomblé and slave resistance. Candomblé helped slaves to endure and even overcome slavery and became an effective tool of negotiation for gaining cultural and social space for Africans. Most of the time these were not grandiose acts but day-to-day acts of resistance.[17] In a sense, candomblé meant a reversal of the power structure: "[t]he use of ritual, magico-phamacopoeic means to alter the extreme inequalities of power in colonial and slave-based societies must be understood as a principal form of black resistance to slavery in Brazil" (Harding 2000). The proliferation of candomblé, however, need not be confined to the quilombo territorial extension, which contributed to the intergenerational transmission of beliefs and values in the proximity of quilombos. This proliferation demanded the formation of kinship groups, promoting the cooperation with their Creole descent, to guarantee a sufficient number of people for intergenerational transmission (Parés 2018).

[16]See Reis (2011) about the colonial period. In the Republic, capoeira and candomblé endured a prohibition that lasted from 1890 to 1935-1940. Capoeira was prohibited by the Law of Vagrants and Capoeiras and a similar law existed prohibiting candomblé under crimes against public health.

[17]"The belief that sorcery could help slaves obtain manumission or break the willpower of and even kill their masters was widespread" (Reis 2011).

3 Institutional Framework and Data

There is a variety of ways in which the quilombo population came to claim some territory after the Abolition.[18] Anjos (2009) cites seven main contexts: Bankrupt and/or abandoned farm occupations; purchase of property by manumitted slaves; donations of land by farm owners to former slaves; payment for services rendered in official wars; lands of some religious order left to former slaves; coastal occupations of land under the Navy control; and extensions of federal land not properly registered.

It was not only until the 1988 Constitution that quilombo descendants received an opportunity to claim formal property rights for their territory. Article 68 of the Transitional Constitutional Provisions Act states that "the remants of the quilombo communities occupying their lands are recognized as having definitive property, and the State shall issue them with the respective titles" (Gomes 2018). This process is not automatic nor easy, though. Quilombo communities have to first be recognized as legitimate slave descendant communities with the Palmares Foundation, a government agency in charge of certifying self-proclaimed quilombos, and then apply for the title with another government agency, depending if the jurisdiction of the land is at the federal or the state level. The titling process is more demanding for the communities, as it involves reports by geographers for the demarcation of the land and by anthropologists to prove slave ancestry.

This new institutional framework led the quilombo communities to come out of the shadow of history. In order to be recognized they had first to be known. The database in Anjos (2009) is constructed since 1997 with an active search for communities consulting all levels of government, federal agencies and ministries, universities, and black associations. The database is constructed by community name at the municipality level and includes communities not yet certified by Palmares Foundation, communities that are already certified, and communities that have the property right title, which are still the very minority. This source is probably the most complete in the sense that it minimizes selection problems by doing an active search, but it does not have the geolocation of any of the communities available. It contains 3,231 quilombo communities.

Palmares Foundation in its process of certifying the communities has also constructed a comprehensive database of quilombos. It has 2,709 quilombos communities in the public database as of the end of 2018. The Foundation asks for the geolocation of the quilombo territory for the communities, which then self-supply the coordinates. From the communities that did supply coordinates I did a consistency check–excluding some obviously wrong (*i.e.* cases that fall in the middle of the ocean, lakes or rivers) and some probably wrong (*i.e.*

[18]Acquisition of public lands by homesteading was not possible, since the 1850 Land Law established the private commercial transaction as the only form of access to unused public lands.

places in desolated areas that do not have any human presence) coordinates–and was able to recover the geographic coordinates of 1,124 quilombos. The states of Amazonas, Rondônia and Roraima in the Amazon forest do not show any presence of black populations until the XIX century, and Acre was not part of Brazil until 1903, thus I exclude these states from the analysis. This leaves me with 1,115 quilombos.

Using the Palmares foundation geolocated data set, I then construct two measures for the "quilombo treatment" to use in the analysis. In the virtual municipality approach I use the number quilombos in a virtual municipality cell and in the randomization inference approach I use the distance from the outcome of interest to the nearest quilombo.

There are two main concerns with my final quilombo selection. One is that quilombos that apply for certification from Palmares Foundation may be different from those that did not apply and the second is that quilombos able to provide geographic coordinates can also be different from the others that did not supply coordinates. In Figure 7 I show the Anjos (2009) database by municipality and my final database as geolocated points. There is not much difference in terms of the geographic location of the quilombos between the two, thus concerns about some systematic geographic selection in the geolocated subset can be probably minimized. What is different is the number of quilombos in some places. In this case, what I measure in the randomization inference approach is the effects of proximity of the nearest quilombo, so there could be one or any number of quilombos in the proximity of a municipality seat, but the treatment measurement of interest (proximity to the nearest quilombo) would be approximately the same.

The outcome I use in the virtual municipality analysis is the number of lit nightlights pixels in a virtual municipality cell nightlights for averaged for consecutive two year across two decades, I look at 1992-1993, 2002-2003, and 2012-2013. I use the DMSP-OLS nighttime lights time series from NOAA. The nightlights are measured in scale from 1 to 63, I consider a lit pixel any pixel which is within this range, and an unlit pixel with zero cloud-free light observations.

The outcomes in the randomization inference approach falls in two categories: at the individual level or the municipality level. At the individual level, I use data from Latinobarometer for generalized trust and from LAPOP (Latin American Public Opinion Project) for community trust and collective action. I then geolocate all the individual responses. Most of the observations I can identify the municipality of the individuals and thus use the geolocation of the municipality seat. For a bulk of the observations of LAPOP I can identify the census tract of the individuals, in this case I use the geolocation of the census tract's centroid. I also use individual-level data from the IPUMS project for two groups of occupations: crafts and related trades, and skilled agricultural and fishery. I then aggregate and geocode this data at the municipality level, which is the lowest level possible.

At the municipality level, I use various outcomes from the Brazilian Municipal Survey (MUNIC) of the Brazilian Institute of Geography and Statistics (IBGE), on the existence of cultural activities for quilombo community and afro-religous supported by the local government, the existence of capoeira groups, and if metal handicraft is among the main handicraft activities of the municipality. In addition, I use schooling data from the 1872 Census and 1875 wage data from Reis (2014). Finally, I use municipal-level data from Naritomi, Soares, and Assunção (2012) on governance, access to justice, land Gini, health centers, sewage, and public libraries. To this set of variables, I add Bolsa Família transfers from IPEAData.

4 Virtual Municipality Approach

4.1 Cross-virtual municipality analysis

I begin the empirical analysis by combining the geocoded location of 1,115 quilombos and divide the Brazilian territory (except Amazon states of Acre, Rondônia, Roraima, and Amazonas) in cells of 0.1 × 0.1 degree, which is equivalent to approximately 11 × 11 kilometers at the equator, effectively creating 53,960 virtual municipality cells.

For each cell I calculate the number of nightlights lit pixels, area, mean elevation, mean ruggedness, annual average temperature, annual precipitation, and using the centroid of the cell the distance to the coast. Thus each cell becomes a "virtual municipality" with different levels of economic activity, number of quilombos, and geographic characteristics. The specification then follows

$$ln(litpixels_v) = \alpha_1 + \alpha_2 ln(quilombos_v) + \alpha_3 GEO_v + \delta_{m,d} + \epsilon_v \tag{1}$$

where $ln(quilombos_v)$ is the natural logarithm of the number of quilombos in a virtual municipality v, GEO controls for all the geographic characteristics, $\delta_{m,d}$ are real municipality m or district d fixed effects, and ϵ is an idiosyncratic error.

Table 1 presents the results for specification 1 with nightlights averaged for 1992-1993, 2002-2003, and 2012-2013 in two versions, one with over 5,000 real municipality fixed effects in columns (1), (3), and (5) and other with over 10,000 district fixed effects in columns (2), (5), and (6). The α_2 coefficients for the quilombos show a positive correlation with lit pixels, significant at the 1% for all specifications. A 10% increase in the numbers of quilombos in a virtual municipality is correlated with a 2.19% increase in lit nightlight pixels in 1992-1993, a 3.69% increase in 2002-2003, and a 4.67% increase in 2012-2013. These results are likely carried with economic significance, although it is not yet clear exactly how much of the lit pixels translate into economic activity. It is unlikely that the effect of certification itself is driving the results because none of these communities were certified by Palmares Foundation in 1992-1993 and a minority of them was in 2002-2003.

4.2 Neighbor-paired analysis

Turning to the neighbor-paired specifications, I pair each virtual municipality with its eight adjacent neighbors, as illustrated in Figure 8, generating 213,100 unique dyads that are the unit of analysis. For the geographic characteristics, I use the same variables as in the cross-virtual analysis and calculate averages for the pair weighted by the area of each of the cells constituting the neighbor-pair. I then run the following specification

$$f(litpixel_{np}) = \beta_1 + \beta_2 f(quilombos_{np}) + \beta_3 GEO_{np} + \eta_{np} + \mu_{np} \tag{2}$$

where $f(litpixel_{np})$ is a function of lit np neighbor-pair pixels that can be either the difference of lit pixels between virtual municipality cell n and its neighbor-pair p or the sum of the common lit pixels of both n and p, $f(quilombos_{np})$ is a function of the number of the np neighbor-pair quilombos that, like the lit pixels, can be either the sum or the difference between n and p. GEO are the geographical controls, η are 53,843 neighbor-pair fixed effects, and μ is an idiosyncratic error.

Table 2 shows the results for specification 2. In column (1) the β_2 coefficient for the difference in lit pixels between the two virtual municipality pairs is 2.91 and in column (2) the β_2 coefficient is 0.18 for the sum of common lit pixels. This shows that, despite a very demanding specification with 53,843 fixed effects, the correlation between quilombos and lit pixels is still very robust, likely economically significant, and statistically significant at the 1% level.

5 Randomization Inference Approach

This section presents the main results of the paper. I present the randomization inference method, how the counterfactual and p-values are constructed, and the geographic balance of the counterfactual sets. In sequence, the persistence mechanisms that rely on the historical process described in section 2, in which the slave trade, African ironworking and related skills, culture, and religion are tied to quilombo establishment and slave resistance. To better validate the persistence mechanisms I present a placebo-type test of destroyed quilombos and tests of some alternative hypothesis. I close the section with a link of African ethnic groups and quilombos that are driving some results.

5.1 Empirical strategy

5.1.1 Quilombo assignment

I use the randomization inference approach developed in Dell and Olken (2020) and adapt it to the setting of quilombos. Explaining the selection of places by run-away slaves to form quilombos is fundamental to identifying its long-run effects. Given the great variety of quilombo types it is useful to diagnose in the literature some general characteristics, instead of trying to impose elements of one specific type of quilombo over the others. This section goes over four issues that can be considered to be general to all quilombos: sparse information, transportation costs, economies of scale, and proximity to rivers. In doing so, we can construct a counterfactual that is equal to the actual quilombos, except for the fact that they are places that were not chosen by chance.

Run-away slaves had sparse information on the surrounding region. There could be an indication of where was a good place in the sense of having natural resources available and conditions for protection against eventual attackers, but it is not the case that they were optimally choosing the best places. A lot of the times there was previous communication of run-away slaves with the enslaved. There are many examples in the literature of either the slave master allowing free communication of his slaves with the outside would or of free blacks and run-away slaves joining the enslaved in their quarters (*senzala*) for parties, festivities, rituals, and commercial trade. This would foster an information flow of places where other quilombos were or what places might allow a new quilombo to flourish.

The general concentration of slaves in commodity-producing areas along with this knowledge exchange would produce an effect similar to an agglomeration with a dispersion effect.[19] An agglomeration effect, on the one hand, has mainly two ingredients: transportation costs and economies of scale. Transportation costs was very high in Brazil in the XIX century, railroad lines were concentrated in specific areas and developed only in end of the century, and roads were precarious (Reis 2018). The lack of a good transportation network, in addition to not having states free of slavery in Brazil, discouraged long-distance travel.[20] Economies of scale can arise internally or externally to the quilombo. Internally, economies of scale can occur in relation to some public goods designed to provide collective services to its inhabitants, like security against slave hunters.[21] Economies of scale can also appear external to the quilombos but specific to the local environment where one quilombo benefits from the

[19]See Proost and Thisse (2019) for a summary of the main driving forces in spatial economics and a broad survey of the literature.

[20]Compared to the "underground railroad" in the United States, for example, where run-away slaves were expected to flee the South and reach the states in the North or Canada and had more modals available.

[21]On a related note, for an examination of how human capital externalities can arise internally in similar village settings see Wantchekon, Klašnja, and Novta (2014)

the presence of other quilombos.

On the other hand, the agglomeration effect is counterbalanced by a dispersion effect. This happens because of the desire of quilombos to avoid competition in capturing the attention of the government and of the slave hunters (*capitães-do-mato*).[22] The Colonial government would be wary of large quilombo agglomerations and would brutally invest against those perceived as a threat, for fear of a rebellion.[23] This effect, however, would not be so strong as to completely disperse the quilombos in isolated areas. The reward for the slave hunter was set up as to value more the run-away slaves captured far away from the municipalities, so the quilombos had an incentive to stay close to towns, villages, and cities.[24]

The quilombo ethnic cartography literature cites the close relationship of quilombos and rivers in every part of Brazil (Anjos 2009). In the Amazon they are inseparable, most quilombos there are referenced by a river. Furthermore, the type of gold mining practiced in Brazil that was inseparable from rivers created a natural link between quilombos and rivers in the gold mining areas. In areas of Minas Gerais and Bahia connected to the gold cycle, quilombos would form in great number in the valleys of the Verde, São Francisco, and Conta rivers where cattle-ranching was also present. In the Rio de Janeiro province, quilombos were known for their resourcefulness in the region of the Baixada Fluminense rivers that enclose the colonial capital, run-away slaves would use the rivers to create a network of mangrove firewood trading and escape routes, making it virtually impossible to catch them all. Quilombos are presented as hydras, inspired by the mythological Hydra of Lerna and accounts of police chiefs that used the term to refer to the fact that many more quilombos were always born from those that they had just destroyed. Gomes (2005) further develops the concept of "the hydra and the swamp" to convey the fluidity of the network of social and economic exchange between the run-away slaves and those still enslaved, indigenous groups, salesmen, dealers, small owners and even farmers, and the fact that slave-hunting expeditions would always bog down in the social environment that encircled the quilombos. This concept further reinforces the basis of the agglomeration with dispersion effect.

[22] For more on the *capitão-do-mato* institution see Goulart (1972), Dantas (2004), and Lara (2012). And for a related theoretical discussion on slave guarding and how it relates to the institution of slavery see Lagerlöf (2009).

[23] The fear of rebellion was largely an aftereffect of Palmares (Guimarães 2012). Other later episodes such as the Huasa revolt of 1814 and the Nago revolt of 1835, both in Bahia, also contributed to the fear of a large-scale rebellion.

[24] One example of this type of compensation is found in 1715 when the governor of São Paulo and Minas do Ouro stipulated that the run-away slaves captured within one league (approximately 6km) from Vila Rica and Vila Real would render four *oitavas* (a Portuguese colonial measurement) of gold; those captured at more than one league, eight *oitavas* of gold; twelve *oitavas* for those "beyond Macaúbas"; thirty *oitavas* at the São Francisco river; and so forth (Lara 2012).

5.1.2 Empirical specification

With a good idea of how assignment of quilombo to places worked, to identify the effect of an actual quilombo on some outcome now it is necessary to have a plausible set of counterfactual quilombo locations. To construct this set, I use the fact that there was numerous potential equilibrium quilombo configurations. A suitable spatial equilibrium for the quilombos has to satisfy the following requirements:

1. Since the agglomeration effect depends upon quilombos being close to one another, I require the counterfactual quilombos to be at least as close as the 90th percentile in the distribution of actual quilombos, which translates in being at most 40km away from an actual quilombo.

2. The dispersion effect cause quilombos to drift apart, thus I require the counterfactual quilombos to be not closer than the 50th percentile in the actual quilombos distribution to actual or other counterfactual quilombos. This requires that counterfactual quilombos need to be at least 6km a part and from actual quilombos.

3. For proximity to rivers, I require the counterfactual quilombos to be at least as close as the 50th percentile in the distribution of proximity of actual quilombos to rivers, which is approximately 20km.

I generate 1,000 $\times$ 1,000 counterfactual quilombos using this method. Figure 3 demonstrates this list of spatial constraints and an example of the placing of counterfactual quilombos. Figure 4 illustrates one (out of the 1,000 sets) random feasible spatial configuration of 1,000 counterfactual quilombos and all 1,115 actual quilombos.

I then estimate equation 3 below for the actual quilombos and for the 1,000 sets of counterfactual quilombo locations:

$$outcome_i = \alpha + \sum_{j=1}^{20} \gamma_j dquilombo_i^j + \beta \boldsymbol{X_i} + \sum_{k=1}^{n} quilombo_i^k + \mu_l + \epsilon_i \tag{3}$$

where we are interested in $outcome_i$ at the municipality or the individual level i and the $dquilombo_i^j$ are indicators that assume value of one if the nearest actual or counterfactual quilombo is located within 0km to 1km, 1km to 2km,. . . , 19km to 20km from the municipality or individual i. The 20km plus bin is omitted. The vector $\boldsymbol{X}$ takes on two sets of variables depending the level of the regression. If at the municipality level $\boldsymbol{X}$ comprehends distance to the nearest river, distance to the coast, elevation, ruggedness, average annual temperature, and annual precipitation. If at the individual level it can contain age, gender, and fixed effects for education, occupation, socioeconomic level, and religion. The $quilombo_i^k$ are nearest (counterfactual) quilombo-fixed effects, giving a within-variation specification, that is, ensuring that municipalities or individuals are compared to other municipalities or individuals near the same (counterfactual) quilombo. The variable μ captures state-fixed effects in the municipality regressions or year-fixed effects in the individual regressions, α is a generic constant, and ϵ is an indiosyncratic error term.

The distribution of the counterfactual coefficients enter in the calculation of both the point estimates and the p-values. The computation of the $dquilombo_i^j$ point estimates of being in the bin j away from the nearest quilombo subtracts the absolute mean of the counterfactual distribution in that bin generated by the estimation of the 1,000 alternative configurations. This ensures any unobserved effect common to the proximity of places suitable to quilombos are differenced out.[25] p-values are calculated entirely based on the distribution of the counterfactual estimates. Using the position of $dquilombo_i^j$ actual quilombo coefficient in relation to the distribution of the coefficients estimated using the 1,000 counterfactual sets it is possible to calculate in what percentile of the absolute distribution the actual coefficient falls, the p-value then follows as one minus this percentile. The intuition here is similar to a two-sided t-test. Small p-values suggest that it is unlikely that the observed patterns in the results found near actual quilombos would exist without the quilombos. Dell and Olken (2020) show that this method is correctly sized.

5.1.3 Geographic balance

For the counterfactual to be valid we expect proximity to it to be very similar to proximity to real quilombos along the geographic dimension. There can be some variation in geographic characteristics, but it is expected that they be more similar with greater proximity to the (counterfactual) quilombos.

One way to analyze this is to estimate a variation of equation 3, with $\boldsymbol{X_i}$ as outcome, the usual (counterfactual) quilombo distance bins and nearest (counterfactual) quilombo fixed effects. Figure 9 plots the difference between the actual and average counterfactual $dquilombo_i^j$ for each bin. Solid dots or crosses indicate that the coefficient is significant at the 10% or 5% level, depending on the figure. This means that the actual quilombo coefficients has to be at least above the 90th percentile of the counterfactual distribution to be considered significant.[26] The lines are simple non-parametric regressions that highlights

[25] In Dell and Olken (2020) the proximity of counterfactual factories to the actual factory could pose a problem as this proximity introduces a flattening bias in the actual effects of the closest bins, they show that this is not quantitatively important in their setting. In my setting this is not a problem because I have constrained the counterfactuals to be at least 6km away from themselves and the actual quilombos.

[26] Appendix 8.1 shows the distribution of the counterfactuals coefficients for the geography variables. The

the general shape of the relationship.

If characteristics are similar we expect the counterfactual coefficients to average out any effects of proximity to an actual quilombo. Figure 9 indicates that close proximity to quilombos is mostly translated in geographic balance. Most estimations are insignificant and when they are significant the coefficients tend to be small. For example, significant coefficients point to small differences in elevation and temperature, a decrease of 40m in elevation with proximity to actual quilombos and an increase in 0.15 to 0.30 degrees Celsius. For this to be a threat to identification we have to believe that these small differences are systematically driving both the placement of real quilombos throughout history, as well as all the outcomes discussed in the next section, which seems unlikely.

5.2 Persistence Mechanisms

5.2.1 Culture and Afro religion

The first set of results I analyze is the effect of quilombos on culture and afro religion. We should expect locations with proximity to quilombos to demonstrate their influence in a variety of forms that are transmitted across generations. This influence could be seen, for example, in the presence of any local government actions towards the quilombos themselves, which in a way makes official their own existence with the government and the municipal society. The outcome in Figure 10 takes the value of one if, in 2014, the local government "promotes, fosters or supports cultural initiative specific to the field of cultural diversity in relation to quilombos".

Figure 10 also serves to better illustrate the methodology. Using the described outcome, I estimate equation 3 with $dquilombo_i^j$ indicating the distance from the municipality seat to the nearest real quilombo and 1,000 sets of counterfactual quilombos. In panel (a), the vertical line that crosses each sub-plot for the distance bins (0 to 1km,. . . ,19 to 20km) marks the coefficient in the regression with the actual quilombos, while the distribution in each sub-plot is the collection of the coefficients using the 1,000 random draws of counterfactual sets.[27] I then compute the p-values depending on the location of the actual coefficient in relation to the counterfactual distribution and presented in each sub-plot. If the location of the actual coefficient is at least beyond the 90th percentile of the distribution I consider it significant and indicate this in the next panel. In panel (b), I plot the real coefficients subtracted of the counterfactual average, with solid dots or crosses if the p-value indicates that the real coefficient is beyond the 90th or 95th percentile. The results indicate that the greater the

illustration of the counterfactual distributions is better discussed in the next section with the main results.

[27]Note that the distribution can contain less than 1,000 coefficients if depending on the outcome there is no counterfactual quilombo in that distance bin from the location of the outcome in one or more of the sets.

proximity of the quilombo to the municipality center, the more influence it can exercise over the local government for promoting cultural initiatives for them. If a quilombo is at most 10km from the municipality it is 25% to 60% more likely (in relation to those municipalities with the nearest quilombo more than 20km away) to develop these government-supported cultural initiatives, with quillombos at most 5km causing the larger coefficients, and this influences diminishes almost monotonically with increased distance.

A second cultural-religious outcome I look at is related, but specifically aimed towards afro-religious communities. The outcome variable is an indicator that assumes the value one if, in 2014, the local government "promotes, fosters or supports cultural initiative specific to the field of cultural diversity in relation to afro-religious communities". One should not expect a one-to-one correspondence between quilombos and afro-religious communities. Despite being religious communities themselves, quilombos will not necessarily assume a public religious face and afro-religious communities will not necessarily want to deal with the local government due to centuries of prejudice. Moreover, quilombos and afro-religious need not necessarily overlap because of the transmission of beliefs over generations. People that left the quilombo could keep passing on the rituals and beliefs outside the quilombos and even people that attend the quilombo but do not live there could also act as cultural transmitters. Panel (a) in Figure 11 suggests the pattern described. Since the method was already demonstrated, I present the counterfactual distributions for this outcome and all other upcoming outcomes in Appendix 8.1. Municipalities with quilombos close by have disproportionately more cultural initiatives, they are over 30% more likely to have some initiative for afro-regligious communities supported by the local government, reinforcing the fact more proximate quilombos are more integrated with the municipal community. This effect dissipates fast and turns to rise with quilombos between 10km and 15km, which could indicate not the direct influence of the quilombo, but of the descendants that migrated from the relatively isolated quilombo to the urban centers.

A third related outcome I look at is the existence of *capoeira* groups. These are community-based groups of a unique blend of dancing with martial arts that convey a strong connection to resistance. It is also a cultural activity where beliefs are transmitted across generations. The dependent variable in this case is a sum of an indicator that takes the value of one if there is the existence of any capoeira group in the municipality in 2006 and 2014. In Panel (b) of Figure 11 I show a similar pattern that with afro-religious communities, where proximity to quilombo leads the municipalities to have more of capoeira groups with the significant coefficient γ of proximity around 0.2.

The last three outcomes are closely tied and have been used extensively in the literature on culture and persistence: generalized trust, community trust, and collective action.

Generalized trust has been measured annually from 2002 to 2018. Community trust and collective action are surveyed in 2007, 2008, 2010, 2012, 2014, and 2017. I pool all years and use year-fixed effects. Panels (c), (d) and (e) of Figure 11 demonstrate the results.

Generalized trust is measured on yes or no basis. The answer to the question "Generally speaking, would you say that you can trust most people, or that you can never be too careful in dealing with others?" is 1 if the individual answers "One can trust most people" and 2 if the answer is "One can never be too careful in dealing with others". In Panel (c) I demonstrate there is no clear pattern for this outcome.

Community trust and collective action are measured on a 1 to 4 scale. In the first case, the question is "Talking about the people from here, would you say they are very trustworthy, somewhat trustworthy, little trustworthy, not trustworthy?", where the answers are numbered 1 to 4 in this sequence. In the second case, the question is "In the last 12 months have you contributed for the solution of any problem of your community or of your neighbors?" and the answers can be "Once a week", "Once or twice a month", "Once or twice a year", or "Never". The scale 1 to 4 corresponds to the answers in this sequence.

Panels (d) and (e) shows that, in contrast to generalized trust, there is a pattern related to quilombo proximity. There is a large and significant increase in both community trust and collective action with 2 to 7km of distance to the nearest quilombo, from where it starts to decrease and flattens out fluctuating around zero. The significant γ of quilombo proximity for community trust is approximately -0.55 and for collective action are -0.3 and -0.4.

All things considered, these results can be interpreted as coming from two sources. One source is the fact that these communities historically had to bound together against many attacker, either by the elite or by the government. These communities were under constant attack, and many still are, in relation to religous practices, cultural practices like capoeira, and even just gatherings at taverns. This would dampen generilzed trust, but increase community trust, which would then lead to collective action. The other source is that community trust and collective action can be also be built through these very religious and cultural practices that were being attacked.

5.2.2 Occupational transmission

As with Afro cultural-religious activities, quilombos could also be linked to occupational transmission across generations, mainly skilled occupations, not limited to but descended from African iron technology, which are intimately connected to the Ogun belief system and slave resistance.

The outcome in panel (a) of Figure 12 is the sum of an indicator that assumes value one if in 2007 or 2014 metal handicraft activities was among the most important activities in the municipality. These types of artisanal handicrafts, commonly called *artesanato* in Brazil, is a type of occupation directly connected to cultural activities. The coefficients γ of quilombo proximity ranges from 0.05 to a significant 0.3 with a distance less than 5km of the municipality seat from a quilombo. Between the 10 and 15km range it is also significant between 0.05 and 0.1. Meaning that with more proximity to a quilombo the indidence of metal handicrafts is 5% to 30% higher than those municipalities with quilombos more than 20km away. This is strong indicator of the influence of quilombos in local economic activities because handicraft made of metal, specifically, is not common in Brazil, only 1.3% of the used sample of 5,430 municipalities in 2014 has metal handicraft among the most important handicraft activities.

Panels (b)-(e) in Figure 12 presents the results for two classes of occupations in 1980 and 2010: (1) number of workers in crafts and related trades and (2) number of workers in skilled agricultural and fishery workers. Data are from IPUMS 10% samples and the occupational classes follow the International Standard Classification of Occupations. This ensures comparability between periods and homogeneity in the occupational categories. Crafts and related trades workers "apply their specific knowledge and skills in the fields of mining and construction, form metal, erect metal structures, set machine tools, or make, fit, maintain and repair machinery, equipment or tools, carry out printing work as well as produce or process foodstuffs, textiles, or wooden, metal and other articles, including handicraft goods" (ILO 2012). These activities are complex in nature and require the knowledge of all stages of the production process, the materials and tools, and the nature and purpose of the final product. Skilled agricultural and fishery workers, as stated in ILO (2012), "grow and harvest field or tree and shrub crops, gather wild fruits and plants, breed, tend or hunt animals, produce a variety of animal husbandry products, cultivate, conserve and exploit forests, breed or catch fish and cultivate or gather other forms of aquatic life in order to provide food, shelter and income for themselves and their households". These tasks require know-how of a wide variety of species cultivation processes and include some basic processing of the produce, and selling and marketing to buyers, organizations, or directly at markets, with the possible supervision of others.[28]

The coefficients γ of quilombo proximity all follow the same "hockey stick" pattern, they start higher when a quilombo is close to the seat of the municipality and then decrease with distance and remain fluctuating around zero. The patterns are consistent for both 1980 in panels (c) and (e) and 2010 in panels (b) and (d). For both types of occupations the results

[28]Note that, according to ILO (2012), in both cases "if the tasks are of a simple and routine nature, mainly entail the use of hand-held tools, some physical effort, little or no previous experience and understanding of the work and limited initiative or judgment" they are delegated to other major group defined as "elementary occupations".

the results carry high economic significance. In 2010, having a quilombo at less than 3km away means, in relation to municipalities with quilombos more than 20km away, 55 to 64% more workers in the crafts and related trades occupation (panel (b)) and 250% more workers in skilled agriculture and fishery (panel (d)). In 1980 the magnitudes are similar, but with more significant coefficients. When taken together, the economic significance of the coeffients and the hockey stick shape of the plots, it is unlikely that this pattern would arise in the quilombos' absense.

5.3 Placebo test: Destroyed quilombos in the XVIII and XIX centuries

I now conduct a placebo-type test to show that the same patterns in the occupations outcomes do not arise if I use the location of quilombos destroyed by slave-hunting raids in the XVIII and XIX centuries in the states of Minas Gerais, Goiás, and Mato Grosso. The destroyed quilombos are digitized from the maps in Guimarães (2012) for Minas Gerais and in Silva (2003) for Central Brazil. These quilombos are represented in Figure 13. There is a total of 75 destroyed quilombos. I run the specification described in equation 3 for the main results but with $dquilombo_i^j$ now measuring the distance to nearest destroyed quilombo and the sample is restricted to these three states.

Since this region was most heavily affected by the gold mining cycle, especially Minas Gerais that was the epicenter of the cycle, it is expected that if the occupation patterns were just an artifact of the quilombos' place, the placebo quilombo results would show a similar shape as the real quilombos results, more so in relation to iron-related skills. In Figure 14, I show that, despite statistical significance of some distance bins, the placebo quilombos does not show any discernible pattern in the data. In addition, Figure 15 shows the results with the placebo quilombos and the cultural-religious outcomes. Likewise, the plots show no systematic pattern in the data.

5.4 Alternative mechanisms

5.4.1 Selection in the XIX century

One alternative story to explain the pattern in the data is that quilombos simply selected into places that were richer or had a greater human capital stock. Thus, these initial conditions lead to more economic activity and occupational differences in the long run. In Figure 16 I show the results for a specification in which $dquilombo_i^j$ are the usual actual (counterfactual) quilombos and the outcomes are average income of municipality employees in 1875 in panel

(a) and literacy of the free population in panel (b) and of the slaves in panel (c) according to the 1872 national census. I demonstrate in these plots that there is no discernible pattern in the data and most of the coefficients are insignificant. This likely means that there was no self-selection of quilombos that still exist today to places with higher income or human capital stock in the late XIX century.

5.4.2 Institutions and public goods

Another hypothesis to consider is that the effects of quilombos on economic activity and culture are in reality a spillover of institutions with colonial origins or colonial investments in public goods. Since places with heavy participation in the commodity cycles, specially sugar, gold, and coffee, tended to have a greater presence of the colonial state, it is possible that investments or institutions put in place at the time generate the patterns seen in the data today.

I show in Figures 17 and 18 that this is not the case. I run the usual specification in which $dquilombo_i^j$ are the real (counterfactual) quilombos and the outcomes are the same as in Naritomi, Soares, and Assunção (2012), plus Bolsa Família transfers. Figure 17 shows the outcomes for institutions, the panels are: (a) an average of four qualitative indicators for municipal governance normalized from 1 (worst) to 6 (best), (b) access to justice measured by an average of three indicators for the presence of small claims courts, youth council and consumer commission in the municipality, and (c) the Gini coefficient of the municipal land distribution. In Figure 18 I show the outcomes for public goods, the panels are: (a) the number of health centers per 10,000 inhabitants, (b) log of per capita municipal spending on education and culture, (c) percentage of households with toilet connected to the public sewage system, (d) a dummy indicator for whether there was at least one public library in the municipality, and (e) log per capita Bolsa Família transfers.

In both figures I show there is no pattern relating either institutions or public goods to the quilombos. If anything, there appears to be worse institutions and public goods near quilombos. Looking at the plots in which the coefficients appear more significant, land tends to be more concentrated and there are less households connected to the sewage system in municipalities near quilombos.

5.5 Discussion

Considering the significant results for the specifications with occupations as outcomes, in this section I present an exploratory analysis relating current occupation patterns to the ethnic groups that disembarked in Brazil. As detailed in the Historical Background section 2 the ethnic groups that had more affinity with iron-related skills and the Ogun belief system were those from the Costa da Mina (Jeje Mina) and from Yorubaland (Yoruba-Nago).

In Figure 19, I overlay those quilombos that are driving the results in the crafts and related trades specification, that is, those that are within 3km from the municipalities. We can see that these quilombos are concentrated exactly in the areas predicted by the cultural mechanism I propose, that is, in areas with Jeje Mina and Yoruba-Nago ethnic groups. This fact gives more confidence to the proposed mechanism of occupational transmission.

6 Conclusion

In this paper I document that ethnic territories connected to slave resistance is correlated with higher levels of economic development in the long run and plausibly transformed the economy of proximate regions by having a direct effect on the occupational structure and cultural-religious values. I propose a new mechanism where initial religious beliefs and African iron-working and other high-valued skills are perpetuated in the long run through cultural-religious intergenerational transmission, but without the need for any human capital initial shock, as mechanisms proposed elsewhere.

The current effects of quilombos on occupations are comparable and sometimes even larger than those derived from the Dutch Java System in Indonesia (Dell and Olken 2020) and Catholic missions in Brazil, Paraguay, and Argentina (Valencia Caicedo 2018). I contribute in showing one novel way on how history persists and how culture and religion can affect economic activity. Ancestral knowledge embodied in cultural traditions of marginalized groups can have rich economic and cultural-religious effects in the long run.

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7 Tables and Figures

	Dependent variable is ln(number of lit pixels) in					
	1992-1993		2002-2003		2012-2013	
	(1)	(2)	(3)	(4)	(5)	(6)
ln(quilombos)	0.281***	0.219***	0.426***	0.369***	0.490***	0.467***
se	(0.064)	0.05	(0.07)	0.056	(0.07)	0.059
GEO controls	Yes	Yes	Yes	Yes	Yes	Yes
Municipality FE	Yes	No	Yes	No	Yes	No
District FE	No	Yes	No	Yes	No	Yes
Observations	53,960	53,960	53,960	53,960	53,960	53,960
R2	0.609	0.694	0.6	0.677	0.625	0.69

Table 1: Regression of number of quilombos and nightlights. Notes: OLS estimates of equation 1 are reported. The dependent variable is the natural log of the number of lit pixels in a cell. The quilomos measure is the natural log of the number of quilombos in a cell. The GEO controls include: absolute latitue and longitute, distance to the coast, area, annual precipitation, annual average temperature, ruggedness, and elevation. Coeffiecients are reported with robust standard errors in parenthesis. Significance at the 1%, 5%, and 10% levels are indicated by $***$, $**$, and $*$.

	Dependent variable is	
	difference in lit pixels	log sum common lit pixels
	(1)	(2)
difference in quilombos	2.918***	
se	(0.407)	
ln(sum common quilombos)		0.185***
se		(0.026)
GEO controls	Yes	Yes
Neighbor-pair FE	Yes	Yes
Observations	213,100	213,100
R2	0.015	0.003

Table 2: Neighbor-pair regression. Notes: OLS estimates of equation 2 are reported. The dependent variable is the difference in lit pixels from one cell in relation to its neighbor-pair in column (1) and the natural log of common lit pixels in the neighbor-pair in column (2) . The quilomos measure the difference in the number of quilombos from one cell in relation to its neighbor-prais in column (1) and the natural log of common quilombos in the neighbor-pair in column (2). The GEO controls include: absolute latitue and longitute, distance to the coast, area, annual precipitation, annual average temperature, ruggedness, and elevation. Coeffiecients are reported with robust standard errors in parenthesis. Significance at the 1%, 5%, and 10% levels are indicated by $***$, $**$, and $*$.

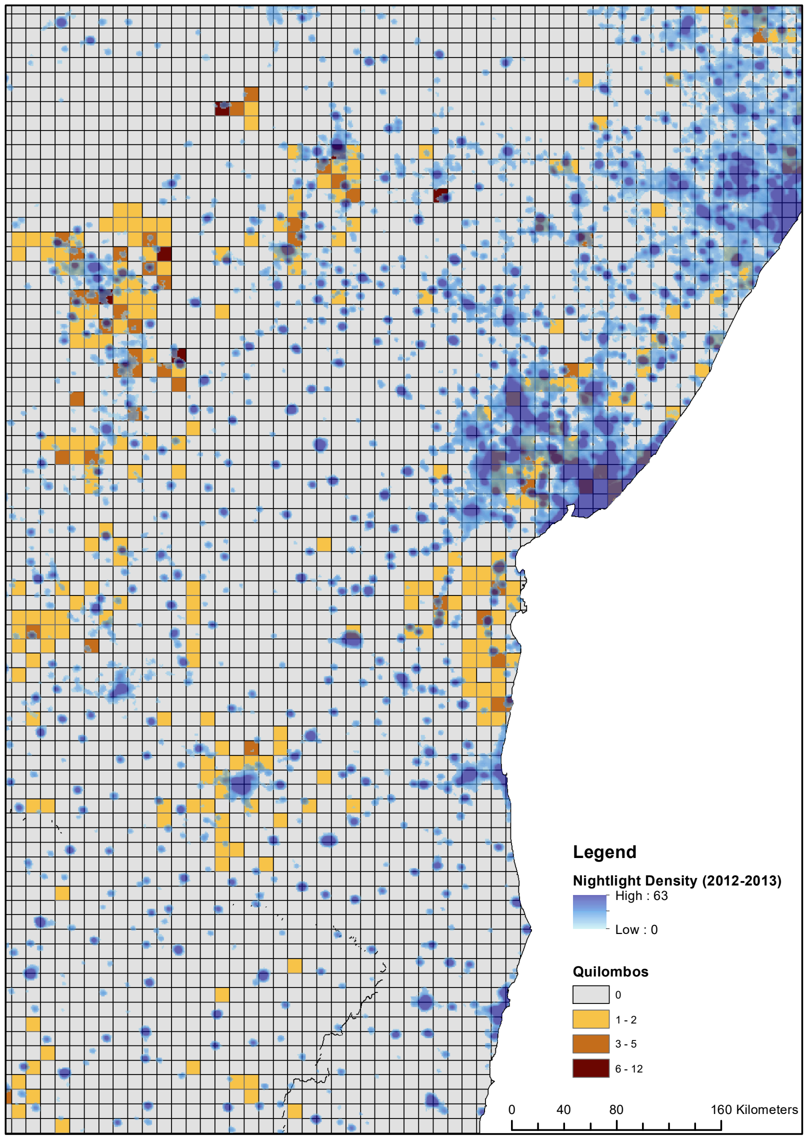


Figure 1: Virtual municipalities and nightlight density. Notes: Each cell is approximately 11 × 11 km and are indicated by different levels of number of quilombos present in each cell. Nightlights have different intensity depending of the density of light observed in that pixel. The map is a zoom on a part of the coast of the Northeast, the central agglomeration of lights is the capital of Bahia, Salvador, and above that the other agglomeration is Aracaju, capital of Sergipe.

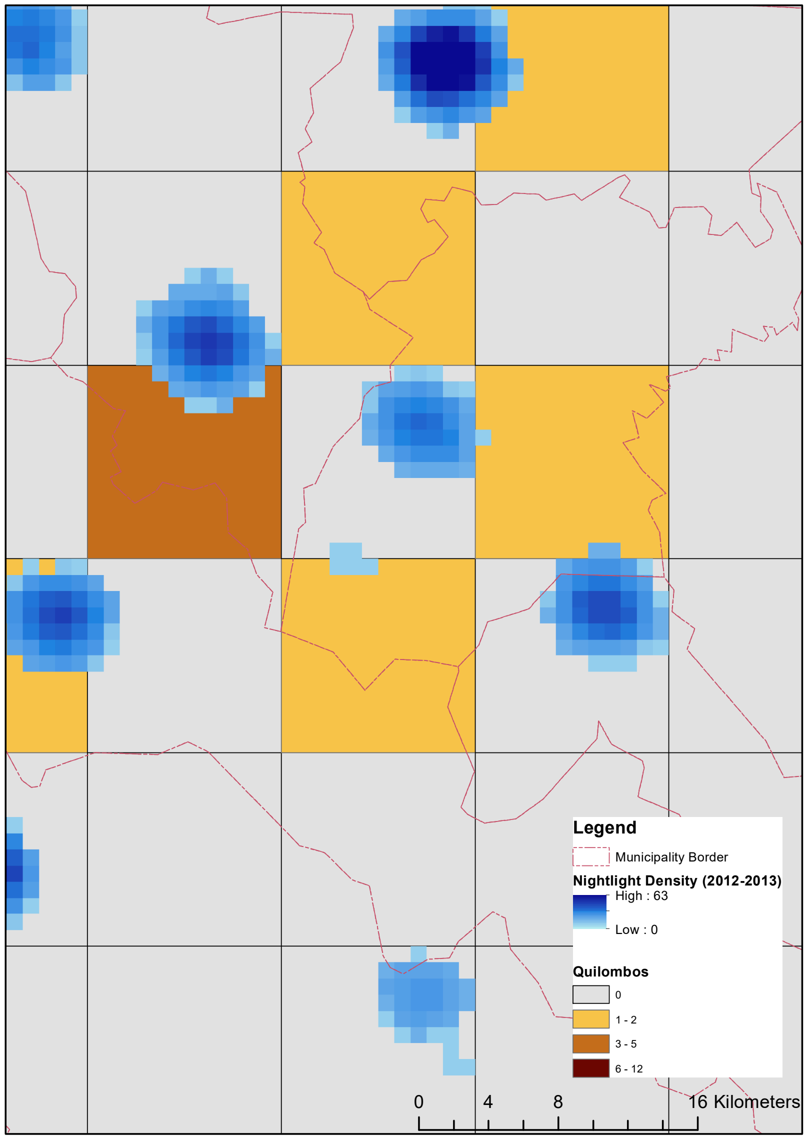


Figure 2: Virtual municipalities, real municipality borders, and nightlight pixels. Notes: This map represents a random zoom over the territory. The lines represent real municipality borders. At this level it is possible to see the pixels that compose the nightlight density, the nightlights outcome is measured by number of such pixels in a virtual municipality cell, independent of the desensity of the pixel.

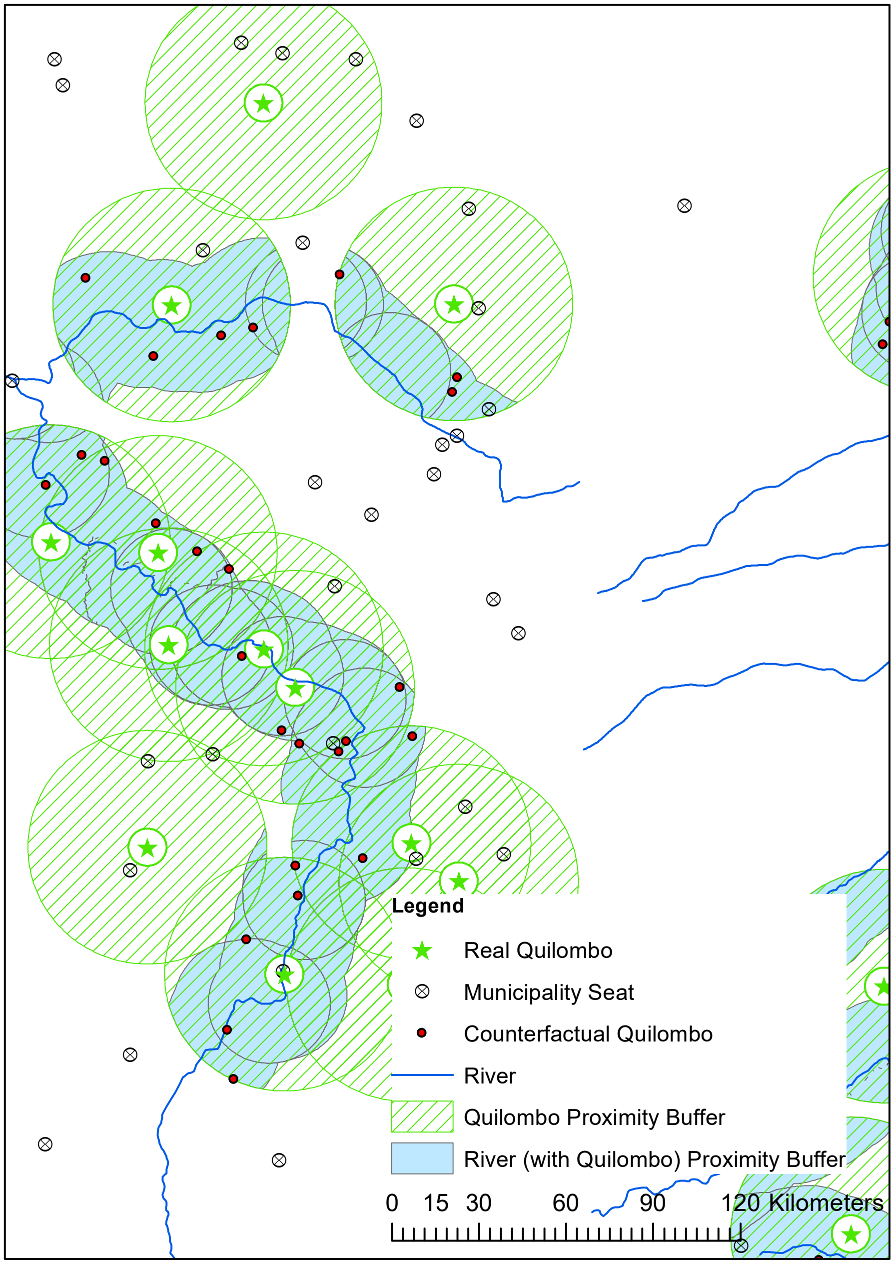


Figure 3: Counterfactual quilombos example. Notes: This map is a random zoom over the territory to illustrate how the method works. In it we can see real quilombos represented by stars and counterfactual quilombos by dots. The constrained area where the method randomly generates quilombos is represented by the filled buffer within the buffer with the lines.

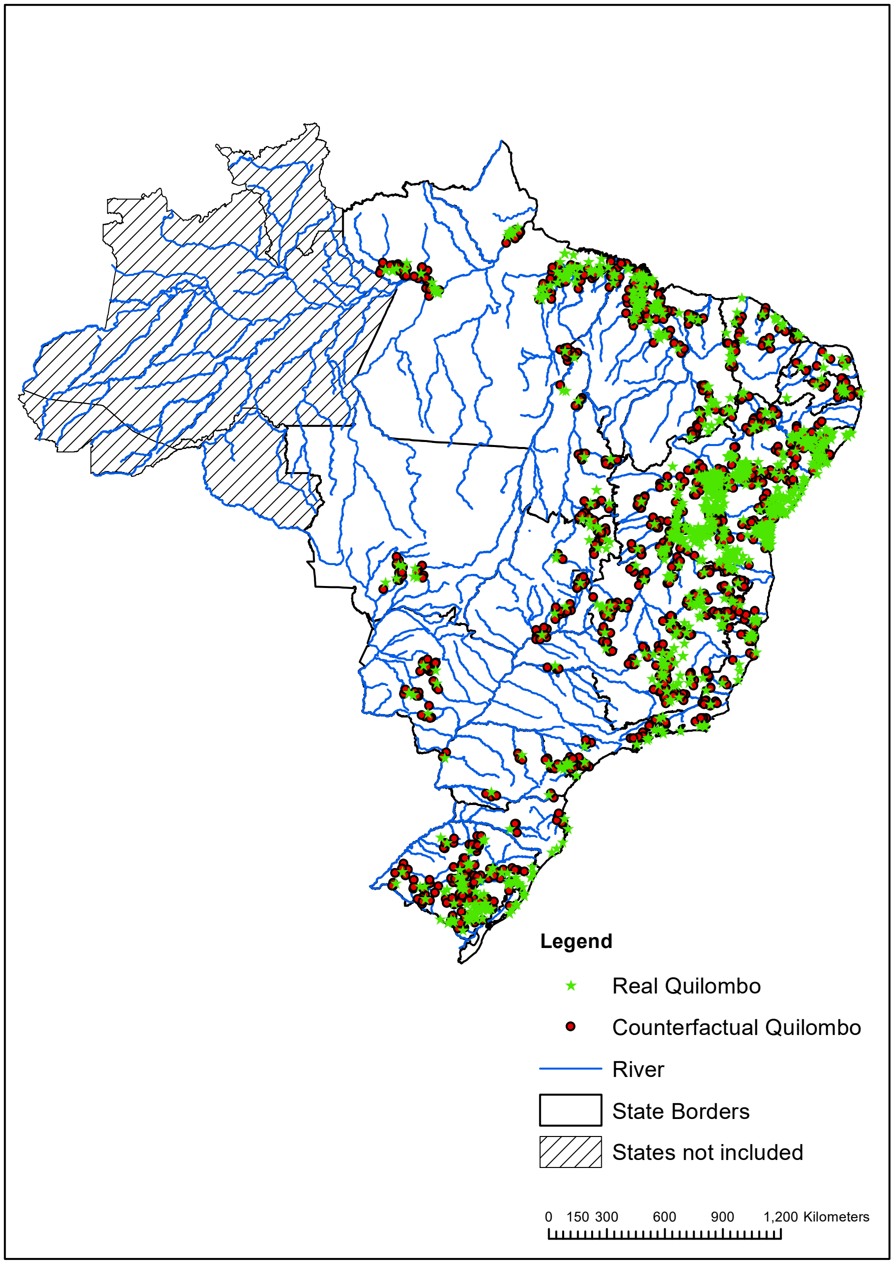


Figure 4: Real quilombos and one random set of counterfactual quilombos. Notes: The counterfactual quilombo dots are one random set out of the 1,000 total counterfactual sets. The stars are the 1,115 quilombos used in the analysis. The lines represent the main rivers in Brazil, which were used in the analysis.

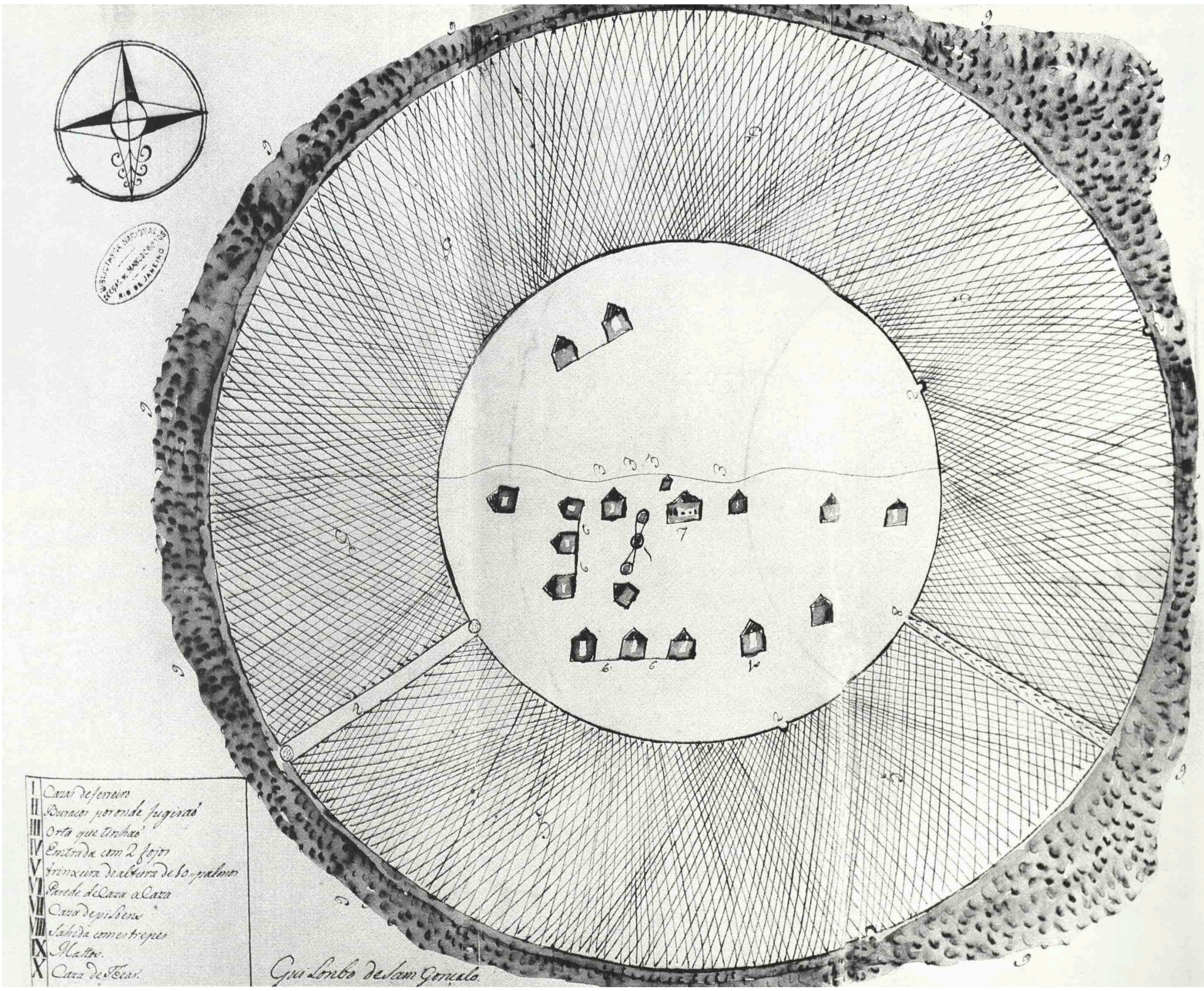


Figure 5: Quilombo São Gonçalo in 1796. Legend: 1 - blacksmith's house, 2 - escape holes, 3 - vegetable garden, 4 - entrance, 5 - trench, 6 - wall, 7 - pestle house, 8 - exit, 9 - woods, 10 - loom house. Notes: Cartographic documentation of the expedition by Captain Antônio Francisco França. This document is part of the manuscripts section of the Brazilian National Library. Source: Anjos (2009).

Figure 6: Quilombo products arrive at the Court market in Rio de Janeiro, c. 1825 ("Rue Droite à Rio Janeiro", M. Rugendas, 1835).

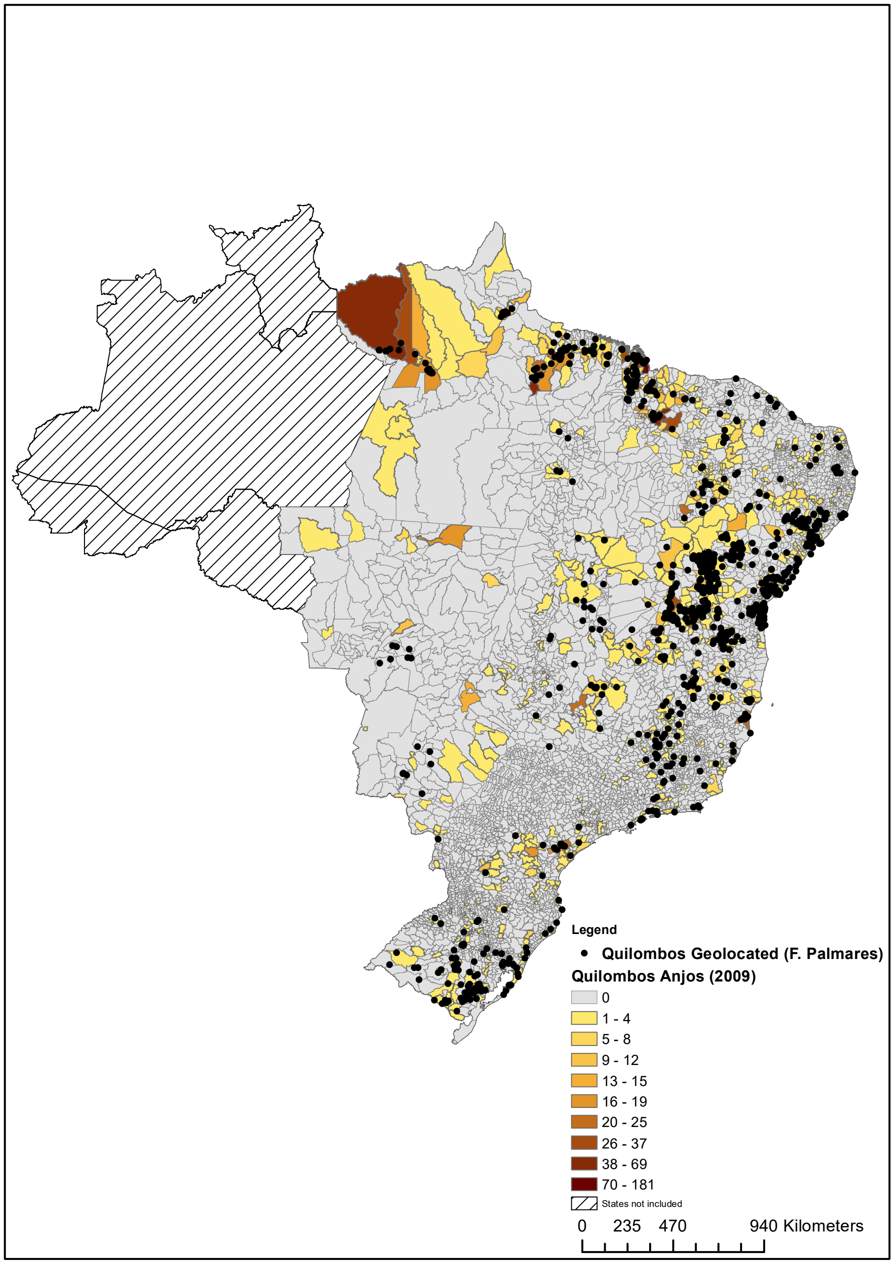


Figure 7: Anjos (2009) and geolocated Palmares Foundation quilombos. Notes: The shapes represent real municipalities in 2010 and indicate the number of quilombos from the Anjos database. The dots represent the geolocated quilombos from the Palmares Foundation database.

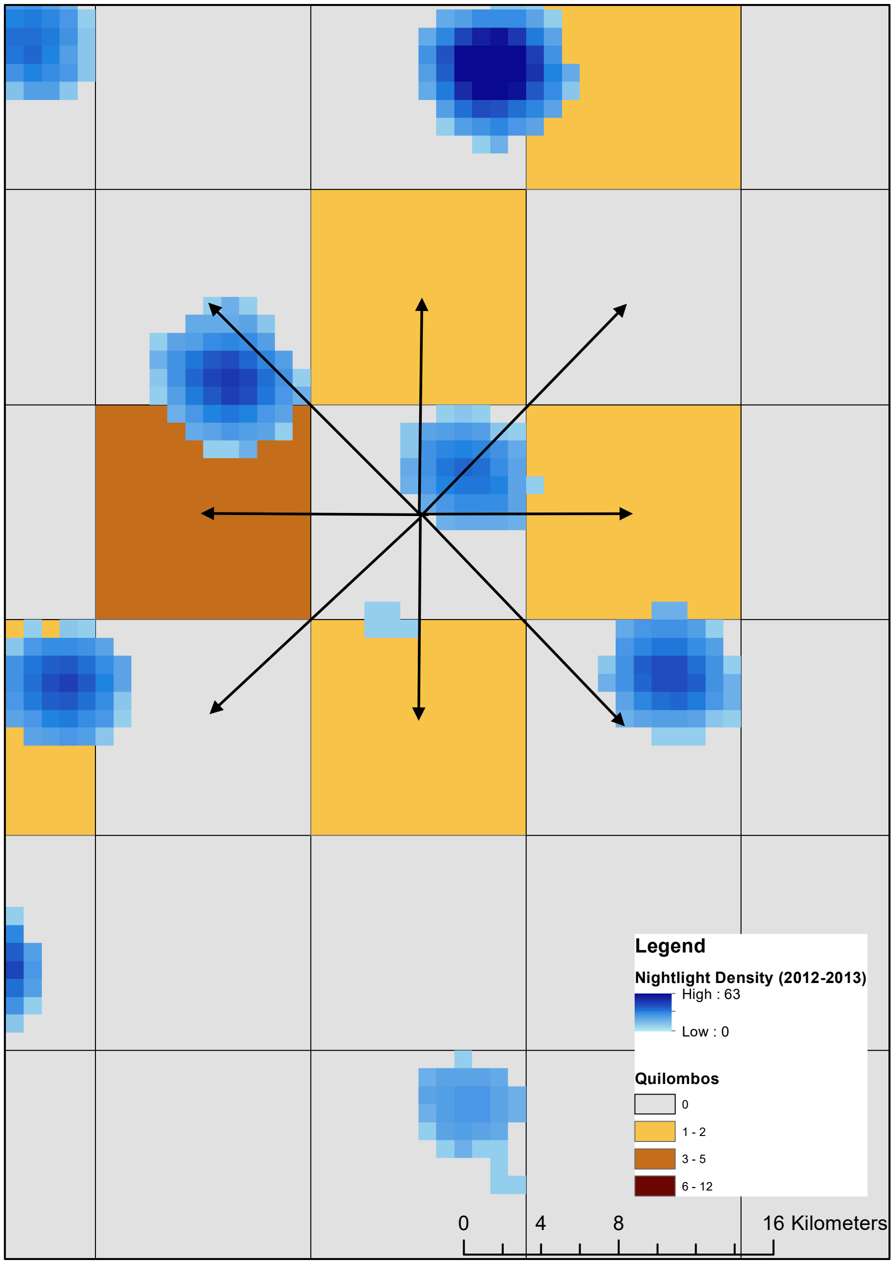


Figure 8: Neighbor-pair example. Notes: This figure illustrates how a neighbor-pair is formed. The center cell is connected by arrows to eight of its imidiate neighbors, each arrow forming an unique pair.

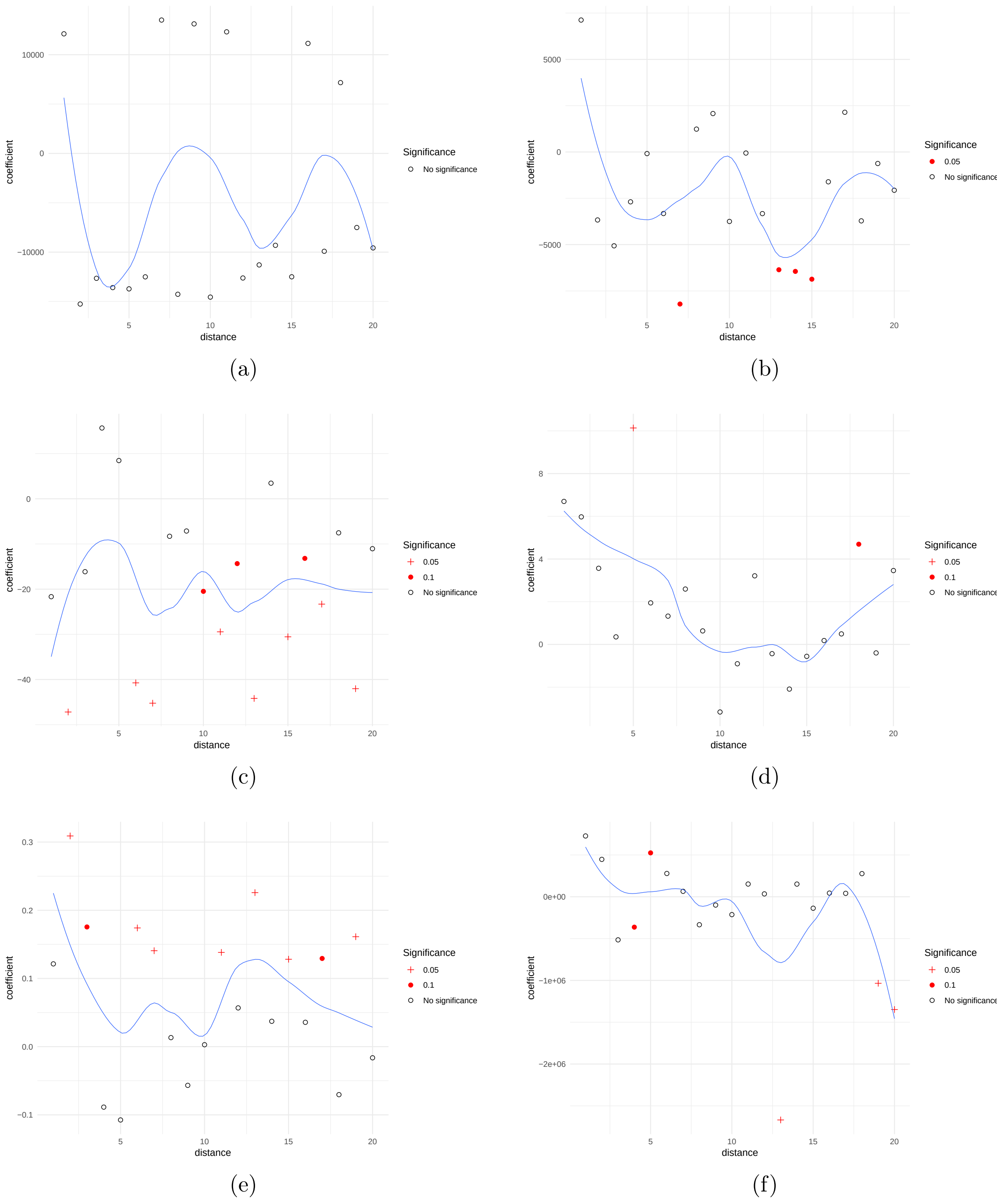
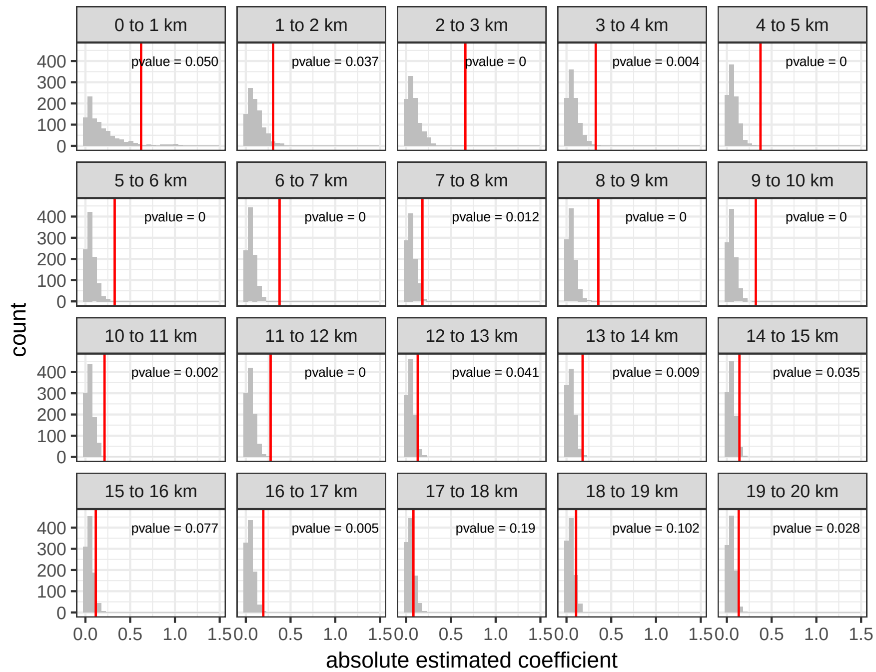
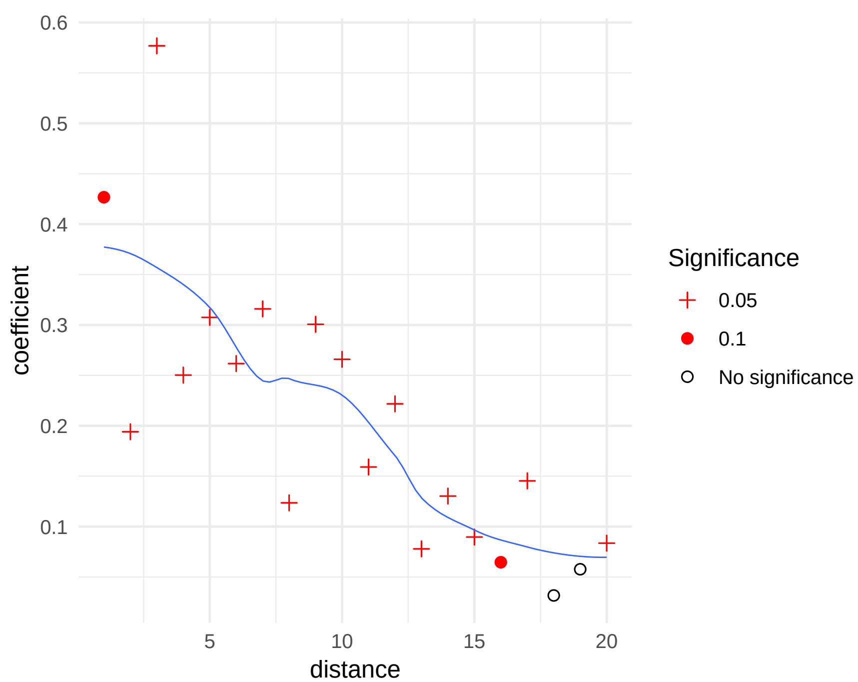


Figure 9: Geography. (a) Distance to river, (b) distance to coast, (c) elevation, (d) ruggedness, (e) temperature, and (f) precipitation. Notes: The regressions are at the municipality level (N=5,430). The point plots are estimated from regressing the outcome variable on 1km bins of distance to the nearest quilombo, controlling for nearest quilombo fixed effects and state fixed effects. The absolute means of same specification computed from 1,000 sets of counterfactual quilombos configurations are subtracted from each coefficient, then p-values compare the position of the effect of an actual quilombo to this counterfactual distribution. The points are fit with a simple local polynomial regression.



(a)



(b)

Figure 10: Local government and quilombo cultural activities. (a) Counterfactual distribution and (b) Point estimates.Notes: The point plots are estimated from regressing the outcome variable on 1km bins of distance to the nearest quilombo, controlling for geographic characteristics, log population, black share of the population, nearest quilombo fixed effects, and state fixed effects. The absolute means of same specification computed from 1,000 sets of counterfactual quilombos configurations are subtracted from each coefficient, then p-values compare the position of the effect of an actual quilombo to this counterfactual distribution. The points are fit with a simple local polynomial regression.

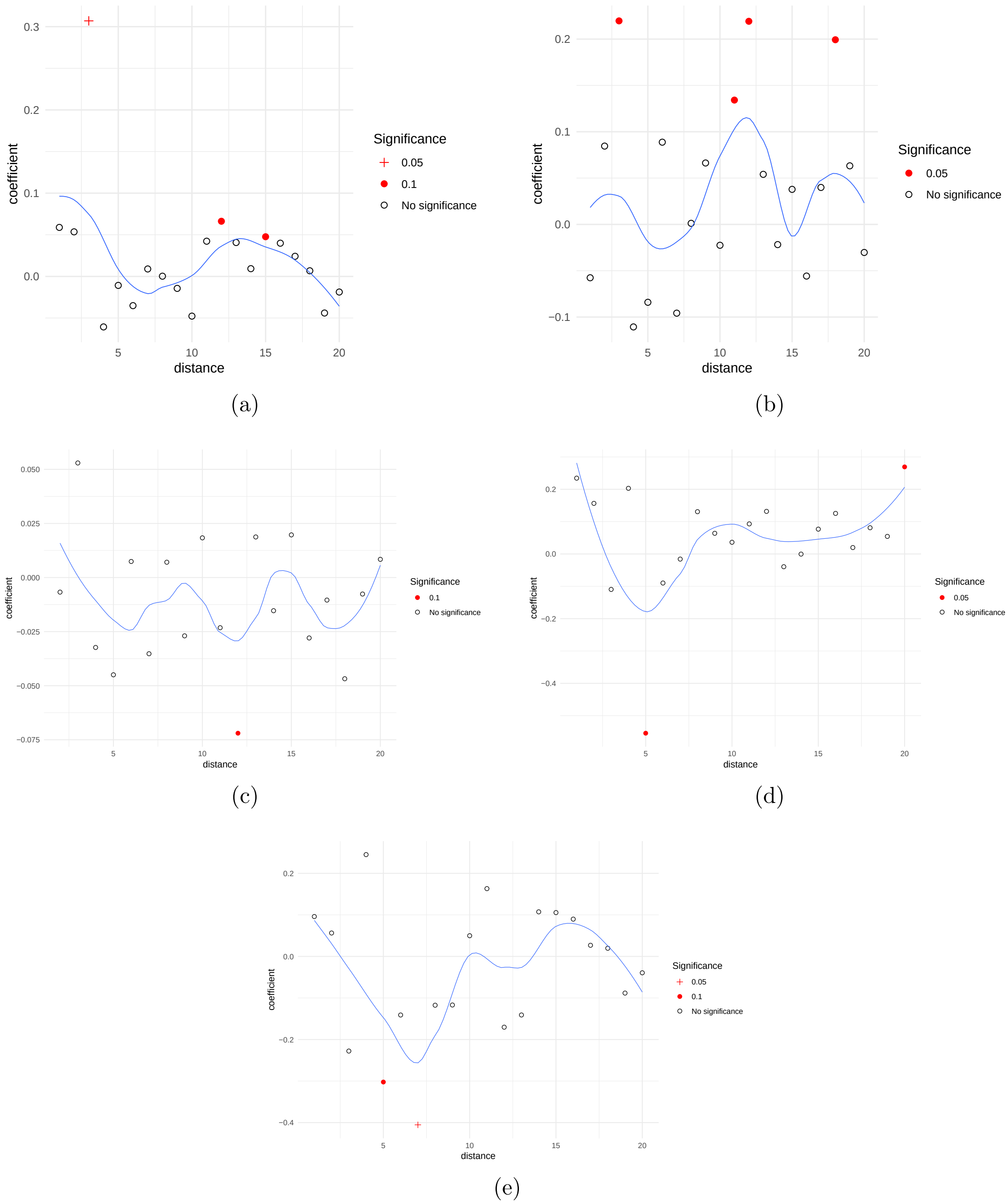


Figure 11: Culture and Afro reglion. (a) Local government and Afro-religious cultural activities, (b) capoeira groups, (c) generalized trust, (d) community trust, and (e) collective action. Notes: The point plots are estimated from regressing the outcome variable on 1km bins of distance to the nearest quilombo. In panels (a) and (b) controlling for geographic characteristics, log population, black share of the population, nearest quilombo fixed effects, and state fixed effects. In panel (c) controlling for age, age squared, fixed effects for gender, occupation, socioeconomic level, religion, nearest quilombo, and year. In panels (d) and (e) controlling for age, age squared, and fixed effects for gender, nearest quilombo, and year. The absolute means of same specification computed from 1,000 sets of counterfactual quilombos configurations are subtracted from each coefficient, then p-values compare the position of the effect of an actual quilombo to this counterfactual distribution. The points are fit with a simple local polynomial regression.

Figure 12: Occupations. (a) Metal handicraft, (b) crafts and related trades 2010, (c) crafts and related trades 1980, (d) skilled agricultural and fishery 2010, and (e) skilled agricultural and fishery 1980. Notes: The point plots are estimated from regressing the outcome variable on 1km bins of distance to the nearest quilombo, controlling for geographic characteristics, log population, black share of the population, nearest quilombo fixed effects, and state fixed effects. The absolute means of same specification computed from 1,000 sets of counterfactual quilombos configurations are subtracted from each coefficient, then p-values compare the position of the effect of an actual quilombo to this counterfactual distribution. The points are fit with a simple local polynomial regression.

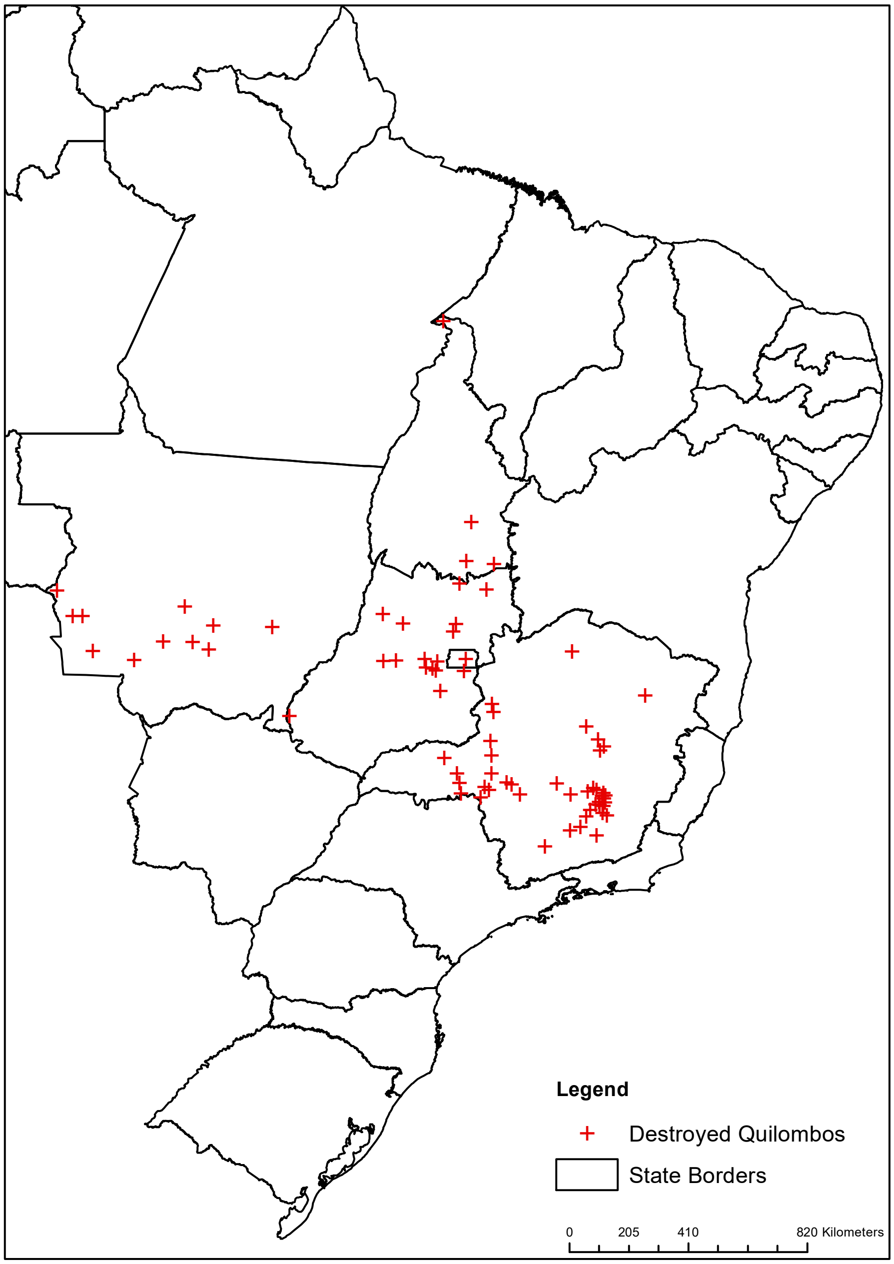
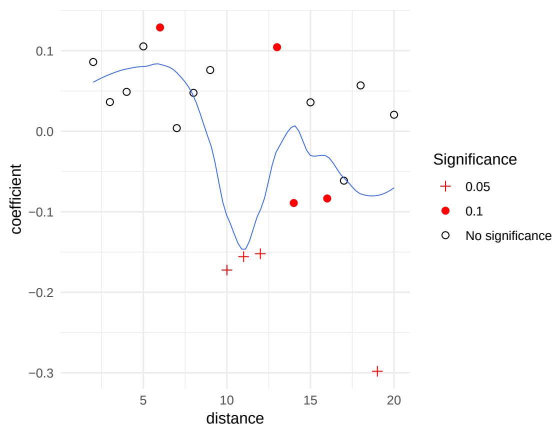
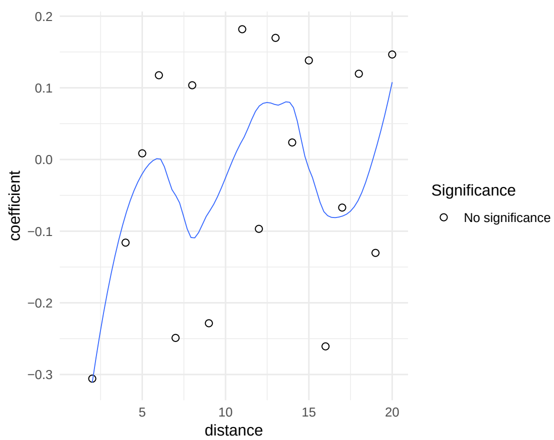


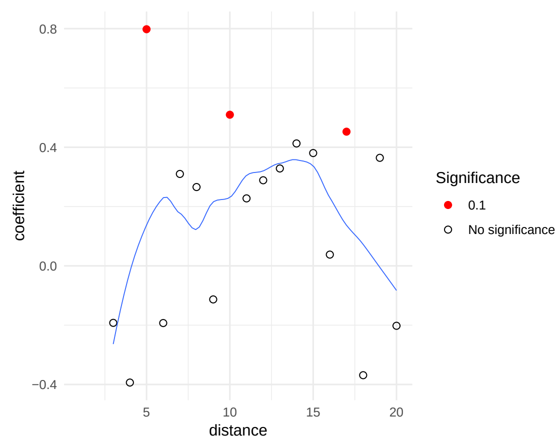
Figure 13: Destroyed quilombos in Minas Gerais and Central Brazil



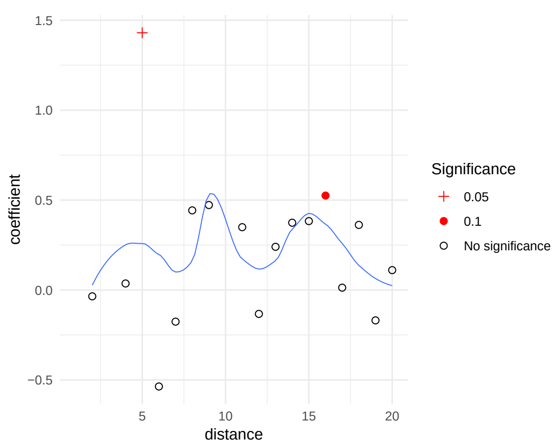
(a)



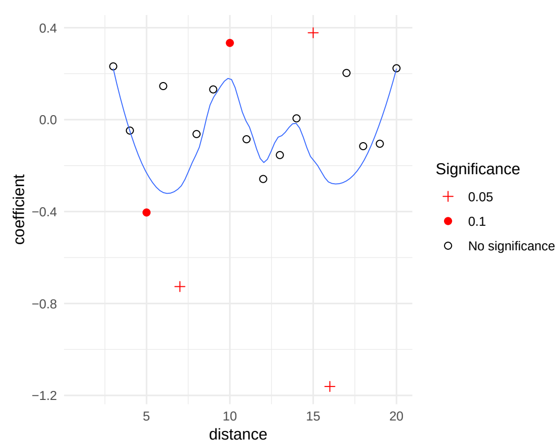
(b)



(c)



(d)



(e)

Figure 14: Placebo test for occupations. (a) Metal handicraft, (b) crafts and related trades 2010, (c) crafts and related trades 1980, (d) skilled agricultural and fishery 2010, and (e) skilled agricultural and fishery 1980. Notes: The point plots are estimated from regressing the outcome variable on 1km bins of distance to the nearest quilombo, controlling for geographic characteristics, log population, black share of the population, nearest quilombo fixed effects, and state fixed effects. The absolute means of same specification computed from 1,000 sets of counterfactual quilombos configurations are subtracted from each coefficient, then p-values compare the position of the effect of an actual quilombo to this counterfactual distribution. The points are fit with a simple local polynomial regression.

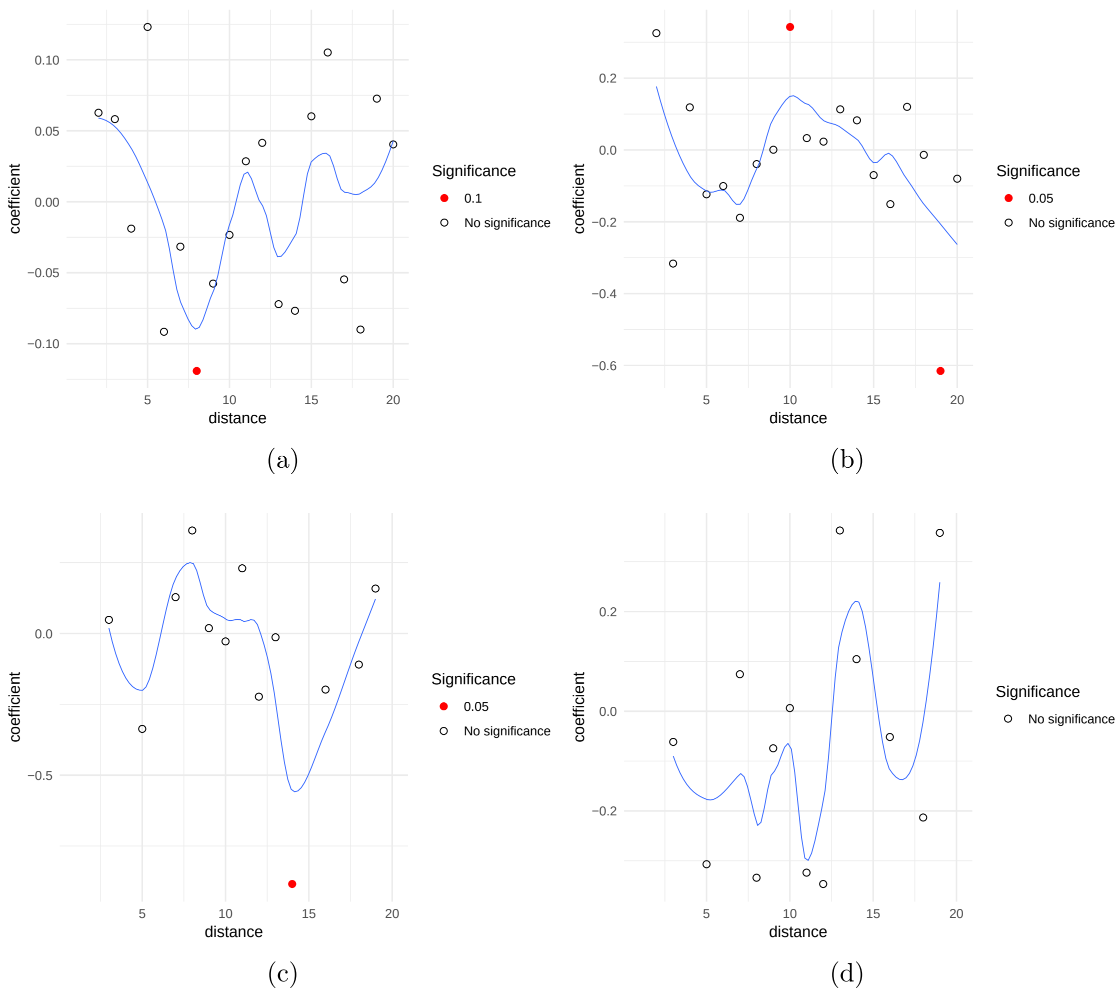
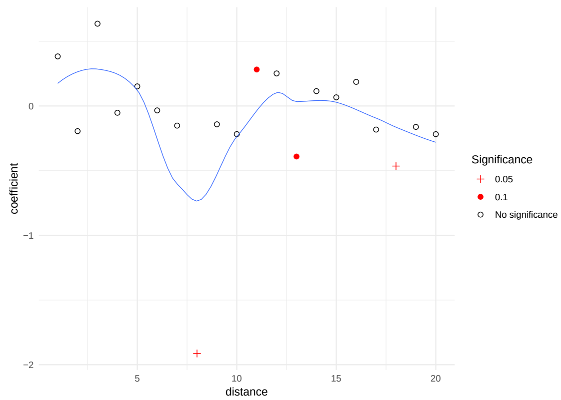
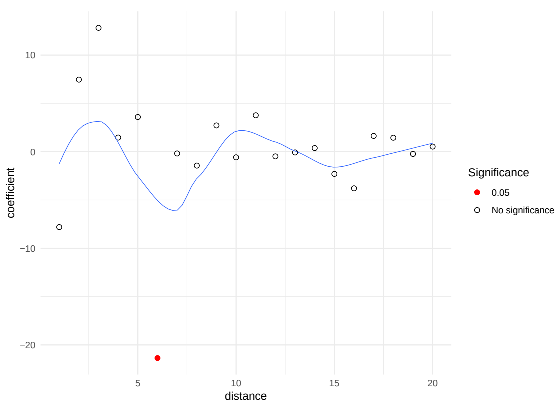


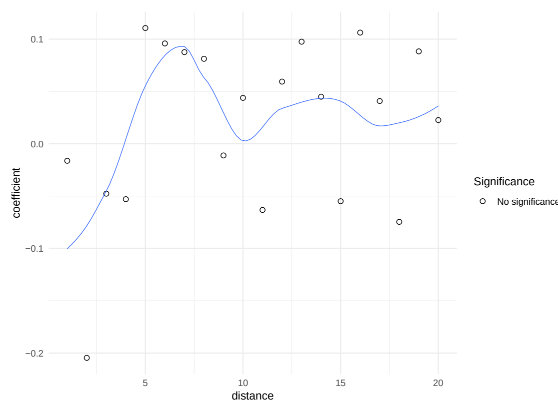
Figure 15: Placebo test for culture and Afro reglion. (a) Local government and Afro-religious cultural activities, (b) capoeira groups, (c) community trust, and (d) collective action. Notes: The point plots are estimated from regressing the outcome variable on 1km bins of distance to the nearest quilombo. In panels (a) and (b) controlling for geographic characteristics, log population, black share of the population, nearest quilombo fixed effects, and state fixed effects. In panels (c) and (d) controlling for age, age squared, and fixed effects for gender, nearest quilombo, and year. The absolute means of same specification computed from 1,000 sets of counterfactual quilombos configurations are subtracted from each coefficient, then p-values compare the position of the effect of an actual quilombo to this counterfactual distribution. The points are fit with a simple local polynomial regression.



(a)

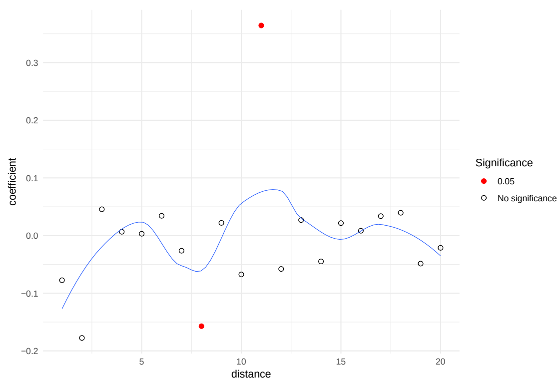


(b)

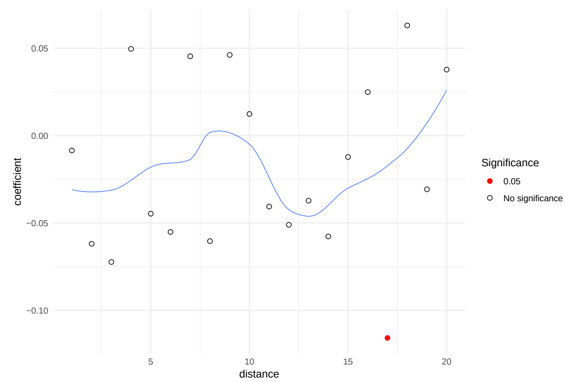


(c)

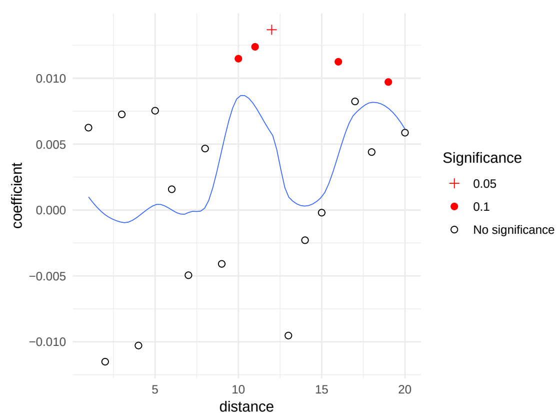
Figure 16: Income and schooling in the 1870s. (a) Income in 1875, (b) literacy of the free population in 1872, and (c) literacy of slaves in 1872. Notes: The point plots are estimated from regressing the outcome variable on 1km bins of distance to the nearest quilombo, controlling for geographic characteristics, slave share of the population, and nearest quilombo fixed effects. The absolute means of same specification computed from 1,000 sets of counterfactual quilombos configurations are subtracted from each coefficient, then p-values compare the position of the effect of an actual quilombo to this counterfactual distribution. The points are fit with a simple local polynomial regression.



(a)



(b)



(c)

Figure 17: Institutions. (a) Governance, (b) access to justice, and (c) land Gini. Notes: The point plots are estimated from regressing the outcome variable on 1km bins of distance to the nearest quilombo, controlling for geographic characteristics, log population, black share of the population, nearest quilombo fixed effects, and state fixed effects. The absolute means of same specification computed from 1,000 sets of counterfactual quilombos configurations are subtracted from each coefficient, then p-values compare the position of the effect of an actual quilombo to this counterfactual distribution. The points are fit with a simple local polynomial regression.

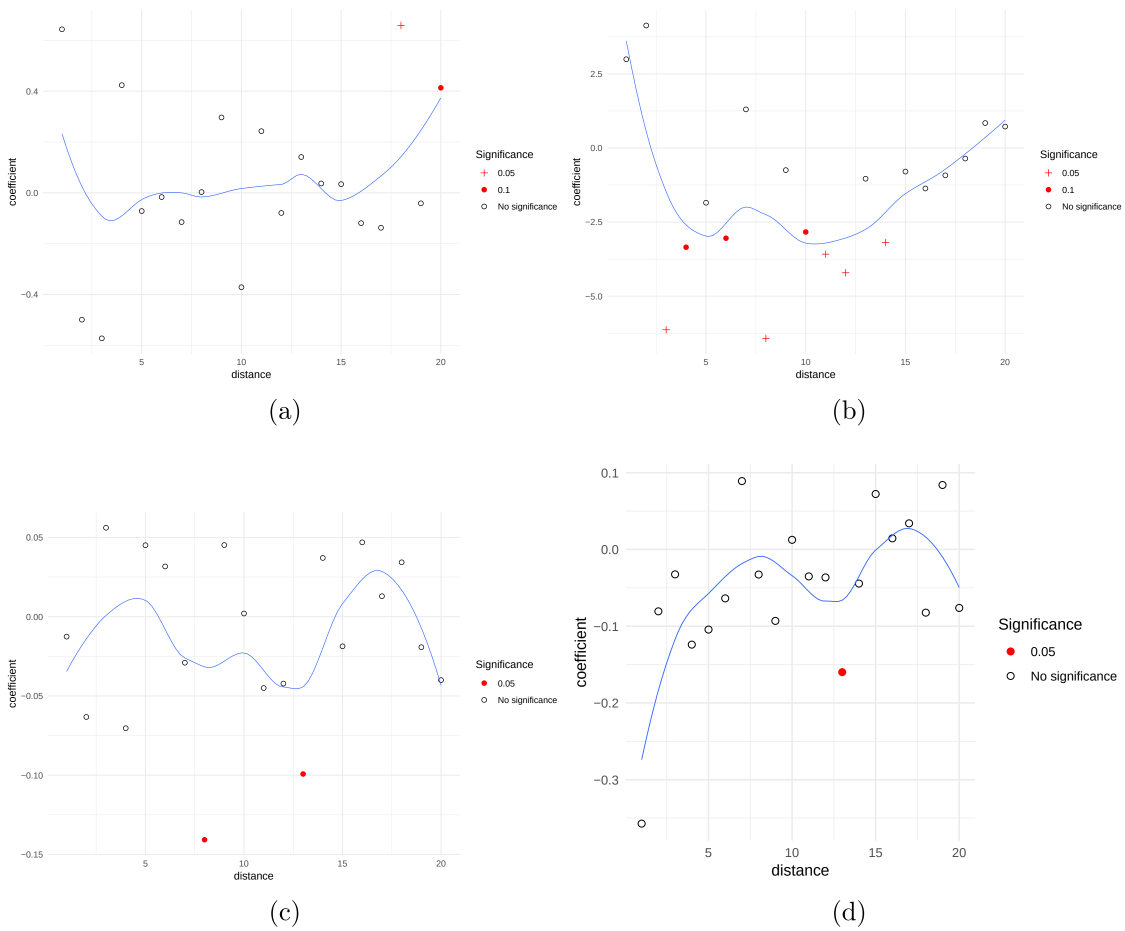


Figure 18: Public goods. (a) Health centers, (b) sewage, (c) public library, and (d) Bolsa Família per capita transfers. Notes: The point plots are estimated from regressing the outcome variable on 1km bins of distance to the nearest quilombo, controlling for geographic characteristics, log population (except in panel (d)), black share of the population, nearest quilombo fixed effects, and state fixed effects. The absolute means of same specification computed from 1,000 sets of counterfactual quilombos configurations are subtracted from each coefficient, then p-values compare the position of the effect of an actual quilombo to this counterfactual distribution. The points are fit with a simple local polynomial regression.

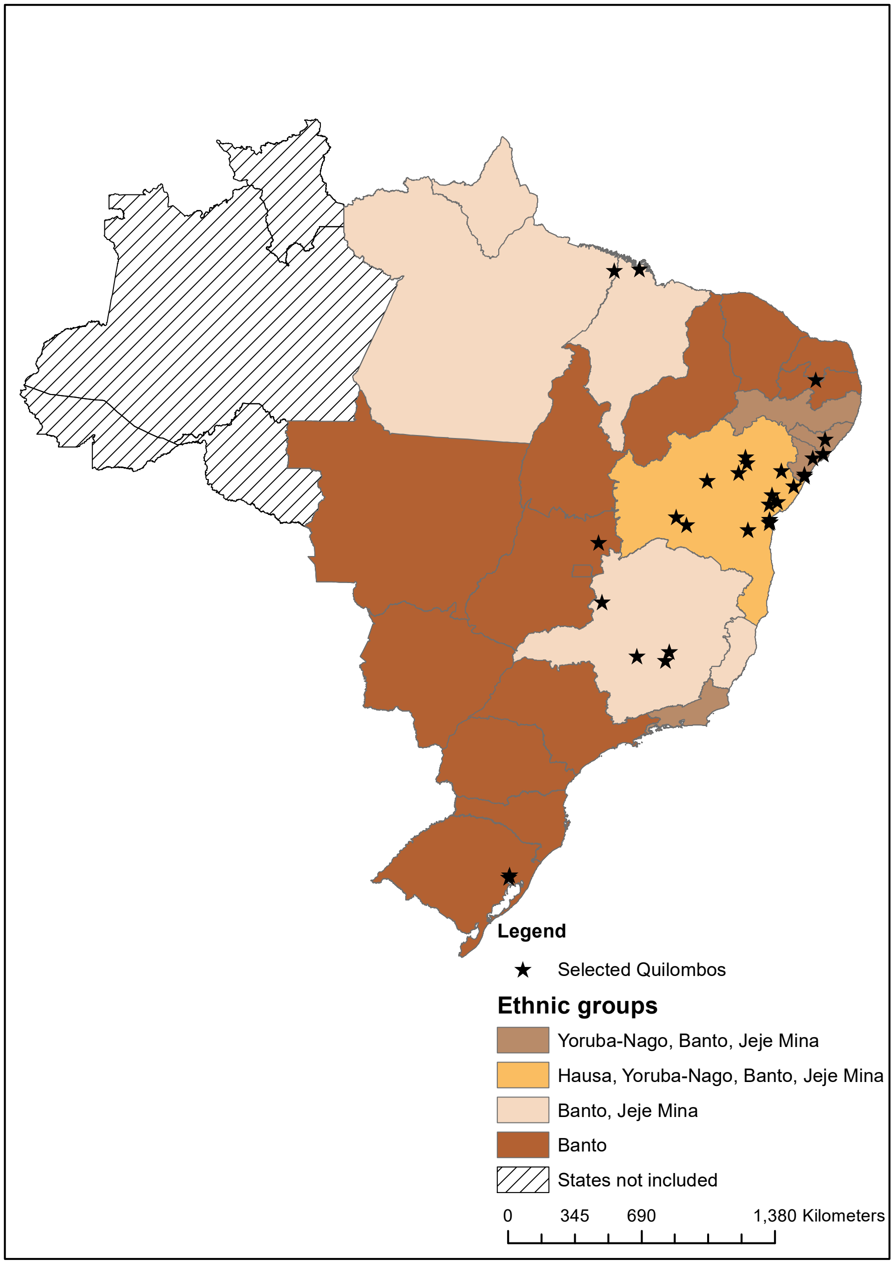
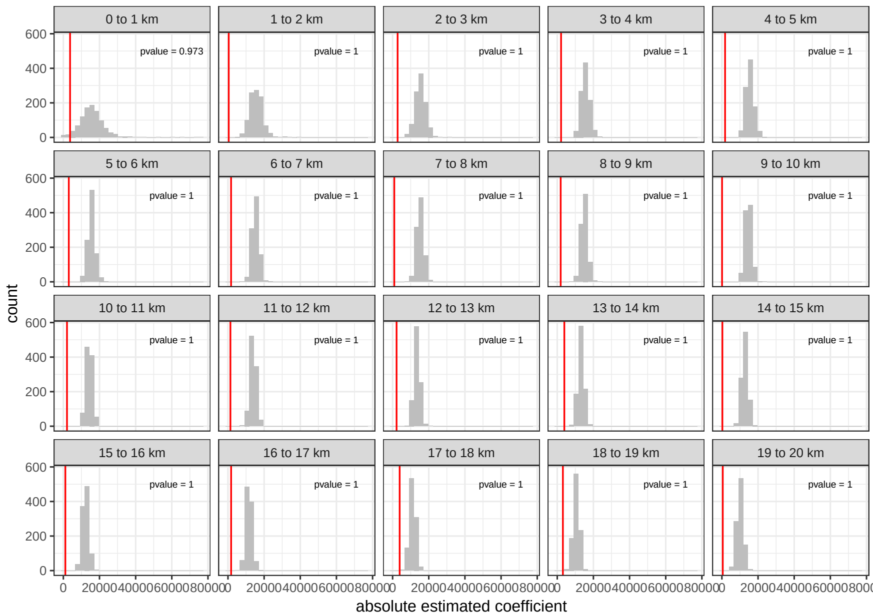


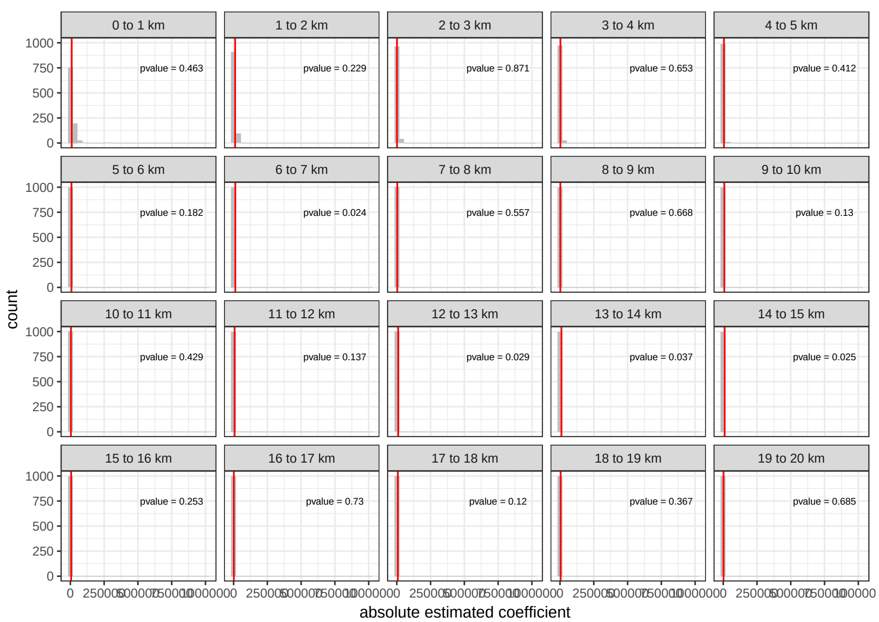
Figure 19: Selected quilombos and ethnic groups. Notes: the source for the ethnic groups is Anjos (2009) and the selected quilombos are those within 3km from a municipality in the 2010 specification with crafts and related trades as an outcome.

8 Appendix

8.1 Counterfactual distributions

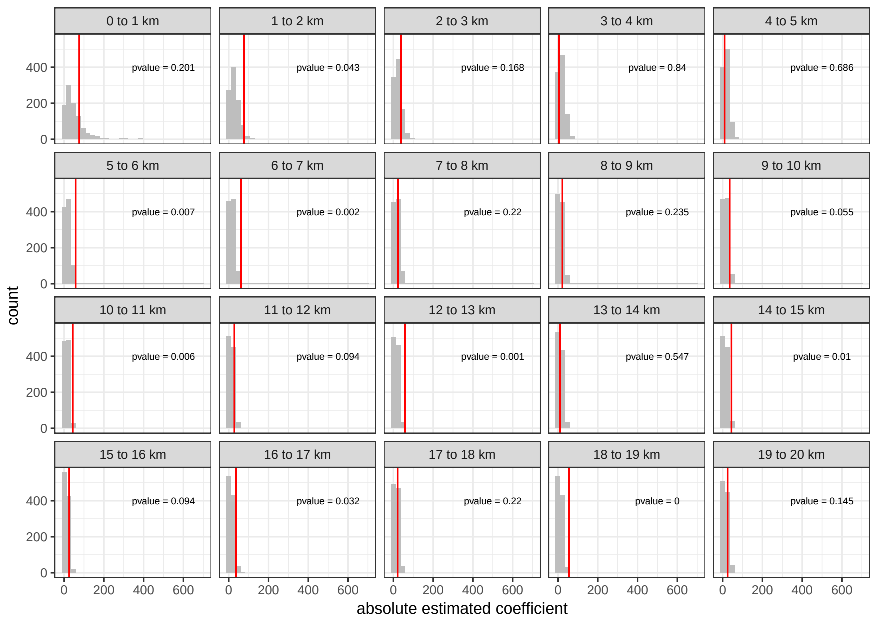


(a)

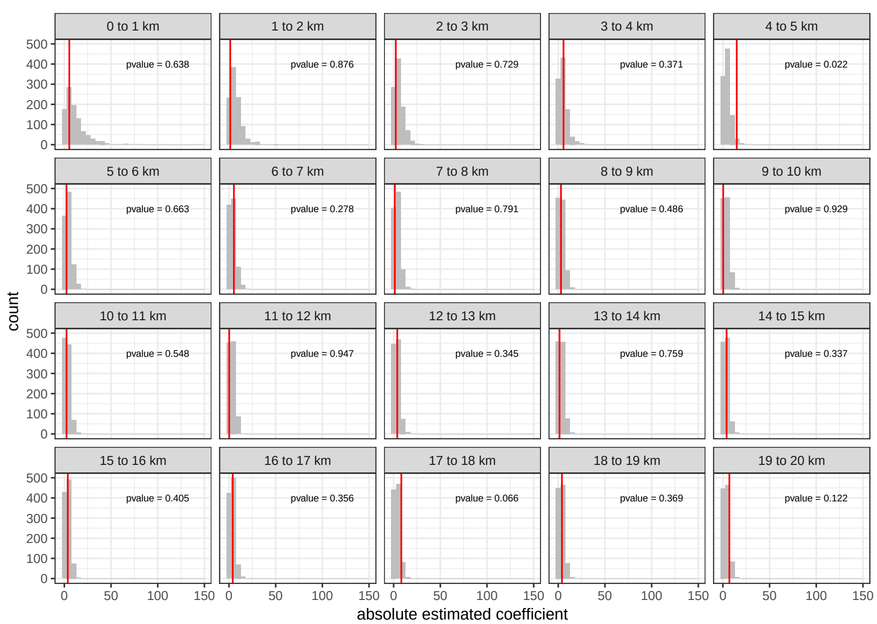


(b)

Figure 20: Counterfactual distributions of (a) distance to river and (b) distance to coast

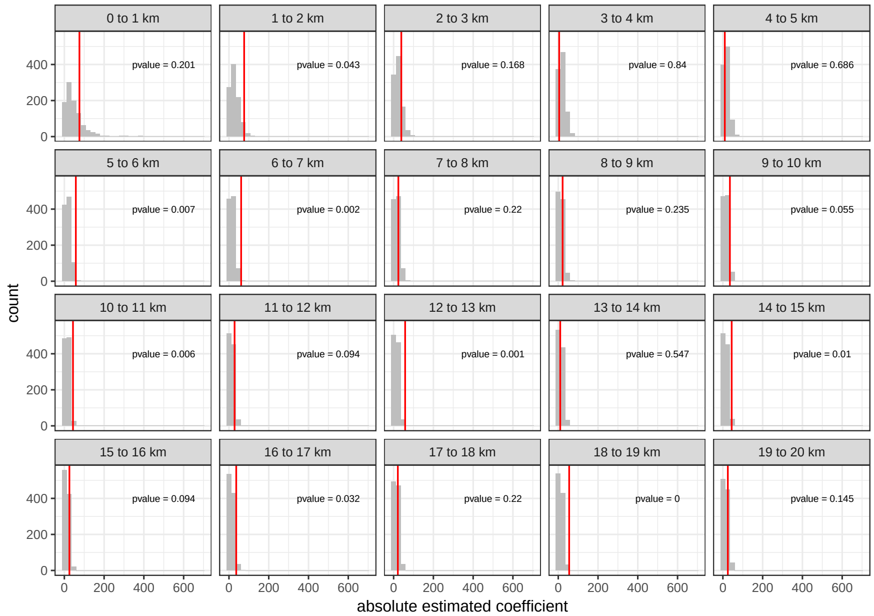


(a)

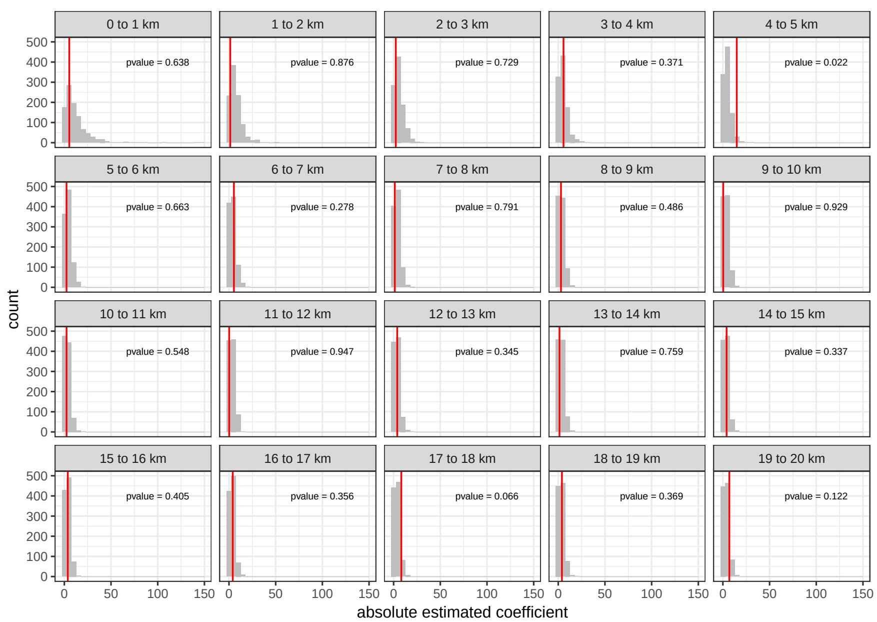


(b)

Figure 21: Counterfactual distributions of (a) elevation and (b) ruggedness

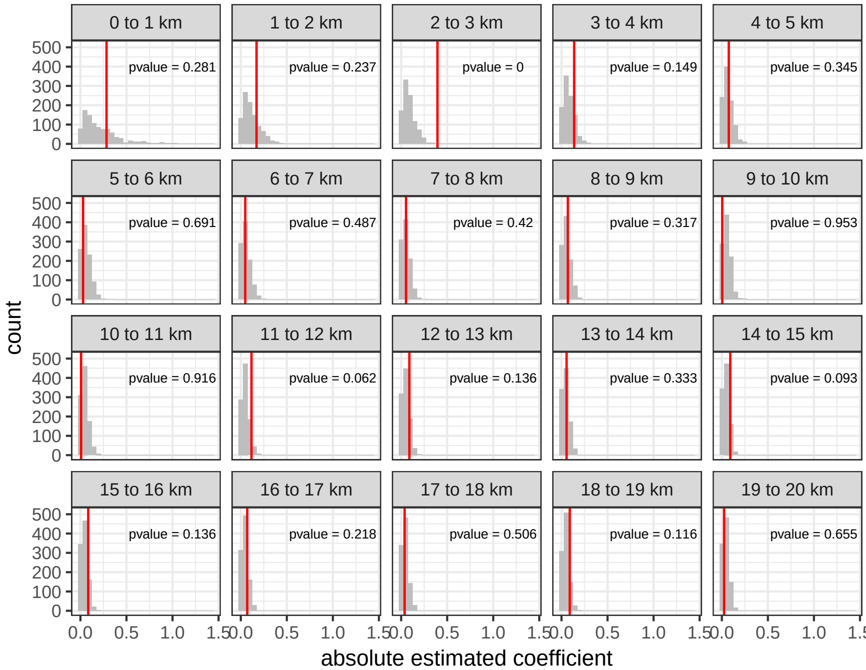


(a)

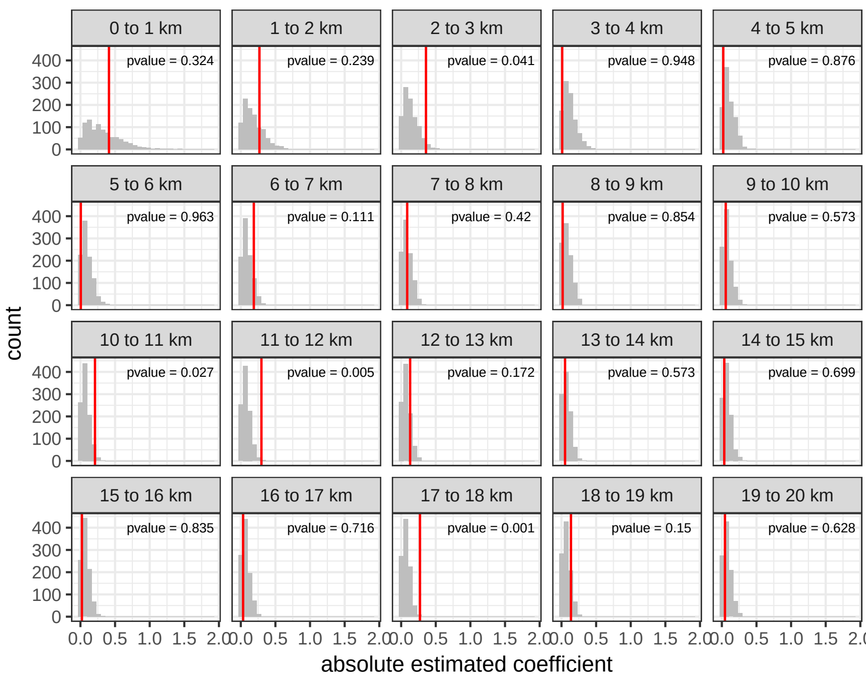


(b)

Figure 22: Counterfactual distributions of (a) temperature and (b) precipitation

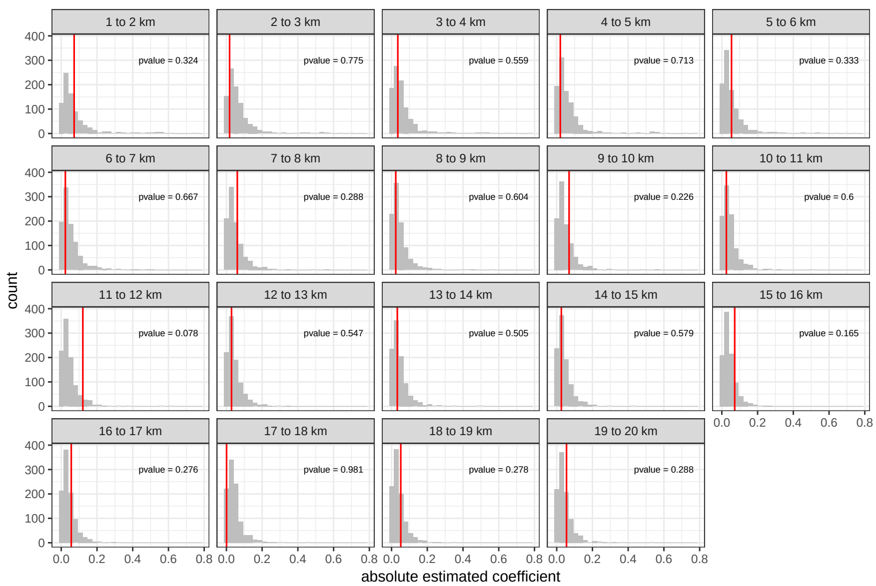


(a)



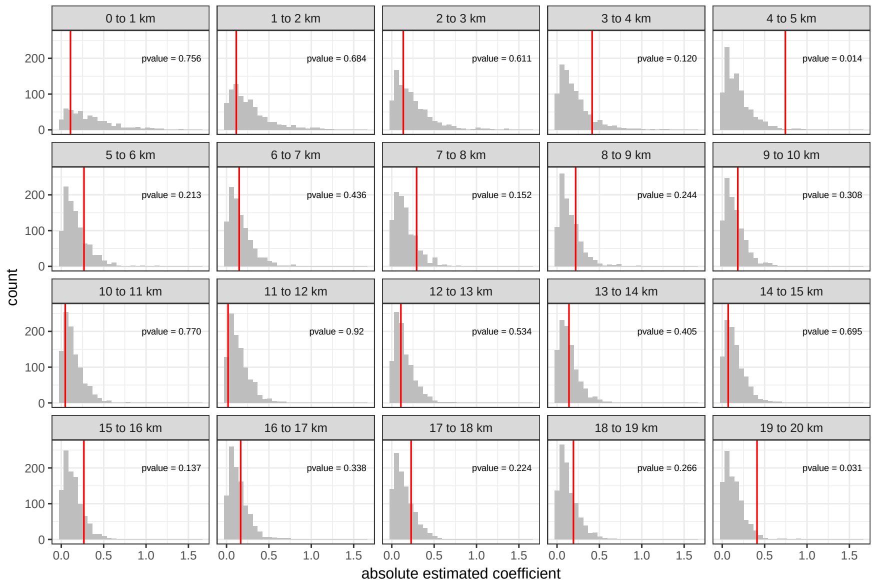
(b)

Figure 23: Counterfactual distributions of (a) local government and Afro-religious activities and (b) capoeira groups

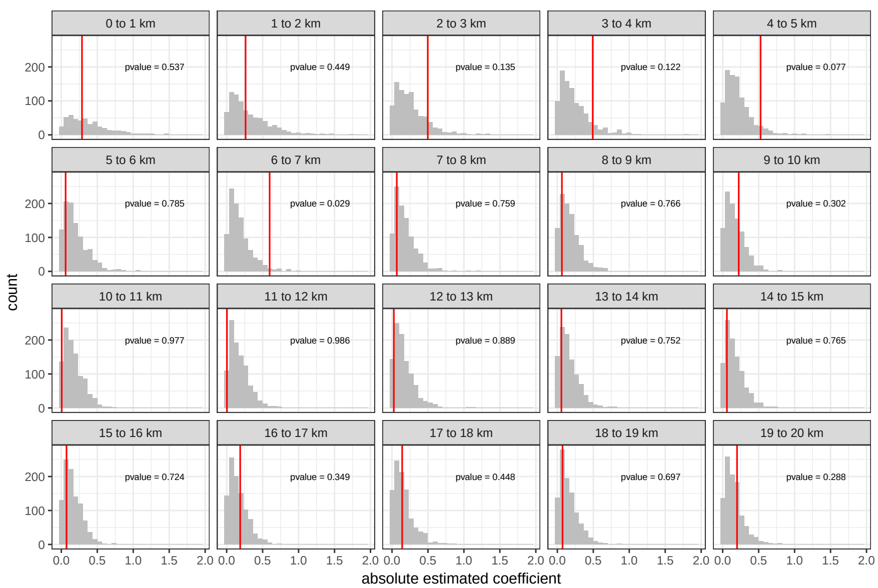


(a)

Figure 24: Counterfactual distributions of (a) generalized trust

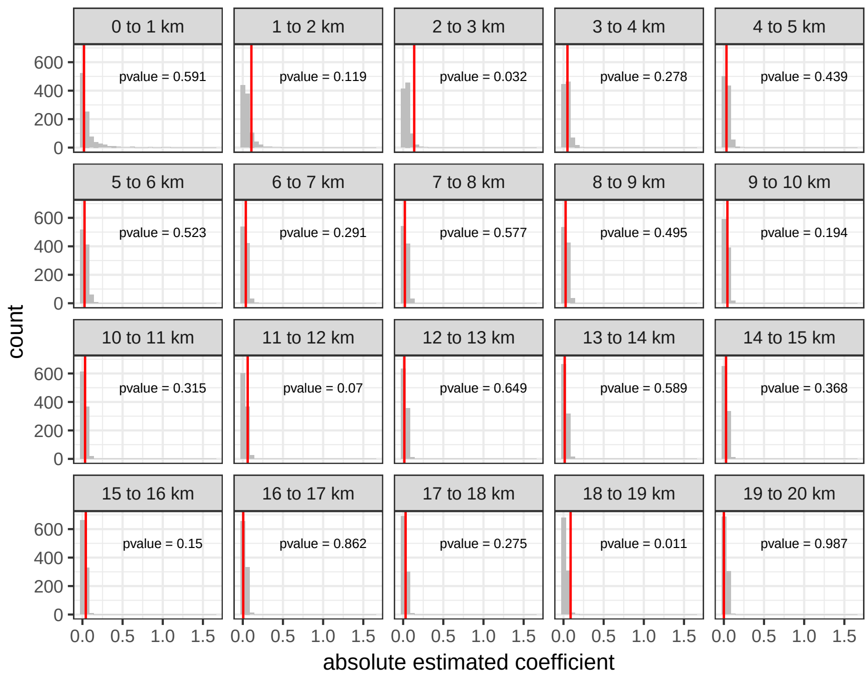


(a)



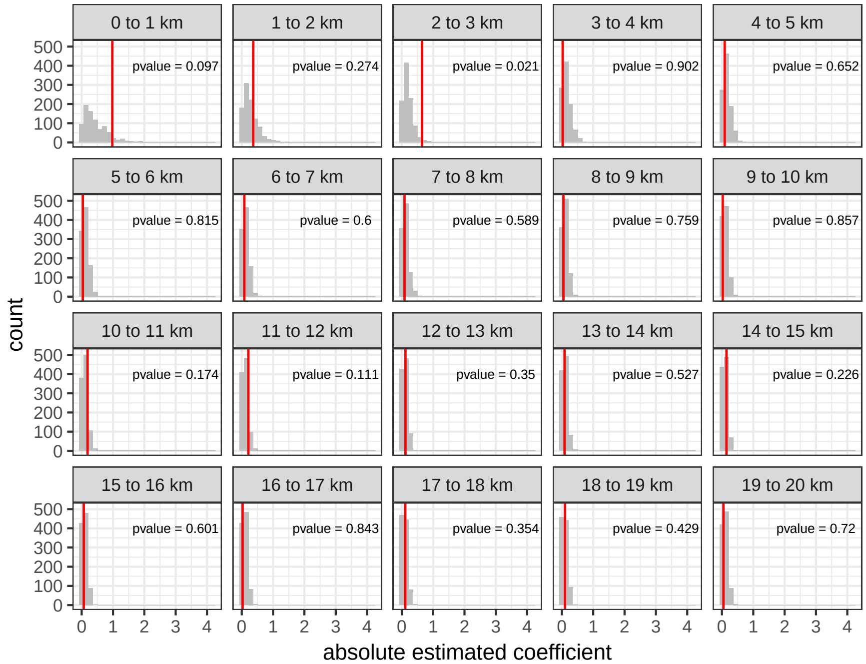
(b)

Figure 25: Counterfactual distributions of (a) community trust and (b) collective action

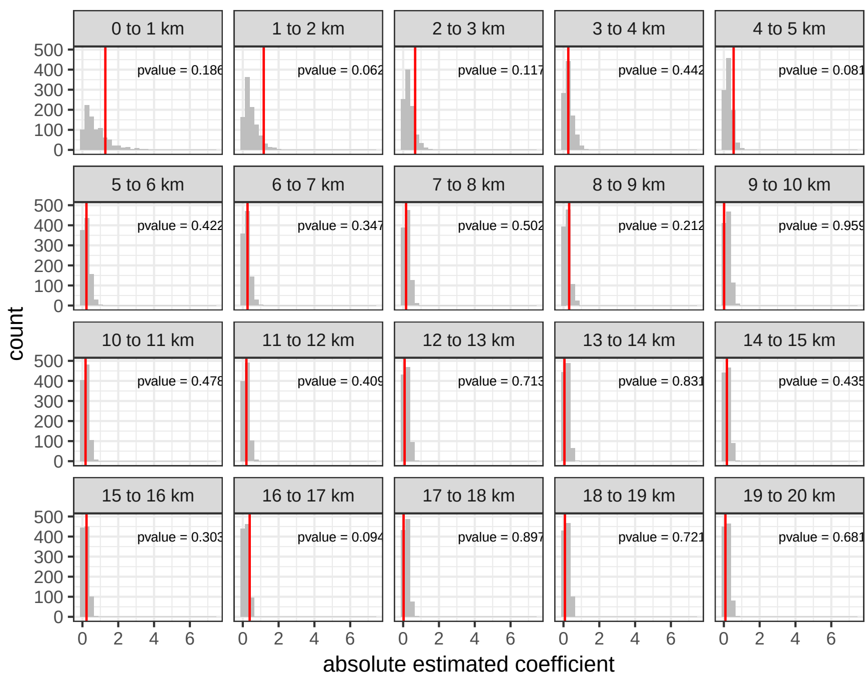


(a)

Figure 26: Counterfactual distributions of (a) metal handicraft

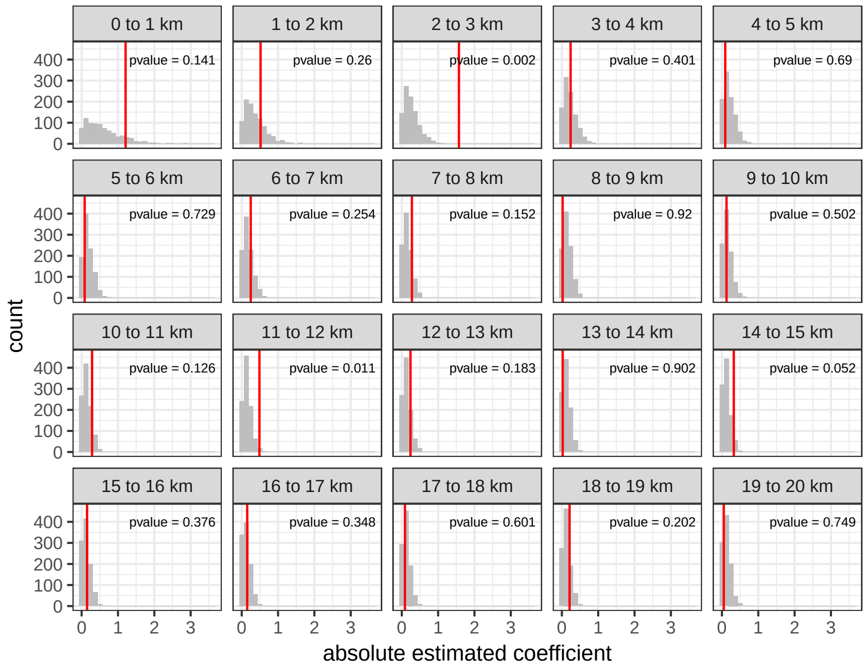


(a)

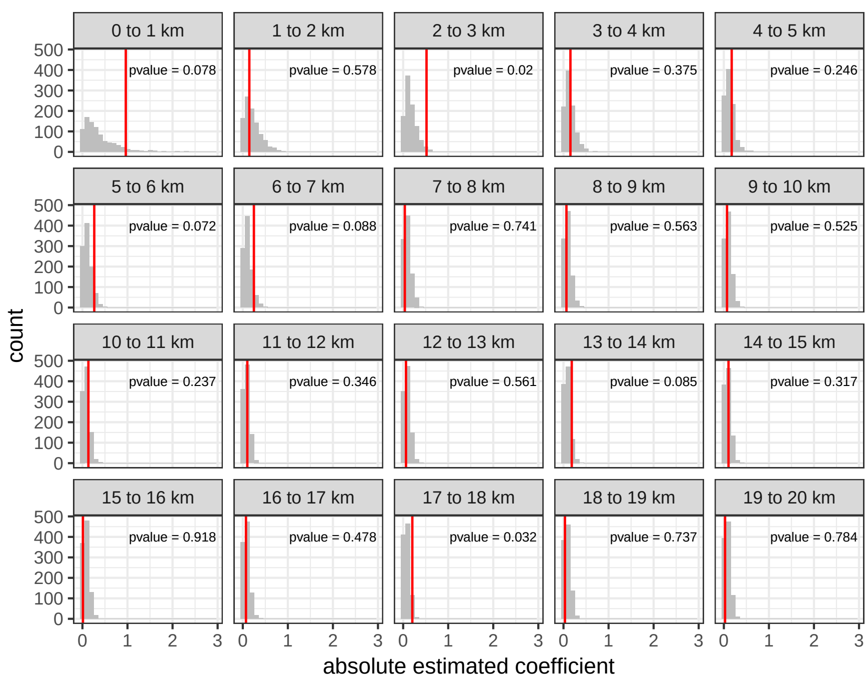


(b)

Figure 27: Counterfactual distributions of (a) crafts and related trades 2010 and (b) craft and related trades 1980

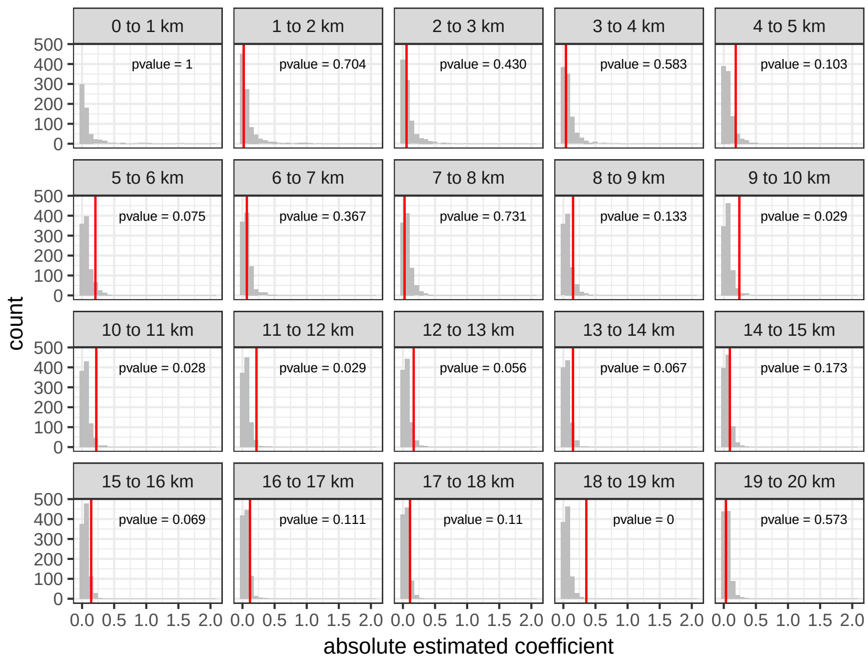


(a)



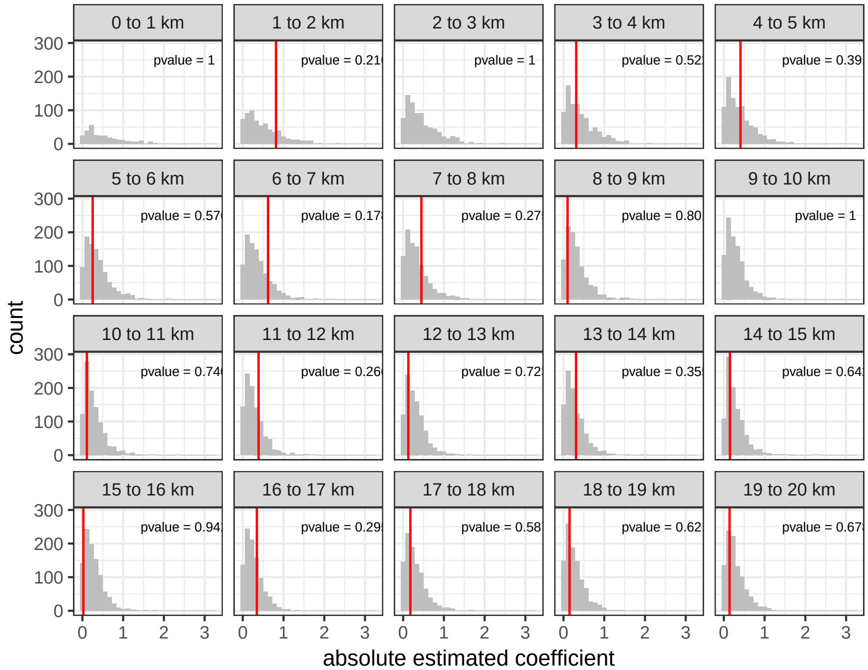
(b)

Figure 28: Counterfactual distributions of (a) skilled agricultural and fishery 2010 and (b) skilled agricultural and fishery 1980

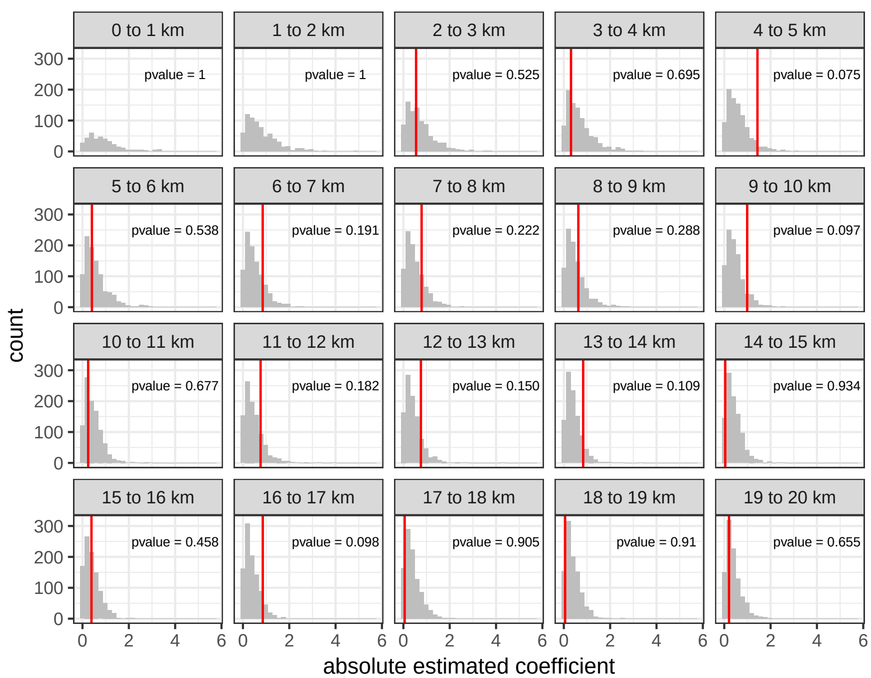


(a)

Figure 29: Counterfactual distributions of the placebo test for (a) metal handicraft

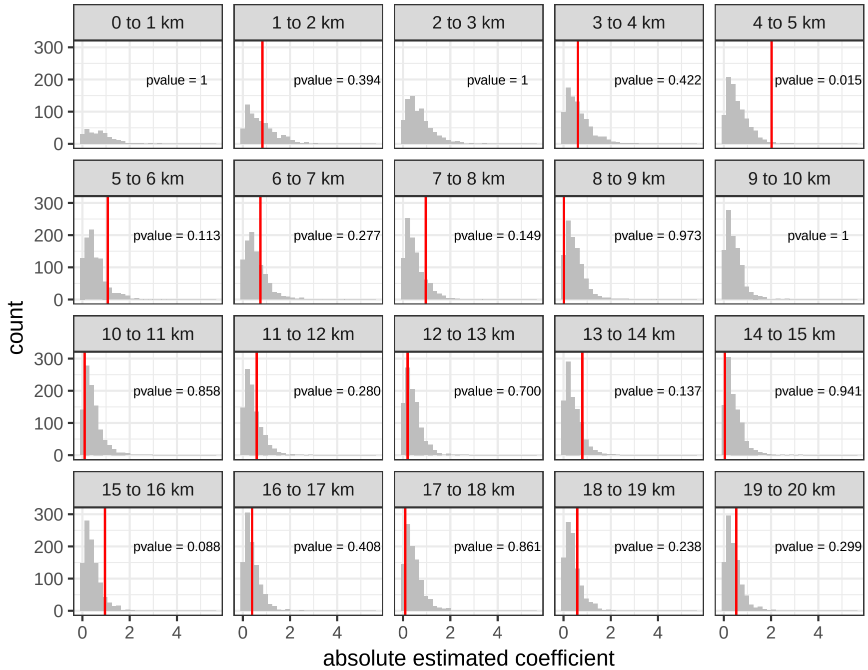


(a)

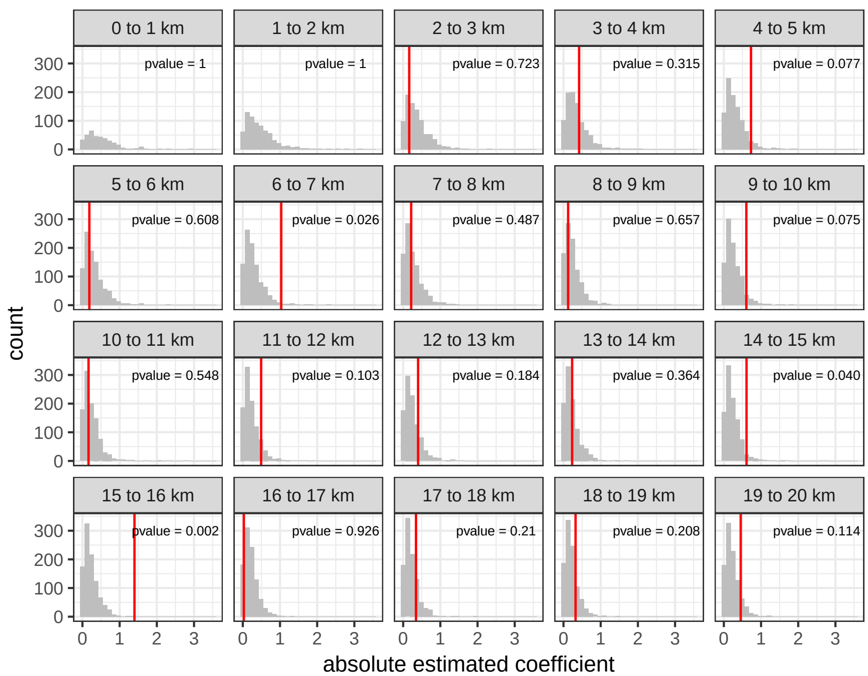


(b)

Figure 30: Counterfactual distributions of the placebo test for (a) crafts and related trades 2010 and (b) craft and related trades 1980

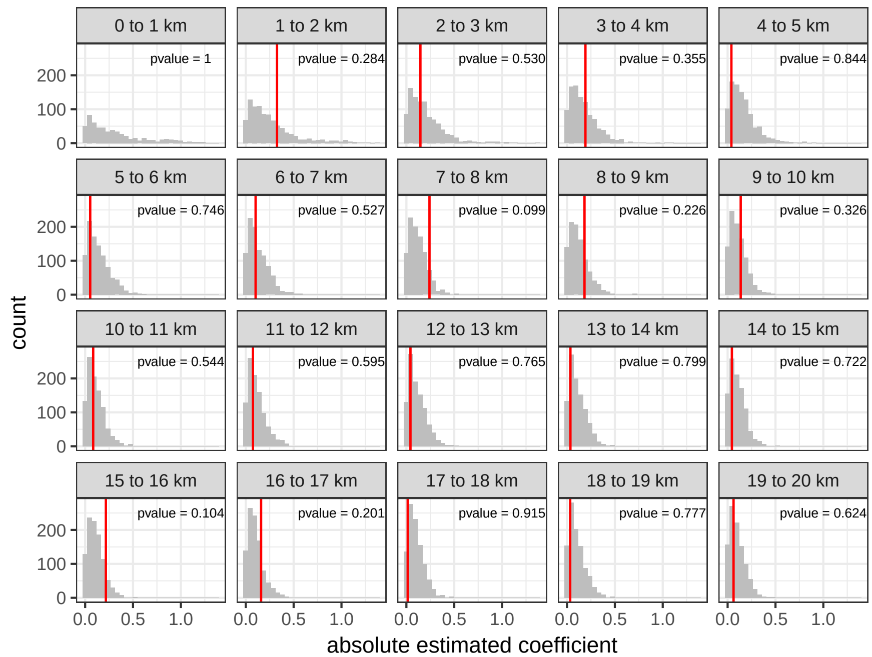


(a)

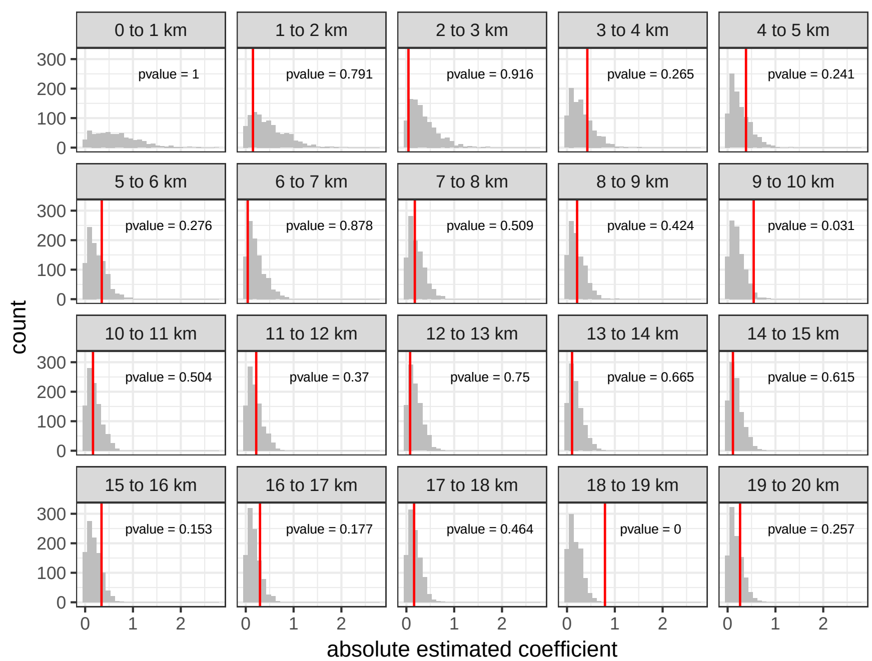


(b)

Figure 31: Counterfactual distributions of the placebo test for (a) skilled agricultural and fishery 2010 and (b) skilled agricultural and fishery 1980

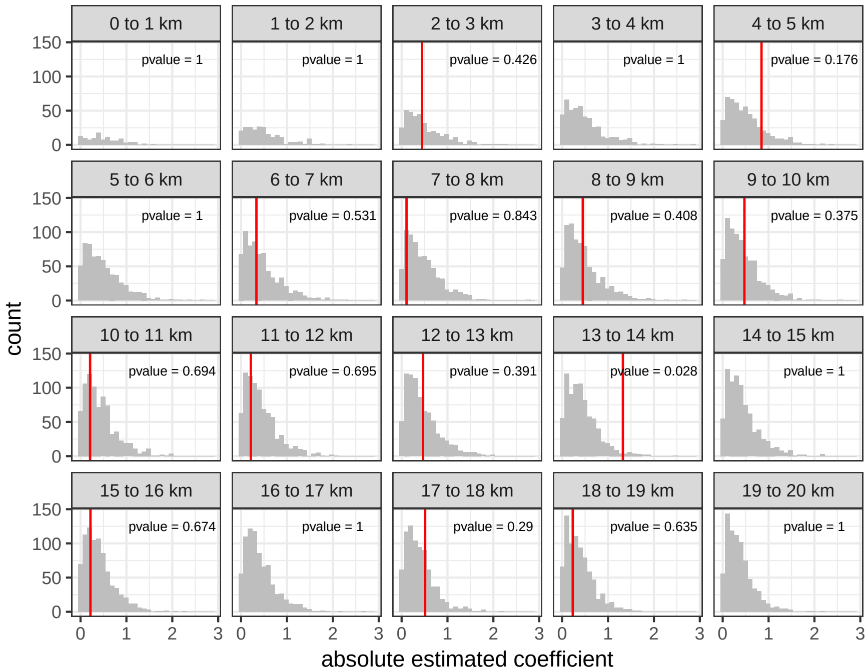


(a)

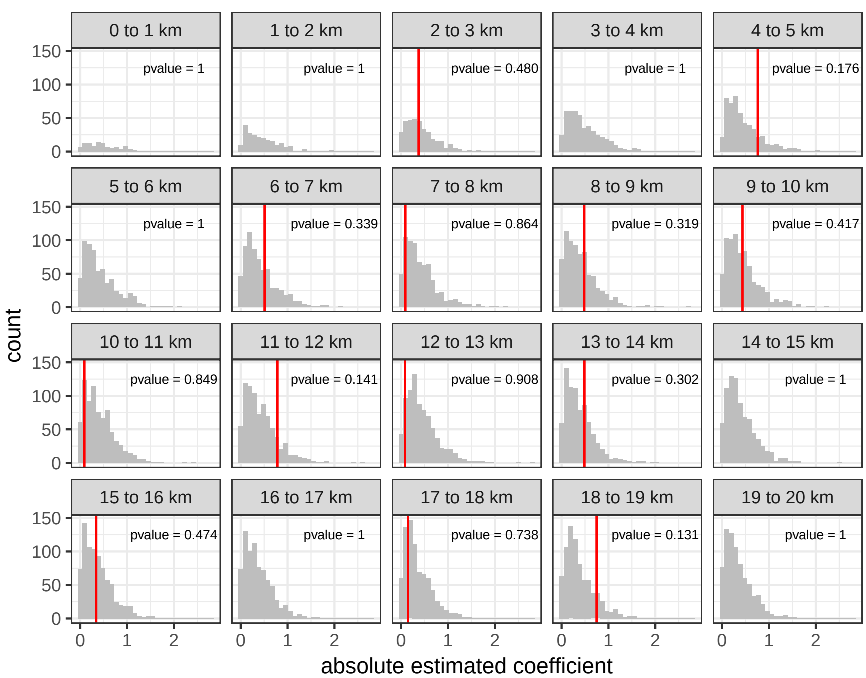


(b)

Figure 32: Counterfactual distributions of the placebo test for (a) local government and Afro-religious cultural activities and (b) capoeira groups

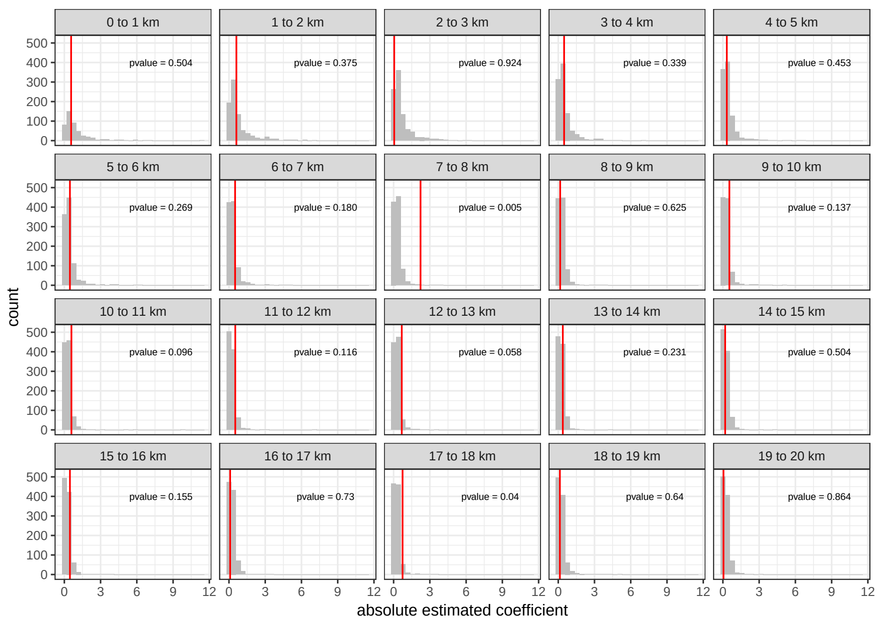


(a)



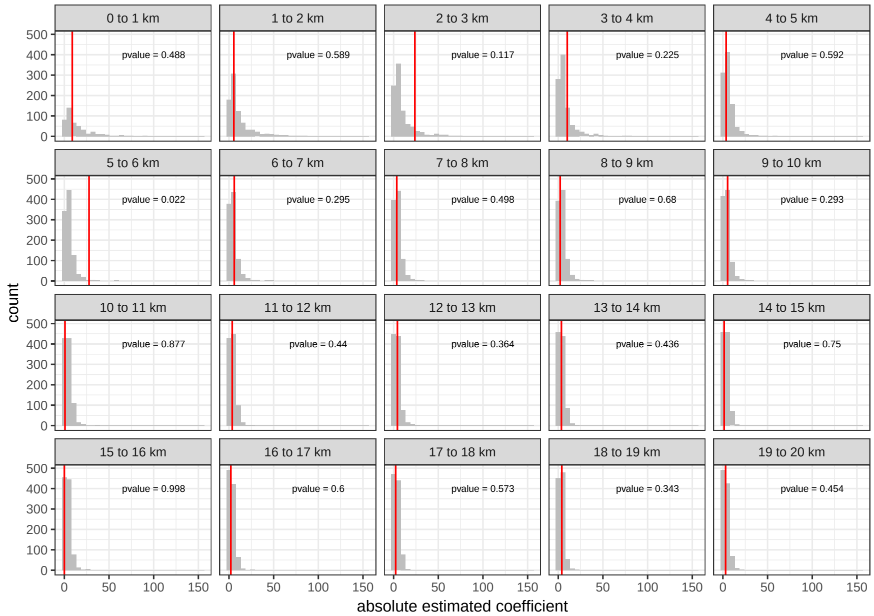
(b)

Figure 33: Counterfactual distributions of the placebo test for (a) community trust and (b) collective action

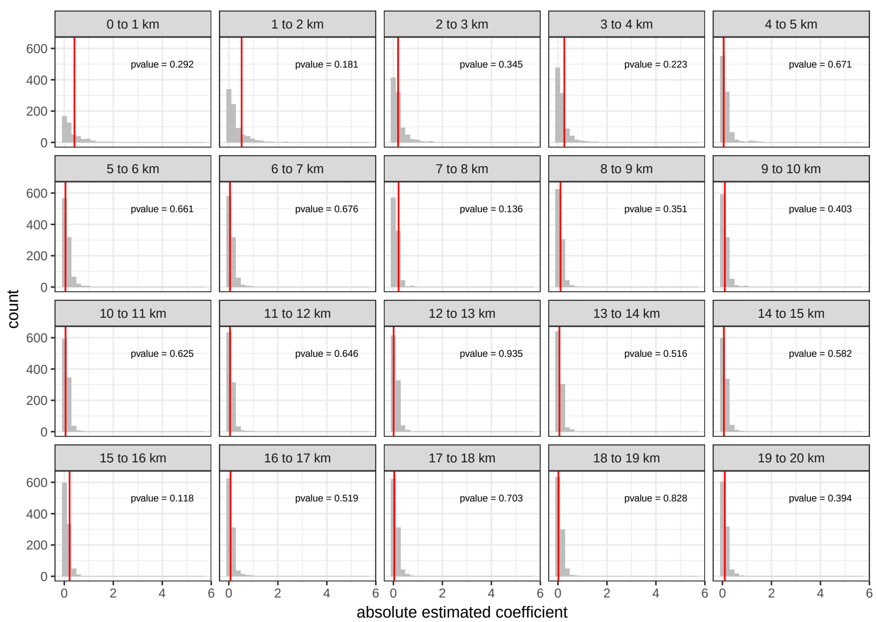


(a)

Figure 34: Counterfactual distributions of (a) income in 1875

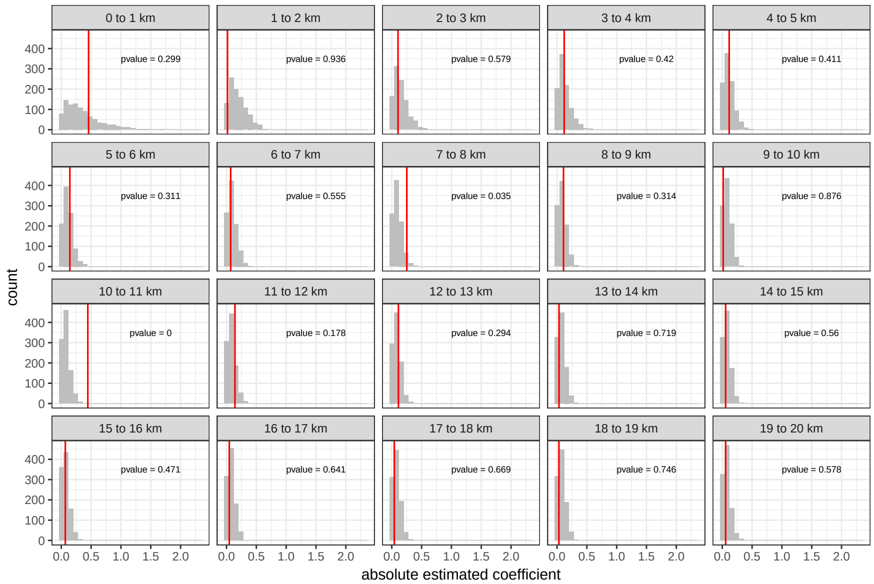


(a)

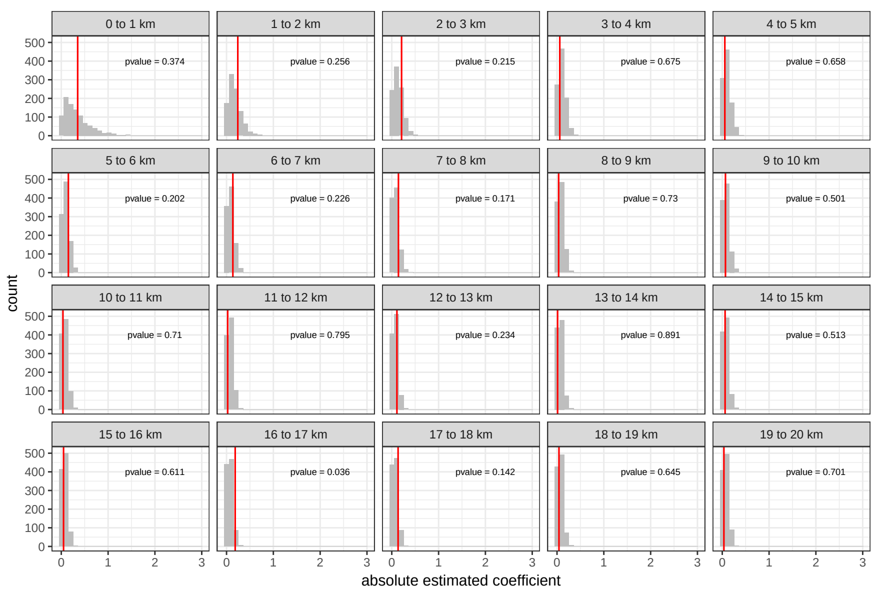


(b)

Figure 35: Counterfactual distributions of (a) literacy of the free population in 1872 and (b) literacy of slaves in 1872

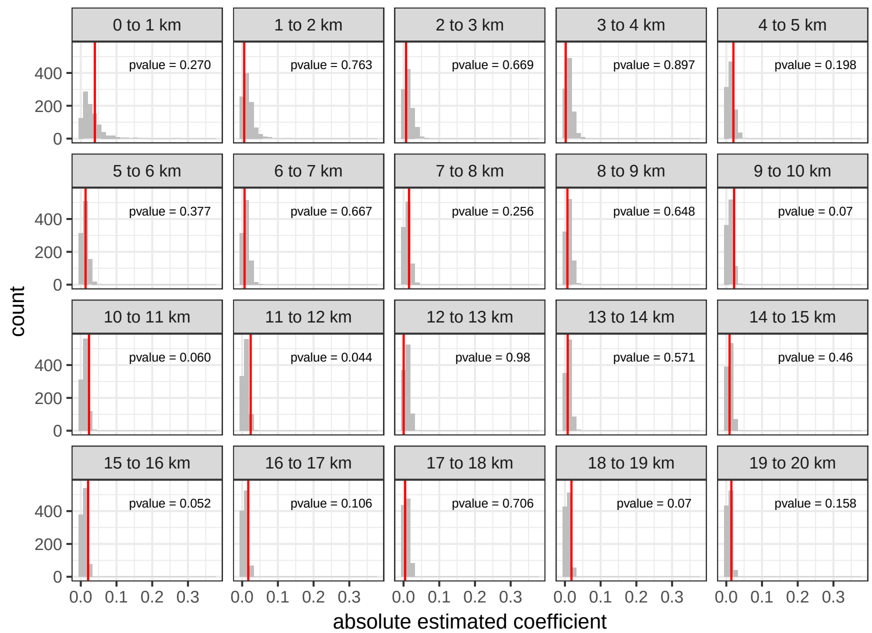


(a)



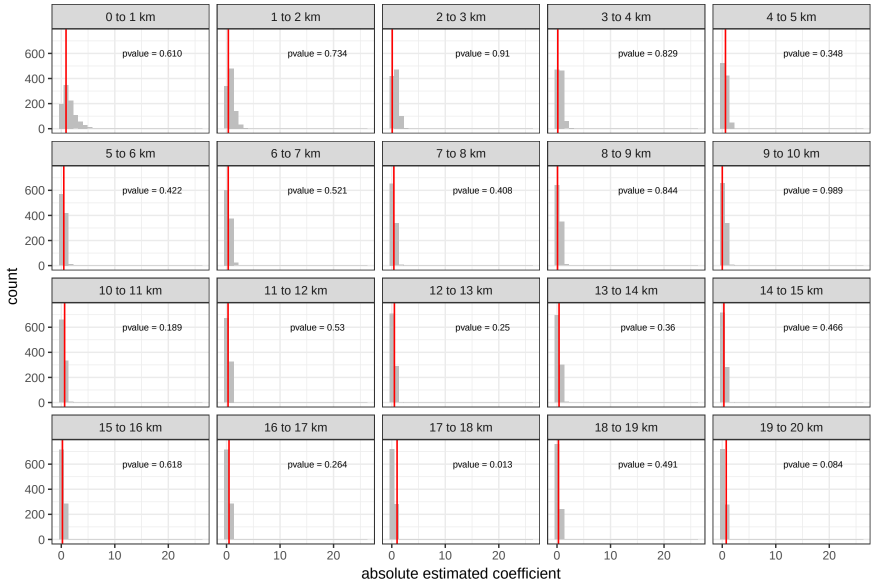
(b)

Figure 36: Counterfactual distributions of (a) governance and (b) access to justice

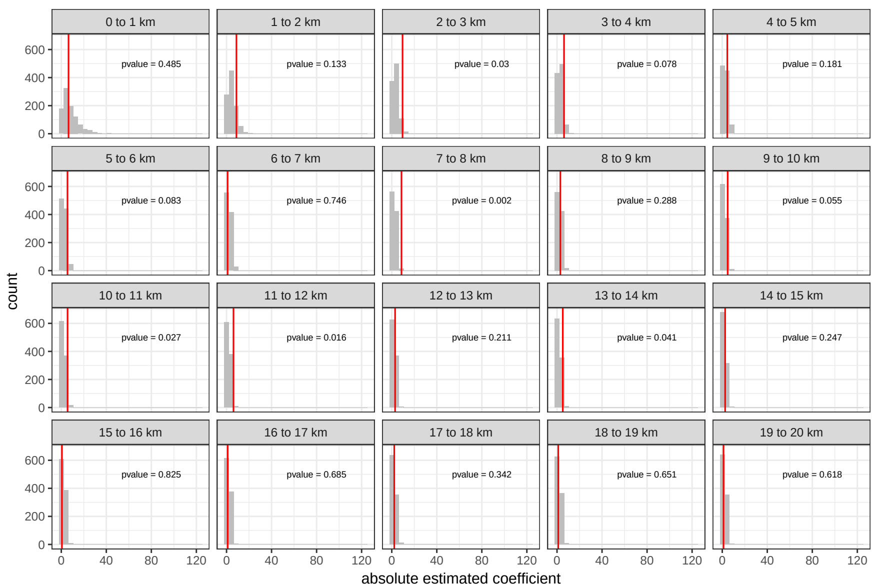


(a)

Figure 37: Counterfactual distributions of (a) land Gini

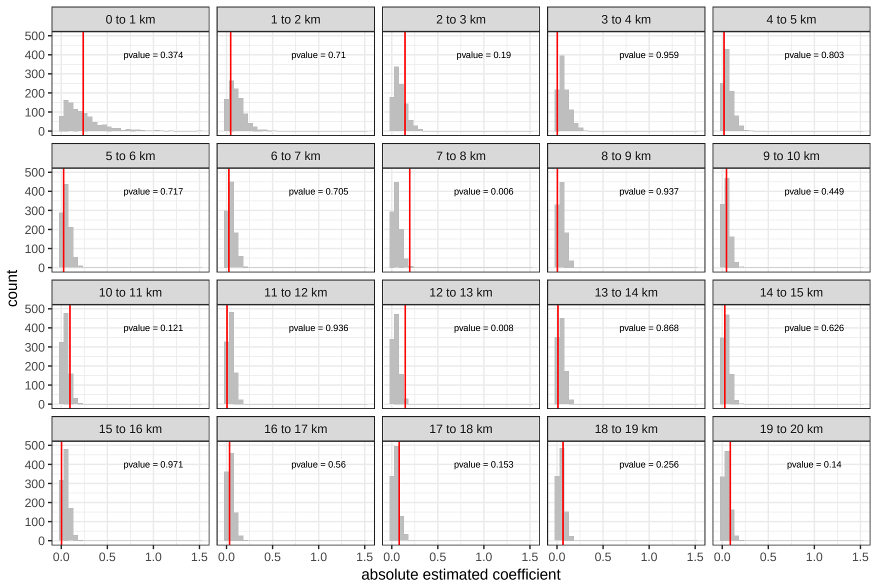


(a)

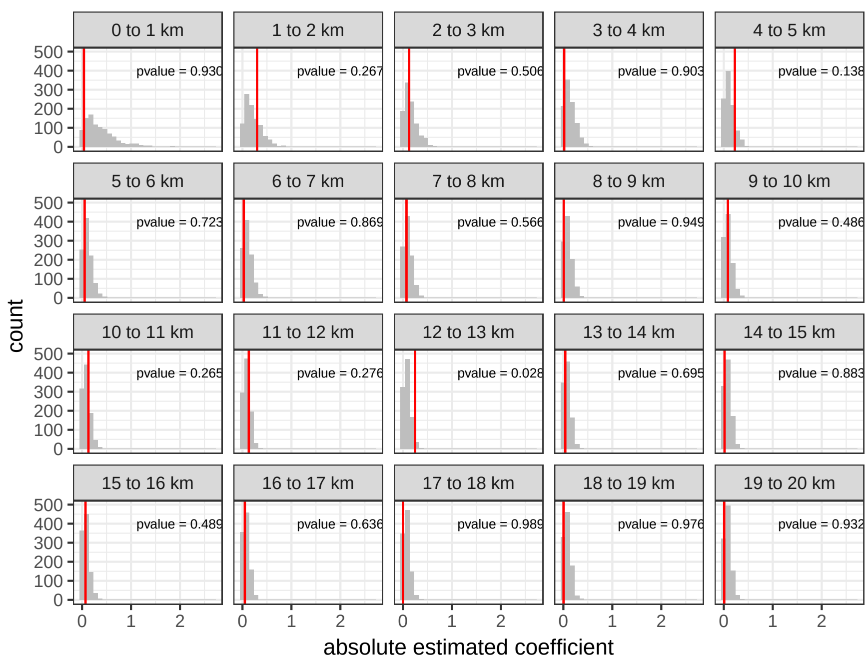


(b)

Figure 38: Counterfactual distributions of (a) health centers and (b) sewage



(a)



(b)

Figure 39: Counterfactual distributions of (a) public library and (b) Bolsa Família transfers

Estimating a Behavioral New Keynesian Model *

Contents

*Special thanks to Tiago Flórido (in memoriam) for sharing code and initial conversations that greatly estimulated this project. We thank Isaiah Andrews, Gabriel Chodorow-Reich, José Angelo Divino, Xavier Gabaix, Bernardo Mueller, Michael Plagborg-Møller, Marina Rossi, and seminar participants at the Central Bank of Brazil for very helpful comments and suggestions. We also thank Jordi Galí for sharing data and Argia Sbordone for help with the trend inflation measure in the first iterations of the paper. Guilherme Lambais developed part of this project as a visiting scholar at the Department of Economics at Harvard University, he gratefully acknowledges Ed Glaeser and everyone there for their hospitality, and funding from CNPq (142182/2015-0) and CAPES (88881.134763/2016-01).

1 Introduction

Benchmark optimization-based New Keynesian macroeconomic models rely on fully rational agents, but usually these models generate a number of paradoxes.[1] Fundamentally, consumers and firms do not appear to be entirely forward looking. One response to this challenge is the contribution by Gabaix (2019), in which agents are inattentive about future macroeconomic events.[2] This paper proposes to estimate this behavioral New Keynesian model, focusing on the main behavioral parameter.

The behavioral mechanism of the model in Gabaix (2019) is fully microfounded and works in the form of a cognitive discounting. That is, as the agent simulate k steps into the future, the impact of her expectation is shrunk by a factor $\bar{m}^k$ towards a simple benchmark, which can be the steady state of the economy. The parameter $\bar{m} \in [0, 1]$ captures this cognitive discounting, which can be though of as a form of myopia; innovations far into the future get heavily discounted relative to the rational benchmark where $\bar{m} = 1$. Another way of seeing this, is that the agent is globally patient in relation to the steady-state variables, yet is myopic with respect to deviations around the steady state, particularly if these deviations are in the remote future.

Theoretical issues that cognitive discounting brings to New Keynesian (NK) models and some impacts on monetary and fiscal policy are already explored in Gabaix (2019), we contribute with a discussion on its estimation. The estimation of macroeconomic models, either in the dynamic stochastic general equilibrium (DSGE) form or in the single equation form, has a very large literature on its own.[3]

Considering limited-information estimation of the New Keynesian Phillips Curve (NKPC), it is known that the purely forward-looking NKPC does not fit well aggregate U.S. inflation dynamics. There is still no consensus in the literature, but just to cite a few developments in response to this problem there is the hybrid NKPC (Gali and Gertler 1999), revisions to lower the size of the forward looking coefficient (Rudd and Whelan 2005), and inclusion of a trend inflation measure (Cogley and Sbordone 2008). In addition, problems also arise in

[1] New Keynesian models are mainly composed by the output and inflation equations and a monetary policy rule. The output equation generalizes the Euler equation for the whole economy and the inflation equation is a microfounded expectation-augmented Phillips curve. With fully rational agents, expectations in these curves are only forward looking, which generates a number of problems. The fully rational model generates the following predictions, which are continually contradicted by empirical facts: fiscal policy has no impact, depressions are moderate and bounded, equilibria is indeterminate at the zero lower bound, forward guidance by the central bank is very powerful, "price level targeting" is the optimal commitment policy, and the neo-Fisherian paradox (a rise in interest rates causes a rise in inflation).

[2] Another proposal that relaxes the full rationality assumption to address these paradoxes is, for example, Farhi and Werning (2019).

[3] See, for example, Fernández-Villaverde, Rubio-Ramírez, and Schorfheide (2016) for DSGE models and Mavroeidis, Plagborg-Møller, and Stock (2014) for the NK Phillips Curve.

relation to the frequency of price re-optimization by firms (Eichenbaum and Fisher 2007).

Likewise, numerous studies have found that the standard Euler equation model does not have a good fit to aggregate U.S consumption time series (*e.g.*, Ascari and Magnusson (2016) and Fuhrer and Rudebusch (2004)).[4] Extensions to the pure forward-looking Euler equation for output include habits (Fuhrer (2000)), hand-to-mouth consumers (Bilbiie and Straub (2012)), and a hybrid version as well (McCallum and Nelson (1998)).

Additionally, the estimation of full DSGE models saw remarkable advances in the past decades, however the estimation of large models can get complex and computationally demanding very quickly. While it is out of the scope of this paper to discuss the literature of DSGE estimation in general, we are particularly interested in issues of weak identification that arise in both simple DSGE models and estimation of single equations that compose these DSGE models. In both strands of literature (DSGE and single equation) the issue of weak identification is abound: for example, Andrews and Mikusheva (2015) and Canova and Sala (2009) analyze identification issues in DSGE models and Mavroeidis, Plagborg-Møller, and Stock (2014), Ascari and Magnusson (2016), and Mavroeidis (2010) analyze identification issues that arise in the estimation of the NKPC, Euler equation, and monetary policy rules.

In this paper our contribution is twofold. First, we analytically solve a version of the model proposed by Gabaix (2019) to show where identification holds and it what conditions does it fail, and estimate the parameters of the system using robust maximum likelihood inference proposed in Andrews and Mikusheva (2015). Second, with a good understanding of what is driving identification we can then use less restrictive single-equation methods to estimate behavioral versions of the NKPC and the IS curve using two-step confidence sets proposed in Andrews (2018) that is also robust to identification failure.

The next section presents the behavorial NK model, section 3 solves the model and analyzes its identification, section 4 provides an initial likelihood-based estimation, section 5 presents the single-equation estimation method, section 6 the two-step robust confidence sets results and section 7 concludes.

2 A Behavioral Macroeconomic Model

We start with proposition 2.5 in Gabaix (2019), a two-equation version of the Behavioral New Keynesian model, for the behavior of the output gap x_t and inflation π_t:

[4] In a study about the Euler equation for consumption, Havranek (2015) conducts a meta-analysis of 169 published studies showing there is pervasive selective reporting of results and publication bias in this literature; exactly the problem we take head-on with the method implemented in this paper.

$$x_t = M\mathbb{E}_t[x_{t+1}] - \sigma(i_t - \mathbb{E}_t\pi_{t+1} - r_t^n) \;\; (IS\,curve), \tag{1}$$

$$\pi_t = \beta M^f \mathbb{E}_t[\pi_{t+1}] + \kappa x_t \;\; (Phillips\,curve), \tag{2}$$

with i_t as the nominal interest rate, r_t^n is the natural interest rate, σ is the sensitivity of the output gap to the interest rate, κ is the sensitivity of the inflation to the output gap, and β is the pure rate of time preference. The equilibrium behavioral parameters $M, M^f \in [0,1]$ are the aggregate-level attention parameters of consumers and firms, respectively, to macroeconomic outcomes:

$$M = \bar{m}, \;\; \sigma = \frac{1}{\gamma R}, \tag{3}$$

$$M^f = \bar{m}\left(\theta + \frac{1-\beta\theta}{1-\beta\theta\bar{m}}(1-\theta)\right), \;\; \kappa = (\frac{1}{\theta} - 1)(1-\beta\theta)(\gamma+\phi) \tag{4}$$

where $\bar{m}$ is the myopia parameter, θ is the survival rate of prices, γ is the risk aversion, σ becomes the "effective" intertemporal elasticity of substitution, ϕ is the inverse Frisch elasticity, and $\kappa = (\frac{1}{\theta} - 1)(1-\beta\theta)(\gamma+\phi)$ is the slope obtained with fully rational firms. Firms are still fully attentive to the steady state, so they discount future profits at the rate $R = \frac{1}{\beta}$. In the traditional benchmark model, $\bar{m} = 1$, so that $M = M^f = 1$.

The next section shows on what conditions does the identification of this model rest on and the procedures for identification-robust inference.

3 Weak Identification in a Behavioral Dynamic Stochastic General Equilibrium Model

This section follows closely Andrews and Mikusheva (2015). We first explore a dynamic stochastic general equilibrium (DSGE) version of the behavioral NK model by adding a monetary policy rule and exogenous technology and monetary policy shocks in addition to equations 1 and 2, which gives the following system:

$$\begin{aligned} x_t &= M\mathbb{E}_t[x_{t+1}] - \sigma(i_t - \mathbb{E}_t\pi_{t+1}) + \eta_{d,t} \\ \pi_t &= \beta M^f \mathbb{E}_t[\pi_{t+1}] + \kappa x_t + \epsilon_{s,t} \\ i_t &= \rho_i i_{t-1} + (1-\rho_i)(\phi_\pi \pi_t + \phi_x x_t) + \eta_{m,t} \end{aligned} \tag{5}$$

where the unobserved exogenous shocks are generated by the law

$$
\begin{aligned}
\eta_{d,t} &= \rho_d \eta_{d,t-1} + \epsilon_{d,t} \\
\eta_{m,t} &= \rho_m \eta_{m,t-1} + \epsilon_{m,t} \\
(\epsilon_{s,t}, \epsilon_{d,t}, \epsilon_{m,t})' &\sim \text{i.i.d.} N(0, \Sigma) \\
\Sigma &= \text{diag}(\sigma_s^2, \sigma_d^2, \sigma_m^2).
\end{aligned} \tag{6}
$$

We make several simplifying assumptions to be able to solve the model analytically. Specifically, assume that $\rho_i = 0$, $\phi_x = 0$, $\phi_\pi = \frac{1}{\sigma}$, and $\sigma_s^2 = 0$, so the model has $\vartheta = (\beta, \theta, \bar{m}, \gamma, \phi, \rho_m, \rho_d, \sigma_m^2, \sigma_d^2)$, knowing that M^f, σ, and κ are functions of $\bar{m}$, β, θ, γ, and ϕ. In Section 8.1 of the Appendix using these restrictions we obtain the following solution for the behavioral DSGE model

$$
\begin{pmatrix} x_t \\ \pi_t \end{pmatrix} = \begin{pmatrix} \dfrac{-\beta M^f \sigma}{\beta M^f + \sigma\kappa - \rho_m \bar{m}} & \dfrac{\beta M^f}{\beta M^f + \sigma\kappa - \rho_d \bar{m}} \\ \dfrac{-\beta M^f \sigma\kappa}{(\beta M^f + \sigma\kappa - \rho_m \bar{m})(1 - \rho_m \beta M^f)} & \dfrac{\beta M^f}{(\beta M^f + \sigma\kappa - \rho_d \bar{m})(1 - \rho_d \beta M^f)} \end{pmatrix} \begin{pmatrix} \eta_{m,t} \\ \eta_{d,t}. \end{pmatrix} \tag{7}
$$

To analyze the identification of the model parameters, let

$$
A_1(\vartheta) = \frac{-\beta M^f \sigma}{\beta M^f + \sigma\kappa - \rho_m \bar{m}} \quad \text{and} \quad A_2(\vartheta) = \frac{\beta M^f}{\beta M^f + \sigma\kappa - \rho_d \bar{m}}, \tag{8}
$$

thus we can write each equation in the system 7 for x_t and π_t as

$$
\begin{aligned}
x_t &= A_1(\vartheta)\eta_{m,t} + A_2(\vartheta)\eta_{d,t} \\
\pi_t &= \frac{\kappa}{1 - \rho_m \beta M^f} A_1(\vartheta)\eta_{m,t} + \frac{\kappa}{1 - \rho_d \beta M^f} A_2(\vartheta)\eta_{d,t}.
\end{aligned} \tag{9}
$$

We can now express the autocovariances and cross-covariances of the series x_t and π_t using the two equations above and the law of motion in 6. In particular, for x_t the autocovariances are

$$
\begin{aligned}
\text{Var}(x_t) &= A_1(\vartheta)^2 \frac{\sigma_m^2}{1 - \rho_m^2} + A_2(\vartheta)^2 \frac{\sigma_d^2}{1 - \rho_m^2} \\
\text{Cov}(x_t, x_{t-k}) &= A_1(\vartheta)^2 \frac{\sigma_m^2 \rho_m^k}{1 - \rho_m^2} + A_2(\vartheta)^2 \frac{\sigma_d^2 \rho_d^k}{1 - \rho_m^2}
\end{aligned} \tag{10}
$$

from which we can identify $\rho_d \neq \rho_m$, $A_1(\vartheta)^2\sigma_m^2$, $A_2(\vartheta)^2\sigma_d^2$. Additionally, the expression for the cross-covariance structure of the processes x_t and π_t is

$$
\begin{aligned}
\mathrm{Cov}(x_t, \pi_t) &= A_1(\vartheta)^2 \frac{\sigma_m^2}{1-\rho_m^2} \frac{\kappa}{1-\rho_m \beta M^f} + A_2(\vartheta)^2 \frac{\sigma_d^2}{1-\rho_a^2} \frac{\kappa}{1-\rho_d \beta M^f} \\
\mathrm{Cov}(x_t, \pi_{t-k}) &= A_1(\vartheta)^2 \frac{\sigma_m^2 \rho_m^k}{1-\rho_m^2} \frac{\kappa}{1-\rho_m \beta M^f} + A_2(\vartheta)^2 \frac{\sigma_d^2 \rho_d^k}{1-\rho_a^2} \frac{\kappa}{1-\rho_d \beta M^f}.
\end{aligned}
\tag{11}
$$

from this structure we can identify $A_1(\vartheta)^2\sigma_m^2 \frac{\kappa}{1-\rho_m\beta M^f}$ and $A_2(\vartheta)^2\sigma_d^2 \frac{\kappa}{1-\rho_d\beta M^f}$.

Thus, in all from the autocovariance structure of processes x_t and π_t, if $0 < \beta < 1$, $0 < \bar{m} < 1$, $0 < \theta < 1$, $0 < \rho_m < 1$, $0 < \rho_d < 1$, $\kappa > 0$, $\sigma_m^2 > 0$, and $\sigma_d^2 > 0$ we can identify six quantities

$$
\rho_m, \;\; \rho_d, \;\; A_1(\vartheta)^2\sigma_m^2, A_2(\vartheta)^2\sigma_d^2, \;\; A_1(\vartheta)^2\sigma_m^2 \frac{\kappa}{1-\rho_m\beta M^f}, \;\; A_2(\vartheta)^2\sigma_d^2 \frac{\kappa}{1-\rho_d\beta M^f}.
$$

Looking at the last four quantities we can see that $\frac{\kappa}{1-\rho_m\beta M^f}$ and $\frac{\kappa}{1-\rho_d\beta M^f}$ are identified, thus $\frac{1-\rho_m\beta M^f}{1-\rho_d\beta M^f}$ is identified. Since ρ_d and ρ_m are part of the six quantities initially identified, we have that the product βM^f is identified as well. The parameter M^f is equal to $\bar{m}\left(\theta + \frac{1-\beta\theta}{1-\beta\theta\bar{m}}(1-\theta)\right)$, thus if we fix a value for β and θ, which is common in the literature, then $\bar{m}$ is identified. Furthermore, this implies that κ is identified. Since κ is equal to $(\frac{1}{\theta}-1)(1-\beta\theta)(\gamma+\phi)$, if we fix a value for ϕ, then γ is also identified. Now since σ is equal to $\frac{\beta}{\gamma}$, σ is identified as well. With these quantities identified so far, it implies that σ_m^2 and σ_d^2 are identified. To sum up, we have three degrees of underidentification - nine structural parameters but only six identified quantities -, thus we have to fix three parameters to identify the other six.

If $\rho_d = \rho_m$ the situation is different. If $\rho_d = \rho_m$ then the series for x_t and π_t becomes

$$
\begin{aligned}
x_t &= \frac{\beta M^f}{\beta M^f + \sigma\kappa - \rho_{m,d}\bar{m}} (\eta_{d,t} - \sigma\eta_{m,t}) \\
\pi_t &= \frac{\beta M^f}{(\beta M^f + \sigma\kappa - \rho_{m,d}\bar{m})(1-\rho_{m,d}\beta M^f)} (\eta_{d,t} - \sigma\eta_{m,t}) = \frac{\kappa}{1-\rho_{m,d}\beta M^f} x_t,
\end{aligned}
\tag{12}
$$

which are linearly dependent AR(1) processes with autoregressive root $\rho_m = \rho_d$. From this system with can only identify four quantities: the autogressive parameter $\rho_m = \rho_d$, the variance of x_t, and the ratio x_t/π_t,

$$
\rho_m = \rho_d, \;\; \frac{\beta M^f}{\beta M^f + \sigma\kappa - \rho_{m,d}\bar{m}} \sqrt{\sigma^2\sigma_m^2 + \sigma_d^2}, \;\; \frac{\kappa}{1-\rho_{m,d}\beta M^f}.
$$

Hence, we now have two extra degrees of underidentification. More importantly, even if $\rho_d \neq \rho_m$, as the difference $\rho_d - \rho_m$ approaches zero there is a difficulty in making reliable statistical inferences. Following the example in Andrews and Mikusheva (2015), take the Wald statistic W for testing the true hypothesis $H_0 : \vartheta = \vartheta_0$. Under usual asymptotic theory of maximum likelihood, if $\rho_m \neq \rho_d$ then as the sample size T increases to infinity, the statistic W converges in distribution to χ^2_9 under H_0. However, if $\rho_m = \rho_d$ this convergence breaks down in the limit distribution of W. The distribution of W experiences a discontinuity at $\rho_m = \rho_d$, which implies that the convergence to χ^2 is not uniform in the parameter $\rho_d - \rho_m$ in the neighborhood of zero.

The consequences can be quite severe in distorting the size of the test. For example, Andrews and Mikusheva (2014) documents for simple DSGE model that if $\rho_m - \rho_d = 0.05$, then the size of a 5 percent Wald test is actually 88.9% and even for a large difference of $\rho_d - \rho_m = 0.7$ the size of the test is 9.8%, that is, instead of falsely rejecting H_0 only the standard 5% of the times, one would be falsely rejecting H_0 between approximately 90% and 10% most of the times.

4 Maximum Likelihood Inference with Robust Confidence Sets

From the solution of the DSGE model in equation 7 we have a space-state representation of the system and we readily apply the maximum likelihood method. The estimation in this section is made using the complete model, but to illustrate the method we proceed with the simplified solution, which is rearranged as

$$Y_t = \begin{pmatrix} x_t \\ \pi_t \end{pmatrix} = C(\vartheta) \begin{pmatrix} \eta_{m,t} \\ \eta_{d,t} \end{pmatrix} = C(\vartheta) U_t \tag{13}$$

and

$$U_t = \Lambda U_{t-1} + \epsilon_t, \quad \Lambda = \begin{pmatrix} \rho_m & 0 \\ 0 & \rho_d \end{pmatrix} \text{ and } \epsilon_t \sim N(0, \Sigma). \tag{14}$$

The log likelihood of the state-space system is:

$$\begin{aligned} \ell_T(\vartheta) \quad = \quad & \text{const} \\ & -\tfrac{1}{2} \textstyle\sum_{t=1}^{T} (C^{-1}(\vartheta) Y_t - \Lambda C^{-1}(\vartheta) Y_{t-1})' \Sigma^{-1} (C^{-1}(\vartheta) Y_t - \Lambda C^{-1}(\vartheta) Y_{t-1}) \\ & -\tfrac{T}{2} \log|\Sigma| - T \log|C(\vartheta)|. \end{aligned} \tag{15}$$

The full model has as endogenous observed series, i_t, the Effective Federal Funds Rate, in addition to x_t, the output gap, and π_t, the inflation rate. Data for these three series are taken from the Federal Reserve Bank of St. Louis' FRED database for the period 1962:Q2 to 2016:Q4 and detrended.

Table 1 reports maximum likelihood estimates using Chris Sims minimization routine that employs a quasi-Newton method with BFGS updates of the estimated inverse hessian for the structural model parameters $\bar{m}$, γ, ϕ_π, and ϕ_x and for the shock parameters ρ_i, ρ_d, ρ_m, σ_d^2, σ_s^2, and σ_m^2 restricting $\beta = 0.99$, $\theta = 0.875$, and $\phi = 1$.

The estimate for $\bar{m}$ is 0.67 with standard deviation of 0.07 and highly significant. However, since $\rho_d = 0.95$ and $\rho_m = 0.88$ making the difference between them less than 0.2 and thus highly susceptible to size distortions in the tests.

In this context, Andrews and Mikusheva (2015) presents a robust test to generate confidence intervals for the model parameters. This approach uses a improved version of the LM test that is robust to weak identification. That is, the derivation of the asymptotic distribution of the LM statistics does not use any assumption about the strength of identification. The LM statistics is calculated using the score function and the (theoretical) Fisher information that can be calculated either using the negative Hessian of the log likelihood or the quadratic variation of the score. Both deliver unbiased estimates of the (theoretical) Fisher information for the whole sample and differ only in computational implementation. We use a version of the test with the quadratic variation of the score that is equivalent to

$$J_T(\vartheta) = [S_T(\vartheta)] = \sum_{t=1}^{T} s_{T,t}(\vartheta) s'_{T,t}(\vartheta), \tag{16}$$

where $s_{T,t}(\vartheta)$ is the increment of the score function $S_T(\vartheta) = S_{T,T}(\vartheta) = \frac{\partial}{\partial \vartheta'} \ell_T(X_T, \vartheta)$ and X_T the data available at time T. Under conditions expressed in Andrews and Mikusheva (2015),

$$LM_o(\vartheta_0) = S_T(\vartheta_0) J_T(\vartheta_0)^{-1} S_T(\vartheta_0) \Rightarrow \chi_k^2 \tag{17}$$

with $k = dim(\vartheta_0)$.

Then to calculate a 95% LM_o confidence set for the parameter ϑ such that $H_0 : \vartheta = \vartheta_0$ is not rejected by an LM_o test with size 5% we first divide the parameters in incremental groups:

1. $\vartheta = (\bar{m}, \gamma, \phi_\pi, \phi_x, \rho_i)$

2. $\vartheta = (\bar{m}, \gamma, \phi_\pi, \phi_x, \rho_i, \rho_d)$

3. $\vartheta = (\bar{m}, \gamma, \phi_\pi, \phi_x, \rho_i, \rho_m)$

4. $\vartheta = (\bar{m}, \gamma, \phi_\pi, \phi_x, \rho_i, \sigma_d)$

5. $\vartheta = (\bar{m}, \gamma, \phi_\pi, \phi_x, \rho_i, \sigma_s)$

6. $\vartheta = (\bar{m}, \gamma, \phi_\pi, \phi_x, \rho_i, \sigma_m)$.

Andrews and Mikusheva (2015) shows how doing composite hypotheses controls the size distortion of the test and so we follow the same strategy here. Next, we draw samples from the model with parameters calibrated to ML estimates obtained in Table 1. The model is point identified at these values. We generate samples with 400 observations and discard the first and last 100. Using this random draw, we treat it as a sample and test each group of parameters with 10^4 uniform draws at random over the parameter space ϑ delineated in items 1-6 and collect all values that the corresponding hypothesis $H_0 : \vartheta = \vartheta_0$ are not rejected. Then by projecting the five-dimensional convex set obtained in (1) on the subspace corresponding to each parameter separately, we obtain one-dimensional confidence sets for $(\bar{m}, \gamma, \phi_\pi, \phi_x, \rho_i)$. To obtain a confidence set for the remaining parameters we project the corresponding six-dimensional sets (2)-(6) on the subspace of the parameter of interest.

Table 2 presents the results for this procedure. The confidence intervals are wide but in most cases they exclude a wide range of values and in some cases they cover only small part of the parameter space, thus generating useful information. The confidence interval for $\bar{m}$ is $[0.013, 0.645]$.

5 Single-equation Estimation and Identification-robust Confidence Sets

In this section we relax some assumptions about the model and the data generating function. Adding unrestricted innovations to equations 1 and 2, u_i and e_i, which can represent unobserved cost-push shocks (either to the markup or input prices) in the case of the Phillips curve and an aggregate demand shock in the case of the IS curve, we obtain the "semi-structural" version of the model.

In this case we can demonstrate how a Generalized Instrumental Variables (GIV) approach with a Generalized Method of Moments (GMM) estimator can be valid.[5] Conditions for identification hinge on exclusion restrictions implied by excluding lags of the model and using them as instruments. The most common implementation of the GIV procedure substitutes

[5]The GIV approach was first proposed for the estimation of rational expectation models by McCallum (1976) and then Hansen and Singleton 1982 in the context of estimation of Euler equations. More recently it has been proposed for the estimation of the NKPC by Roberts (1995) and Gali and Gertler (1999) (see also Mavroeidis, Plagborg-Møller, and Stock (2014)).

the rational expectation by its realization. With this substitution and the addition of the idiosyncratic shocks, equations 1 and 2 become

$$\pi_t = \beta M^f \pi_{t+1} + \kappa x_t + \underbrace{u_t + \underbrace{\beta M^f [\pi_{t+1} - \mathbb{E}(\pi_{t+1})]}_{\pi \text{ forecast error}}}_{\tilde{u}} \tag{18}$$

$$x_t = M x_{t+1} - \sigma(i_t - \pi_{t+1} - r_t^n) + \underbrace{e_t + \underbrace{M[x_{t+1} - \mathbb{E}(x_{t+1})]}_{x \text{ forecast error}} + \underbrace{\sigma[\pi_{t+1} - \mathbb{E}(\pi_{t+1})]}_{\pi \text{ forecast error}}}_{\tilde{e}}. \tag{19}$$

Let $\vartheta^1 = (\bar{m}, \theta)$ and $\vartheta^2 = (\bar{m}, \beta)$, and define the "residual" function of both equations

$$h_t^1(\vartheta^1) = \pi_t - \beta M^f \pi_{t+1} - \kappa x_t \tag{20}$$

and

$$h_t^2(\vartheta^2) = x_t - M\mathbb{E}_t[x_{t+1}] + \sigma(i_t - \mathbb{E}_t \pi_{t+1} - r_t^n) \tag{21}$$

with the assumption that there exists two vectors of valid instruments, Z_t^1 and Z_t^2, such that

$$\mathbb{E}[Z_t^i h_t^i(\vartheta^i)] = 0 \;\; \forall i = 1, 2 \tag{22}$$

holds at the true parameter value $\vartheta^i = \vartheta_0^i \;\; \forall i = 1, 2$.

The efficient GMM estimator is based on the sample moments $f_T(\vartheta^i) = T^{-1} \sum_{t=1}^{T} Z_t^i h_t^i(\vartheta^i)$ and a heteroskedasticity and autocorrelation (HAC) consistent estimator of their variance, because of possible autocorrelation of $\tilde{u}$ and $\tilde{e}$ due to the presence of forecast errors. Specifically, we use the Newey and West (1987) covariance estimator with four lags. Given $f_T(\vartheta^i)$, the estimator wants to minimize the GMM objective function

$$S_T(\vartheta^i, \bar{\vartheta}^i) = f_T(\vartheta^i)' W_T(\bar{\vartheta}^i) f_T(\vartheta^i) \tag{23}$$

with respect to ϑ^i, where W_T is weighting matrix. Setting $\bar{\vartheta}^i = \vartheta^i$ and evaluating $W_T(\vartheta^i)$ at the same parameters as $f_T(\vartheta^i)$ gives us the continuous updating estimator (Hansen, Heaton, and Yaron 1996).[6]

A common identifying assumption in the literature for both the Phillips and the IS curves

[6] Two-step GMM and continuous updating GMM (CUGMM) are asymptotically equivalent under strong identification, but CUGMM has some advantages under weak identification (Stock, Wright, and Yogo 2002), thus it is the preferred estimator in the robust method presented below.

is that both cost-push and aggregate demand shocks satisfy $\mathbb{E}_{t-1}(u_t) = 0$ and $\mathbb{E}_{t-1}(e_t) = 0$. Given the rational expectations assumption and the law of iterated expectations, the identifying assumption yields $\mathbb{E}_{t-1}(\tilde{u}_t) = 0$ and $\mathbb{E}_{t-1}(\tilde{e}_t) = 0$. Thus, we can have unconditional moment restriction for the form of equation 22 with $Z_t^i = Y_{t-1}^i$, for any vectors of predetermined variables. Any vector of variables Y known at time $t-1$ can be used as instruments and implementations of GIV will differ in these choices. In this paper we take a novel approach in the sense that we don't pretest or screen for sets of instruments prior to estimation.

To implement the estimation we use the fully structural version of the model guided by the identification analysis and restrictions already imposed on the DSGE model. Particularly for the single equation setting, because of the difficulty to forecast inflation and the output gap, weak instruments is a pervasive problem that threatens the validity of structural inference under any identification approach (Mavroeidis (2004)). In addition, in a setting with weak instruments one would want a identification-robust method to avoid selective reporting and control coverage distortions.[7] *Identification robust* is understood in the sense that if point identification fails the robust confidence set still covers the true parameter value. In other words, the confidence sets are uniformly asymptotically valid even when we allow for near or complete identification failure. Thus we need to derive a test statistic whose distribution under the null is insensitive to weak identification.

Fortunately, Andrews (2018) has already shown that there are statistics with good properties for this setting. To apply this method we proceed in two steps. Represent the outcome of the first step using a identification category selection (ICS) statistic $\phi_{ICS} \in 0, 1$. Where ϕ is some test statistic and $\phi_{ICS} = 1$ indicates evidence of weak identification and $\phi_{ICS} = 0$ of strong identification. In the second step we use: CS_N if identification seems strong and CS_R if identification seems weak. We can write two-step confidence sets as

$$CS_{2S} = \begin{cases} CS_N & \text{if } \phi_{ICS} = 0 \\ CS_R & \text{if } \phi_{ICS} = 1 \end{cases} \tag{24}$$

and we are interested in the coverage of this two-step confidence set $Pr_{\vartheta_0^i}\{\vartheta_0^i \in CS_{2S}\}$. And we will assume CS_N has coverage of at least $1 - \alpha$ under strong identification and CS_R has coverage at least $1 - \alpha$ under both weak and strong identification. We define the maximal coverage distortion for CS_{2S} as the smallest Γ such that $Pr_{\vartheta_0^i}\{\vartheta_0^i \in CS_{2S}\} \geq 1 - \alpha - \Gamma$.

This procedure has mainly two elements: controlled coverage distortion of the test and

[7] An interesting thought experiment put forth by I. Andrews is the following: imagine a world in which no instruments have any identifying power whatsoever, then by pure chance in a linear application we will sometimes observe a large value of the first-stage F statistic, but still any confidence set reported based on this screening will be invalid.

test inversion. Controlled coverage distortion works by using a linear combination of the K and S statistics that have be shown to have good properties (Andrews 2016). The robust confidence set thus has a statistic produced by a linear combination of K and S statistics which derivation does not depend on the strength of identification, creating for sure a $1-\alpha$ coverage. Then we can see how much do we need to distort the test size for the confidence interval to fit in the non robust confidence set which test statistic is a conventional W statistic and has coverage $1-\alpha-\hat{\Gamma}$, where $\hat{\Gamma}$ is defined in this process as shown in Figure 1. In Appendix 8.2 we present the test and algorithm in more detail.

We present the results in this section using $\Gamma_{min} = 0.05$, which is just a initialization value for $Gamma$, and $\alpha = 0.05$. In the Appendix 8.3 we present results for $\alpha = 0.10$. The results are broadly similar but in some cases we can get smaller confidence sets.

For the behavioral IS curve the parameter grid used was $\vartheta = (\bar{m}, \gamma) \in \Theta_D = 0.01, 0.02, ..., 0.99 \times 0.01, 0.02, ..., 10$. Table 3 presents the results illustrated in Figure 2. The CUGMM point estimates are $\bar{m} = 0.9029$ and $\gamma = 2.281$ and the distortion cutoff $\hat{\Gamma}$ is 0.068 for the entire set. This means that for one to believe in the non-robust set one has to be willing to add 6.8% on top of the original test size of 5%. Looking individually, the distortion cutoff are a bit lower at the minimum 5% for both $\bar{m}$ and γ. The robust set is valid at the 5% level. If one is willing to make the trade-off between uncertainty and a tighter confidence set, then the predicted value of $\bar{m}$ lies between 0.80 and 1.00, while for γ it is between 1.07 and 3.49.

Figure 3 illustrates the results for the behavioral NKPC estimation. The parameter grid is the same. The CUGMM point estimates are $\bar{m} = 0.393$ and $\gamma = 7.944$ and the distortion cutoff $\hat{\Gamma}$ is 14% for the entire set. Table 4 details the results for each parameter. The distortion cutoff is a lower at 9.93% each. More importantly, there is an upper bound for $\bar{m}$ at 0.95 in the robust case and at 0.84 in the non-robust case and lower bound of 0.07 in the non-robust case and 0.14 in the robust case.

6 Conclusion

In this paper we analyzed the identification issues of a behavioral New Keynesian model and estimated it with likelihood-based and limited-information methods with identification-robust confidence sets. As a result we are able to, in the first place, validate to a certain degree Gabaix (2019) cognitive discounting parameter. In the robust confidence sets for the complete system the cognitive discounting $\bar{m}$ is between 0.013 and 0.645 and in the robust confidence set for the single-equation estimations $\bar{m}$ most of the time bellow one with at least 95% coverage in the robust confidence sets and with a small trade-off between uncertainty and more tightness in the confidence sets. We are also able to take a novel approach where we do not pretest or screen for instruments prior to estimation. By reporting CS_R, CS_N and $\hat{\Gamma}$ we are able to provide the reader all ingredients one needs to interpret the results according to how much uncertainty one is willing to accept in exchange for tighter confidence sets.

Taken together, these results have important implications for New Keynesian models, while still containing a certain degree of uncertainty as to where the cognitive discounting parameter lies, it seems clear that the parameter exist and could be an important ingredient for behavioral models.

7 Tables and figures

Table 1: Maximum likelihood estimates of the complete behavioral DSGE model

Parameters	Estimate	s.d.	t-stat
$\bar{m}$	0.6799	0.0704	9.6565
γ	1.9709	0.4620	4.2662
ϕ_π	1.5058	0.2370	6.3543
ϕ_x	1.9672	0.2292	8.5844
ρ_i	0.4623	0.0659	7.0120
ρ_d	0.9591	0.0233	41.1592
ρ_m	0.8843	0.0250	35.4231
σ_d^2	0.6536	0.0946	6.9104
σ_s^2	0.7443	0.0358	20.7978
σ_m^2	1.0000	0.0000	0.0000

Table 2: 95% LM_o confidence intervales parameters based on a single draw of simulated data and 10^4 draws over the parameter space.

Level	$\bar{m}$	γ	ϕ_π	ϕ_x	ρ_i	ρ_d	ρ_m	σ_d^2	σ_s^2	σ_m^2
Lower	0.013	1.82	0.70	0.51	0.22	0.90	0.79	0.71	0.70	0.71
Upper	0.645	4.91	0.98	1.55	0.44	0.98	0.98	0.90	0.73	0.80

Table 3: Confidence sets and distortion cutoffs $\hat{\Gamma}$ for parameters myopia $\bar{m}$ and risk aversion γ for the behavioral IS curve. Notes: $\alpha = 0.05$ and $\Gamma_{min} = 0.05$.

Parameter	CS_R	CS_N	$\hat{\Gamma}$
$\bar{m}$	[0.00, 1.00]	[0.80, 1.00]	5.0%
γ	[0.27, 10.00]	[1.07, 3.49]	5.0%

Table 4: Confidence sets and distortion Cutoffs $\hat{\Gamma}$ for parameters myopia $\bar{m}$ and risk aversion γ for the behavioral NKPC curve. Notes: $\alpha = 0.05$ and $\Gamma_m in = 0.05$.

Parameter	CS_R	CS_N	$\hat{\Gamma}$
$\bar{m}$	[0.07, 0.95]	[0.14, 0.84]	9.934%
γ	[0.00, 10.00]	[1.59, 10.00]	9.934%

Figure 1: Illustration of the test procedure. Notes: α is the desired coverage, usually 5% or 10% and $\hat{\Gamma}$ is the minimal additional distortion that can be accepted to match the robust and non-robust sets.

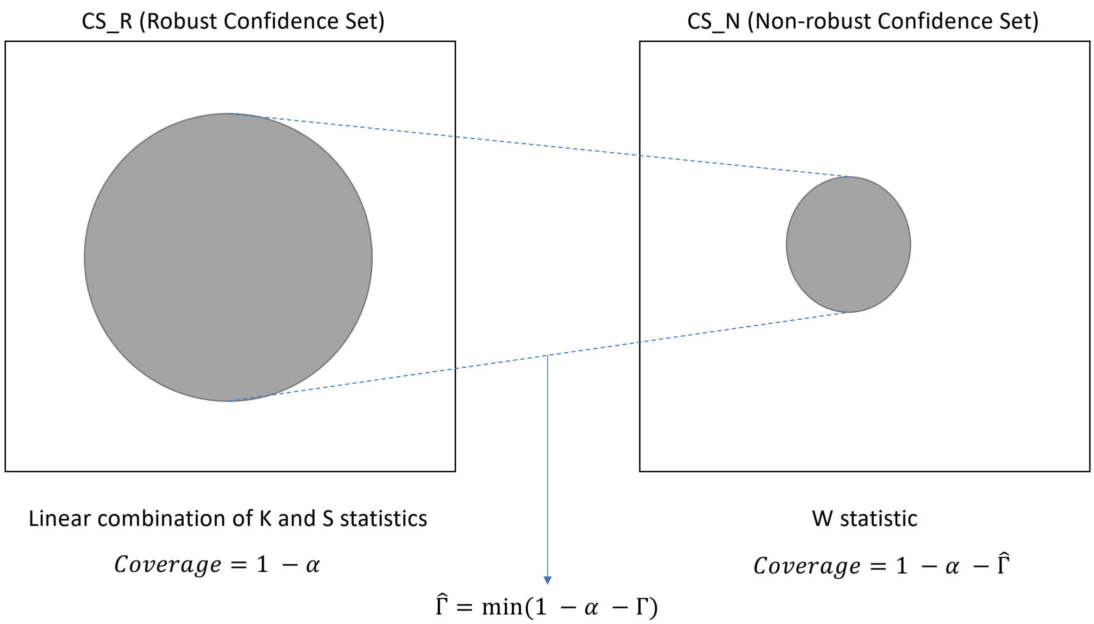


Figure 2: Estimation of the behavioral IS curve using as instruments a constant and three lags of output gap and $(i_t - \pi_{t+1} - r_t)$ as in Ascari and Magnusson 2016. The CUGMM point estimates are $\bar{m} = 0.903$ and $\gamma = 2.281$. The size of the test is $\alpha = 0.05$ and the distortion cutoff $\hat{\Gamma}$ is 0.068 for the entire set.

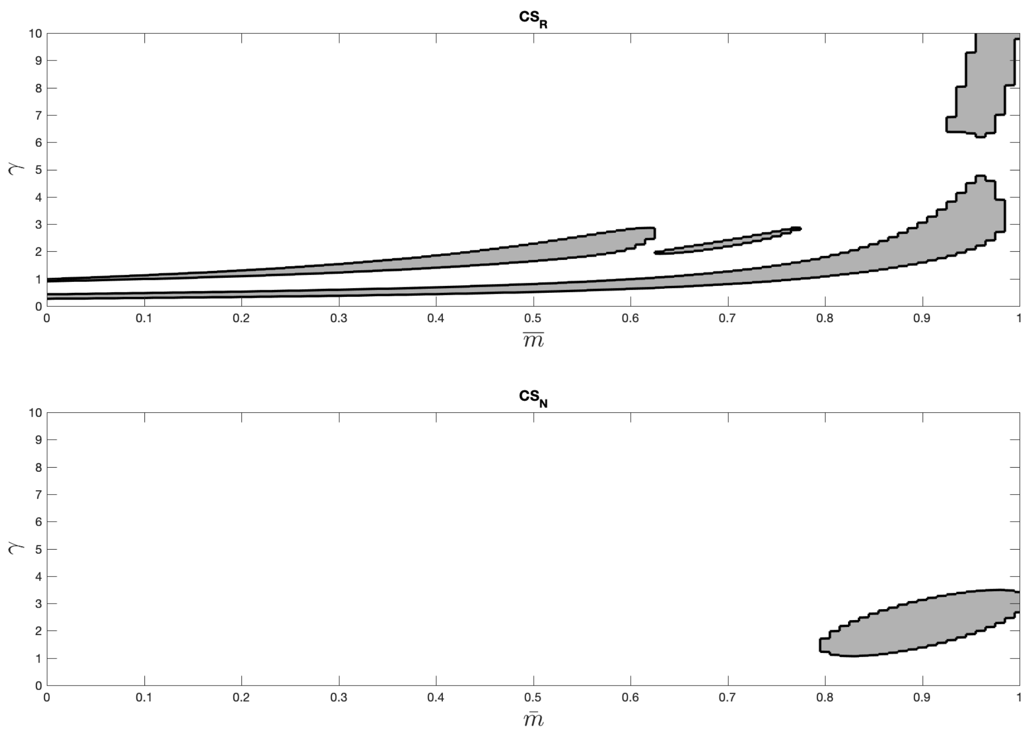
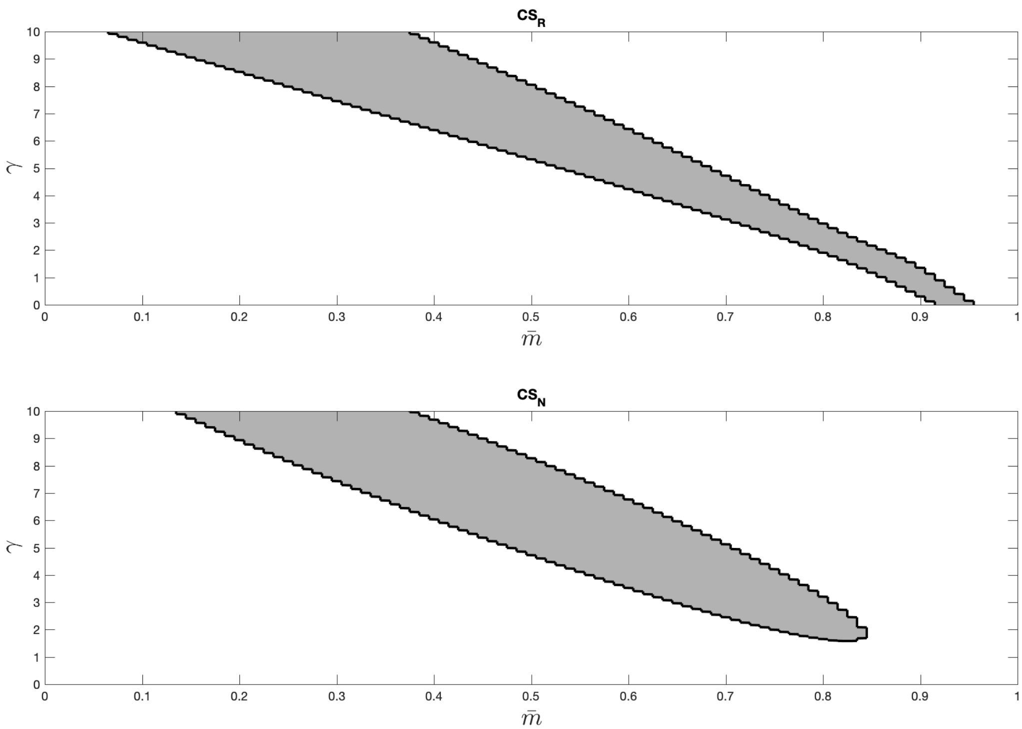


Figure 3: Estimation of the behavioral NKPC using as instruments four lags of inflation and three lags of the labor share, as in Mavroeidis, Plagborg-Møller, and Stock 2014. The CUGMM point estimates are $\bar{m} = 0.393$ and $\gamma = 7.944$. The size of the test is $\alpha = 0.05$ and the distortion cutoff $\hat{\Gamma}$ is 0.14 for the entire set.



8 Appendix

8.1 DSGE solution

This section solves the DSGE model presented in Section 3

$$\begin{aligned} x_t &= \bar{m}\mathbb{E}_t[x_{t+1}] - \sigma(i_t - \mathbb{E}_t\pi_{t+1}) + \eta_{d,t} \\ \pi_t &= \beta M^f \mathbb{E}_t[\pi_{t+1}] + \kappa x_t + \epsilon_{s,t} \\ i_t &= \rho_i i_{t-1} + (1-\rho_i)(\phi_\pi \pi_t + \phi_x x_t) + \eta_{m,t} \end{aligned} \tag{25}$$

where the unobserved exogenous shocks evolve according to

$$\begin{aligned} \eta_{d,t} &= \rho_d \eta_{d,t-1} + \epsilon_{d,t} \\ \eta_{m,t} &= \rho_m \eta_{m,t-1} + \epsilon_{m,t} \\ (\epsilon_{s,t}, \epsilon_{d,t}, \epsilon_{m,t})' &\sim \text{i.i.d.} N(0, \Sigma) \\ \Sigma &= \text{diag}(\sigma_s^2, \sigma_d^2, \sigma_m^2). \end{aligned}$$

This is a restricted linear rational expectations system, to solve it we substitute out i_t and solve the expectations forward. First, substitute out i_t in the first equation of 25 and rearrange the terms with expectations to the left-hand side to obtain the system

$$\begin{aligned} \bar{m}\mathbb{E}_t x_{t+1} + \sigma \mathbb{E}_t \pi_{t+1} &= x_t + \sigma \frac{1}{\beta M^f} + \sigma \eta_{m,t} - \eta_{d,t} \\ \beta M^f \mathbb{E}_t \pi_{t+1} &= -\kappa x_t + \pi_t . [2ex] \end{aligned}$$

Solve for $\mathbb{E}_t x_{t+1}$ and get the expectation equation

$$\bar{m}\mathbb{E}_t x_{t+1} = (\beta M^f + \sigma\kappa) x_t + \beta M^f \sigma \eta_{m,t} - \beta M^f \eta_{d,t},$$

which can be rewritten as

$$x_t = \frac{\bar{m}}{\beta M^f + \sigma\kappa} \mathbb{E}_t x_{t+1} - \frac{\beta M^f \sigma}{\beta M^f + \sigma\kappa} \eta_{m,t} + \frac{\beta M^f}{\beta M^f + \sigma\kappa} \eta_{d,t}.$$

Now this expectation equation can be solved by forward iteration, giving

$$x_t = \sum_{j=0}^{\infty} \left(\frac{\bar{m}}{\beta M^f + \sigma\kappa} \right)^j \mathbb{E}_t \left[-\frac{\beta M^f \sigma}{\beta M^f + \sigma\kappa} \eta_{m,t+j} + \frac{\beta M^f}{\beta M^f + \sigma\kappa} \eta_{d,t+j} \right].$$

Note that $\mathbb{E}_t \eta_{i,t+j} = \rho_i^j \eta_{i,t}$ for $i = d, m$, thus resulting in

$$
\begin{aligned}
x_t &= -\frac{\beta M^f \sigma}{\beta M^f + \sigma\kappa} \frac{1}{1 - \rho_m \frac{\bar{m}}{\beta M^f + \sigma\kappa}} \eta_{m,t} + \frac{\beta M^f}{\beta M^f + \sigma\kappa} \frac{1}{1 - \rho_d \frac{\bar{m}}{\beta M^f + \sigma\kappa}} \eta_{d,t} \\
&= -\frac{\beta M^f}{\beta M^f + \sigma\kappa - \bar{m}\rho_m} \eta_{m,t} + \frac{\beta M^f}{\beta M^f + \sigma\kappa - \bar{m}\rho_d} \eta_{d,t}.
\end{aligned}
$$

Substitute the last expression into the IS equation and repeat the same process solving the resulting expectation equation for π_t

$$
\begin{aligned}
\pi_t &= \beta M^f \mathbb{E}_t \pi_{t+1} + \kappa x_t \\
&= \beta M^f \mathbb{E}_t \pi_{t+1} - \frac{\beta M^f \sigma\kappa}{\beta M^f + \sigma\kappa - \bar{m}\rho_m} \eta_{m,t} + \frac{\beta M^f \kappa}{\beta M^f + \sigma\kappa - \bar{m}\rho_d} \eta_{d,t} \\
&= \textstyle\sum_{j=0}^{\infty} (\beta M^f)^j \mathbb{E}_t \left[-\frac{\beta M^f \sigma\kappa}{\beta M^f + \sigma\kappa - \bar{m}\rho_m} \eta_{m,t+j} + \frac{\beta M^f \kappa}{\beta M^f + \sigma\kappa - \bar{m}\rho_d} \eta_{d,t+j} \right] \\
&= -\frac{\beta M^f \sigma\kappa}{(\beta M^f + \sigma\kappa - \bar{m}\rho_m)(1 - \rho_m \beta M^f)} \eta_{m,t} + \frac{\beta M^f \kappa}{(\beta M^f + \sigma\kappa - \bar{m}\rho_d)(1 - \rho_d \beta M^f)} \eta_{d,t}.
\end{aligned}
$$

One obtains, therefore, the solution to the system 25:

$$
\begin{aligned}
x_t &= -\frac{\beta M^f}{\beta M^f + \sigma\kappa - \bar{m}\rho_m} \eta_{m,t} + \frac{\beta M^f}{\beta M^f + \sigma\kappa - \bar{m}\rho_d} \eta_{d,t} \\
\pi_t &= -\frac{\beta M^f \sigma\kappa}{(\beta M^f + \sigma\kappa - \bar{m}\rho_m)(1 - \rho_m \beta M^f)} \eta_{m,t} + \frac{\beta M^f \kappa}{(\beta M^f + \sigma\kappa - \bar{m}\rho_d)(1 - \rho_d \beta M^f)} \eta_{d,t}.
\end{aligned}
$$

8.2 Two-step identification-robust confidence sets algorithm

This section details the test and is entirely based on Andrews (2018). In GMM models, for all the commonly-used non-robust confidence sets CS_N and any $\Gamma > 0$ we can construct preliminary robust confidence set CS_P with the same coverage regardless of identification strength and which is contained in the non-robust set with probability one under strong identification. For this we define the S statistic of Stock and Wright (2000) and K statistic of Kleibergen (2005). The problem is the S statistics is inefficient with over identification and the K statistic is often inconsistent (*i.e.* fails to shrink towards the true parameter even as the sample grows because it gathers local minima and maxima) with the equivalency with the Wald confidence set holding only locally, not globally.

Thus, to obtain a consistent confidence set, for $a > 0$ consider $CS_R = (\vartheta : K(\vartheta) + a.S(\vartheta) \leq$

$\chi^2_{1,1-\alpha}$) where $K(\vartheta) + a.S(\vartheta)$ is a linear combination statistic, as in Andrews (2016). This confidence set has coverage $1 - \alpha - \Gamma(a) = Pr((1 + a).\chi^2_1 + a.\chi^2_{k-1} \leq \chi^2_{1,1-\alpha})$ regardless of identification strength. So $\Gamma \to 0$ as $a \to 0$, and we can choose a to obtain any desired level of Γ.

Now pick some $\Gamma_{min} \geq 0$. For $\Gamma \geq \Gamma_{min}$, consider the family of robust confidence sets $CS_P = (\vartheta : K(\vartheta) + a(\Gamma).S(\vartheta) \leq \chi^2_{1,1-\alpha})$ where $CS_P(\Gamma) = (\vartheta : K_\Gamma(\vartheta) \leq \chi^2_{k,1-\alpha})$ is designed to have coverage exceeding $1 - \alpha - \Gamma$.

Define the robust confidence set as $CS_R(\Gamma) = (\vartheta : K_\Gamma(\vartheta) \leq H^{-1}_{k,1-\alpha})$, where $H_{k,1-\alpha}$ is $1 - \alpha$ quantile of $(1 + a(\Gamma)\chi^2_1 + a(\Gamma)\chi^2_{k-1})$ and has the correct critical values with coverage exceeding $1 - \alpha$.[8] And we end up with the following two-step confidence set

$$CS_{2S}(\Gamma) = \begin{cases} CS_N & \text{if } CS_P(\Gamma) \subseteq CS_N \\ CS_R(\Gamma) & \text{if } CS_P(\Gamma) \nsubseteq CS_N. \end{cases} \tag{26}$$

Note that these preliminary confidence sets are decreasing in Γ: $\Gamma \leq \Gamma' \implies CS_P(\Gamma') \subseteq CS_P(\Gamma)$. Thus, we have the property that $CS_P(\Gamma) \subseteq CS_2(\Gamma)$, so $CS_2(\gamma)$ has coverage exceeding $CS_P(\Gamma)$ which exceeds $1 - \alpha - \Gamma$. Therefore, we get a bounded size distortion. Also note that under strong identification we have $CS_P(\Gamma) \subseteq CS_N$ so $CS_2(\Gamma) = CS_N$ asymptotically. Now define the maximal distortion cutoff as $\hat{\Gamma} = min(\Gamma \geq \Gamma_{min} : CS_P(\Gamma) \subseteq CS_{NR})$ and report CS_N, $CS_R(\hat{\Gamma})$, and $\hat{\Gamma}$.

To empirically implement CR_R, CS_N, we set Γ_{min} equal to 5% and α equal to 10% or %5\

1. *Choose the weighting matrix and estimator.* We use the CUGMM of the form of equation 23 with $\hat{W}(\vartheta) = \hat{\Sigma}(\vartheta)^{-1}$ as the efficient weighting matrix. Then define the Wald statistic, where $\hat{\Sigma}_{\hat{\beta}}$ is the usual GMM variance estimator for $f(\hat{\vartheta})$.

2. *Choose grid of parameter values.* Since to calculate the confidence sets we work with test inversions we need to discretize the parameter space to obtain all values where the test statistics falls bellow given thresholds. In this implementation we consider

   $$\vartheta^1 = (\bar{m}, \gamma) \in \Theta^1_D = (0, 0.1, ..., 1) \times (0, 0.1, ..., 10)$$

   and

   $$\vartheta^2 = (\bar{m}, \gamma) \in \Theta^2_D = (0, 0.1, ..., 1) \times (0, 0.1, ..., 10).$$

[8] $H(x; a, k, p)$ is the cumulative distribution function for the a $(1 + a) \times \chi^2_p + a \times \chi^2_{k-p}$ distribution, which is a linear combination of χ^2 variables, and $H^{-1}(1 - \alpha; a, k, p)$ the $1 - \alpha$ quantile of this distribution

Let Θ_D represent the elements of Θ_D^1 and Θ_D^2, which are $(\vartheta_1^i, ..., \vartheta_{|\Theta_D|}^1) \forall i = 1, 2$.

3. *Calculate test statistics.* Given this discrete approximation to the parameter space, for each $\vartheta_n^i \in \Theta_D$ we can calculate $S_T(\vartheta_n^i)$ and $\hat{\Sigma}(\vartheta_n^i)$ and the test statistics S, K and W.

4. *Calculate* $a(\Gamma_{min})$. Now, determine the value of $a(\Gamma_{min})$ to be used in the construction of the robust confidence set.

5. *Calculate* CR_R and CS_N. With $a(\Gamma_{min})$ we can calculate the critical value used in H^{-1}. The robust confidence is then

$$CS_R = (f(\vartheta_n^i) : \vartheta_n^i \in \Theta_D, K_{\Gamma,f}(\vartheta_n^i) + a \times S(\vartheta_n^i) \leq H^{-1}(1 - \alpha, a(\Gamma_{min}), k, p))$$

   and the nonrobust confidence set is

$$CS_N = (f(\vartheta_n^i) : \vartheta_n^i \in \Theta_D, W(f(\vartheta_n^i)) \leq \chi^2_{p,1-\alpha}).$$

6. *Calculate* $\hat{\Gamma}$. Finally, the distortion cutoff can be calculated.

8.3 Two-step confidence sets for $\alpha = 0.1$

For the behavioral IS curve the parameter grid used was $\vartheta = (\bar{m}, \gamma) \in \Theta_D = 0.01, 0.02, ..., 0.99 \times 0.01, 0.02, ..., 5$, with $\alpha = 0.1$ and $\Gamma_{min} = 0.05$. Table 3 presents the results illustrated in Figure 2. The CUGMM point estimates are $\bar{m} = 0.9029$ and $\gamma = 2.281$ and the distortion cutoff $\hat{\Gamma}$ is 0.08 for the entire set. This means that for one to believe in the non-robust set one has to be willing to add 8% on top of the original size of 5%. Looking individually the distortion cutoff are a bit lower at 0.053 for $\bar{m}$ and 0.052 for γ. The robust set is valid at the 5% level. However, in this case if we consider the controlled size distortion we can then have a bounded set for both variables. If one is willing to make the uncertainty trade-off, then the predicted value of $\bar{m}$ lies between 0.81 and 0.99, while for γ it is between 1.22 and 3.34.

Figure 3 illustrates the results for the behavioral NKPC estimation. The parameter grid was the same with $\alpha = 0.1$ and $\Gamma_{min} = 0.05$ as well. The CUGMM point estimates are $\bar{m} = 0.393$ and $\gamma = 7.944$ and the distortion cutoff $\hat{\Gamma}$ is 0.16 for the entire set. Table 4 details the results for each parameter. The distortion cutoff is a bit lower at 11.16% each. More importantly, there is an upper and lower bound for $\bar{m}$.

Table 5: Confidence Sets and Distortion Cutoffs $\hat{\Gamma}$ for parameters $\bar{m}$ and γ for the behavioral IS curves. Notes: $\alpha = 0.10$ and $\Gamma_{min} = 0.05$.

Parameter	CS_R	CS_N	$\hat{\Gamma}$
$\bar{m}$	[0.01, 0.97]	[0.81, 0.99]	5.3%
γ	[0.28, 4.31]	[1.22, 3.34]	5.2%

Table 6: Confidence Sets and Distortion Cutoffs $\hat{\Gamma}$ for parameters $\bar{m}$ and γ for the behavioral NKPC curve. Notes: $\alpha = 0.10$ and $\Gamma_{min} = 0.05$.

Parameter	CS_R	CS_N	$\hat{\Gamma}$
$\bar{m}$	[0.55, 0.95]	[0.50, 0.78]	11.16%
γ	[0, 5.0]	[2.37, 5.00]	11.16%

Figure 4: Estimation of the behavioral IS curve using as instruments a constant and three lags of output gap and $(i_t - \pi_{t+1} - r_t)$ as in Ascari and Magnusson 2016. The CUGMM point estimates are $\bar{m} = 0.903$ and $\gamma = 2.281$. The size of the test is $\alpha = 0.1$ and the distortion cutoff $\hat{\Gamma}$ is 0.08 for the entire set.

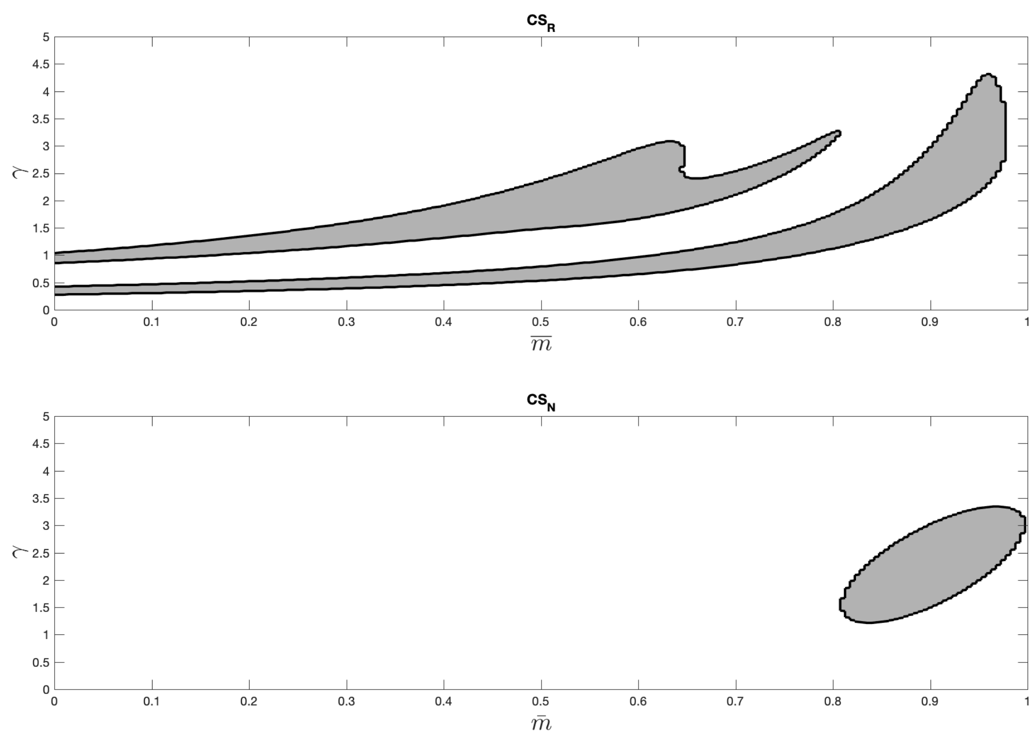
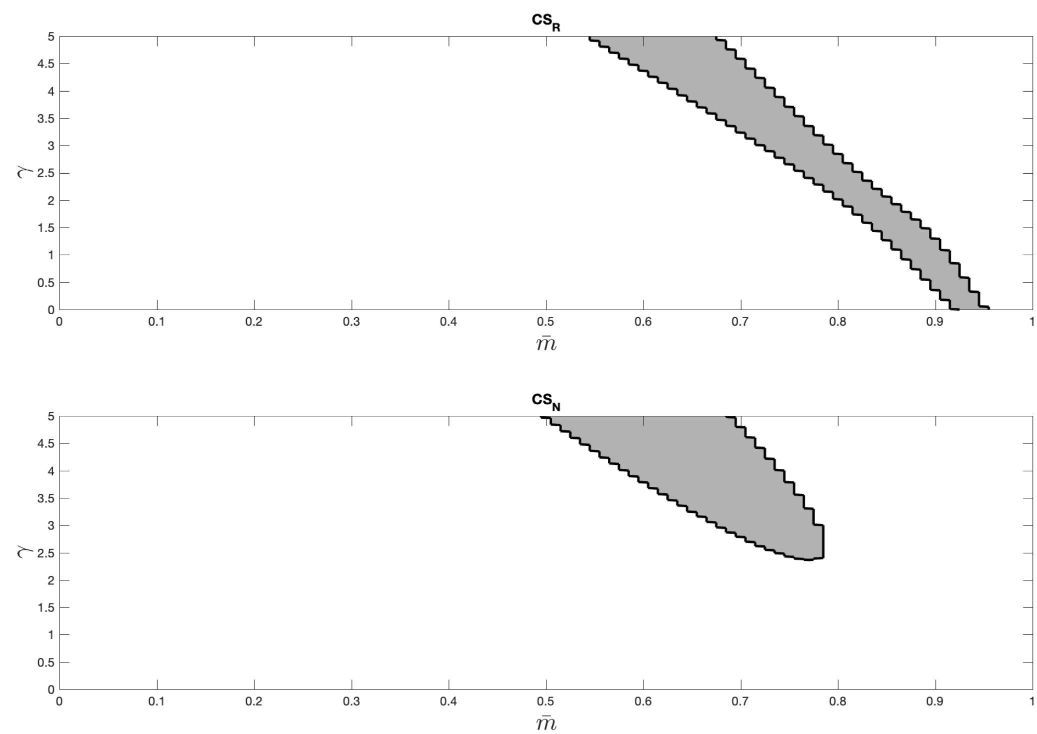


Figure 5: Estimation of the behavioral NKPC using as instruments four lags of inflation and three lags of the labor share, as in Mavroeidis, Plagborg-Møller, and Stock 2014. The CUGMM point estimates are $\bar{m} = 0.393$ and $\gamma = 7.944$. The size of the test is $\alpha = 0.1$ and the distortion cutoff $\hat{\Gamma}$ is 0.16 for the entire set.



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Geography, slavery, and income in Brazilian municipalities in the 1870s: a spatial equilibrium approach*

Contents

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1 Introduction

What determines the large degree of regional inequalities and economic retardation in late XIX century Brazil? Some argue that Brazil has a geography problem. Others argue that initial factor endowments, slavery, and colonial institutions are to blame. Others go even further, arguing, more in general, that a commodity-based economy with external dependency is the culprits. In this paper we argue that it is unlikely that one of these factors alone are the sole cause of regional inequality and economic backwardness, but that they all interact in spatial equilibrium to explain heterogeneity in prices, income and population levels across municipalities.

To understand Brazil's place in the "wealth of nations" it is first necessary to understand the "wealth of cities", as put by Glaeser and Gottlieb 2009. While a pure macroeconomic view tells us about business cycles, aggregate income and growth levels across the world, taking a look at how wealth is generated in cities will tell us about the large differences in income and population density observed within countries[1]. Brazil is not the only place where these large differences are observed, but it was unexpected since it has land abundance and high land-labor ratios and could have perfectly followed a similar path with respect to productivity and distribution of income as the United State, a pertinent observation made in Leff 1972b.

The secular roots of spatial inequality is explored in detail in Reis 2014 and, moreover, inequality in general is a paramount theme in Brazil's economic history (see, for example, Cano 1977, Leff 1972a, Buescu 1979, Bértola et al. 2009, Bértola et al. 2010, Monasterio 2010, and Zamberlan Pereira 2019). Some authors such as Summerhill 2005 attribute some source of regional inequalities to high transportation costs, an issue also discussed in Leff 1972b, and, consequently, to a geography problem. Other current of literature, arising from seminal papers such as Sachs and Warner 1995 blame natural resource abundance and geography in general, including climate. On the other hand, other current of literature that arose from seminal contributions such as Engerman and Sokoloff 1994 attribute it to initial factor endowments, which likewise is connected to geography but only in relation to soil suitability for sugar and other commodities that has economics of production in the use of slaves and, consequently, to the colonial institutions put in place to explore these commodities. Colonial institutions play a prime role in the literature derived from Acemoglu, Johnson, and Robinson 2001 to explain why some countries are less developed than others. Slavery, specifically, plays

[1]This literature deals in terms of cities, which we use interchangeably with municipalities that is the official level of local aggregation in Brazil. The difference is that the municipality refers to the legal territory in its entirety and not just the urban center. This distinction might be more appropriate considering the urban dynamics of the XIX century and also ensure comparability with the bulk of the literature on historical Brazil that uses the municipality as the locus of political and economic activity (see, for example, Leal 1977).

the main role in the view of Nunn 2008. Finally, the structuralists account much of the blame on the country's export orientation, where commodities production would constitute export-oriented enclaves in the territory that would dictate the development path of the economy (Furtado 1968). Leff 1972b argues that the problem is not commodities for export in itself, but that the rate in which export growth materialized between the different cultures of the Southeast (coffee) and the Northeast (sugar and cotton) caused by a shift in the country's comparative advantage (along with redirection of capital but with imperfect labor mobility) that generated the regional differentials in economic development.

In contributing to this literature, we add one more explanation for the puzzle of why a country with such abundance of natural resources and high land-labor ratios would generate such unequal development path could rest on the configuration of the initial spatial equilibrium across municipalities. Combining a novel source of income data in 1876 from archival research with the first nation-wide census in 1872 and GIS-constructed data on geography, climate, and soil suitability for commodities and staple foods we are able to shed some light on this topic.

We show that ruggedness, temperature, and soil suitability are correlated with income, workforce, and our proxy for land and housing prices. But that, ruggedness, for example, which can be considered "bad geography" is actually correlated with higher levels of productivity but only in places with lower levels of factor share of slavery and that it depresses welfare[2] in general. Furthermore, we show that people do seem to pay a welfare premium on higher average temperatures, which is strange considering that the country is warm in general, and that this higher temperatures also take a toll on productivity. In addition, we show that soil suitability for a commodity, sugarcane in the case, depresses welfare in the form of higher prices, but that is correlated with higher levels of productivity, which decreases as the factor share of slaves increases. Finally, we show that soil suitability for staple foods increases welfare but that it ceases to depresses productivity only with high levels of slavery factor share.

This paper is organized as follows, in section 2 we provide a brief historical background of Brazil in the XIX century and, more specifically, of the 1870s decade. In section 3 we outline our theoretical approach. In section 4 we detail the data sources, how we construct our variables and estimating equations to apply the spatial equilibrium framework, and also show a direct test of the model. Section 5 details the marginal impacts of our variables on municipality-specific welfare and productivity and what is the role of slavery, and section 6 concludes the paper.

[2]In this version of the paper we consider welfare to be interchangeable with the income of the consumers. Future versions should improve this definition.

2 Historical background

Brazil in the 1870s was in the midst of a structural transformation. The gold cycle was long gone and the cycles of sugar and cotton in Northeast were rapidly giving place to the coffee cycle in the Southeast[3]. The recent Paraguay War (1864-1870), involving Paraguay against Brazil, Uruguay and Argentina, and the American Civil War (1861-1865) would intensify abolitionist ideals. The origins of mass immigration to Brazil was in the making to substitute slave labor. According to the 1872 Census, Brazil had almost 10 million people, of which 1.5 million were slaves, but already 2.5 million were free men of working age (16-60 years old). In the ten years between 1870 an 1879, an average of 20,780 immigrants entered the workforce annually, a number that would only grow; in the last decade of the XIX century an average of 118,170 immigrants would enter the country annually (Leff 1972b).[4]

In 1871 the "Lei do Ventre Livre" declared all children born to female slaves would be born free. During this decade the number of voluntary manumissions would increase. Between 1873 and 1887, the year before the abolition, the number of slaves would decrease from 1.5 million to 723 thousand and the concentration of slaves in the coffee provinces would increase from 57% to 67% of all slaves. Beyond the 1871 law, during the first half of the 1870s the country would see reforms in the police, the judiciary, the national guard, the first nation-wide census, the connection of Brazil to Europe through Lisbon by telegraph, the adoption of the metric system, and construction of railroads (Carvalho 2012). In 1874 the country had almost 1300 kilometers of railroad (800 miles), a figure that would grow to 2100 kilometers (1300 miles) in 1876 and 6200 kilometers (3900 miles) in 1884 (Leff 1972b).[5]

This profusion of new ideas, new people, and technological innovations makes the 1870s a good starting place to analyze the initial spatial equilibrium across municipalities in relation to prices, income, and working population, taking into account also the degree of slavery, that is, the decision of consumer and producers in deciding where to locate across the territory. It would be interesting, of course, to analyze previous spatial equilibria, but the lack of previous nation-wide census makes this task almost impossible, or at least incomplete.

[3]Coffee grows from 18.4% of the total exports considering the eight main commodities (coffee, sugar, cocoa, mate herb, tobacco, cotton, rubber, and leather) in the 1821-1830 decade to 56.6% in the 1871-1880 decade. In contrast, sugar falls from 30.1% in the 1821-1830 decade to 11.8% in the 1871-1880 decade and cotton from 20.6% to 9.5% considering the same periods (Carvalho 2012).

[4]To put these numbers in perspective, the population in the United States in 1870 was of almost 40 million people, having received in the 1870s 3 million immigrants, against 527 thousand that went to Brazil (Carvalho 2012)

[5]By comparison, the US had 85 thousand kilometers in 1870 and 135 thousand kilometers in 1880 (Carvalho 2012).

3 The spatial equilibrium framework

We frame the empirical exercise employing a basic model of spatial equilibrium across cities, in what is known as the Rosen-Roback framework (Rosen 1979, Roback 1982), following the exposition in Glaeser 2008 and Harari 2018. In this most basic version of the model we use cities and municipalities interchangeably, but in the next iterations of the paper we would like to bring the model closer to the reality of the municipality in the late XIX century, that is, to better model the role of slavery and agricultural production. For now this framework features consumers, or the free population, and production and construction markets. Consumer households choose optimally in which municipality to live. The spatial equilibrium condition is given at the point where consumers are indifferent across cities with different amenities, that is, the indirect utility value of a location choice must equal a reservation utility level. Production and construction of housing is done competitively in each municipality over a fixed supply of land. The production sector considers production in general, making no distinction between agriculture and industry, and slaves are regarded as a form of tradable capital.

Consumer households have a Cobb-Douglas[6] utility function $\theta C^{1-\alpha} H^{\alpha}$ defined over tradable goods, the numéraire good C, non-traded housing H, and municipality-specific amenities, captured by an index θ. The supply of labor is inelastic, for which they receive a municipality-specific wage W. Optimizing behavior gives the following indirect utility

$$log(W) - \alpha log(p_H) + log(\theta) = log(\bar{\vartheta}) \tag{1}$$

where p_H is the rental price of housing. This shows that the reservation utility ($\bar{\vartheta}$) is equalized across cities, otherwise households could move around to exploit differences in utility. This shows the key intuition behind the spatial equilibrium model: that consumers, in equilibrium, implicitly pay for amenities θ by having lower wages (W) or higher housing prices (p_H) in a municipality. Note that θ could include amenities and disamenities. Thus empirically looking at these compensating differentials reveals the value placed by households on certain amenities (or disamenities).

Turning to the production sector, firms also choose where to locate and competitively produce a good Y, using free labor N, traded numéraire slave capital K and a fixed supply of non-traded capital $\bar{Z}$. Assume that every municipality is characterized by a location-specific productivity level A, the production function is then given by $AN^{\beta}K^{\gamma}\bar{Z}^{1-\beta-\gamma}$. The

[6]The intuition of the Rosen-Roback framework does not require functional forms assumptions, but in bringing the model to the data it is usual to turn to particular functional forms, where the Cobb-Douglas form is a fairly standard assumption to derive a set of estimable equations.

zero-profit condition for the firms yields the following demand curve

$$(1-\gamma)log(W) = (1-\beta-\gamma)(log(\bar{Z} - log(N)) + log(A) + \kappa_1. \tag{2}$$

To close the model, housing is also produced competitively in a combination of height (h) and land (L). Thus the total quantity of housing supplied (H) is equal to hL. There is a fixed quantity of land available in each municipality, denoted by $\bar{L}$. In the short run this variable can be taken as given, either by regulators or, as we develop here, by geography. Using a measure of quantity of land available to be developed given by geography constraints has the advantage of being totally exogenous in the short run, as opposed to available land given by regulators, which can be thought of as an endogenous process. This fixed supply $\bar{L}$, in turn, determines an endogenous price for land (p_L) and housing (p_H).

The cost of producing H unites of housing is $c_0 h^\delta L - p_L L$ where $\delta > 1$, thus the profit function is $p_H H - c_0 h^\delta L - p_L L$. Free entry of construction gives us the equilibrium condition of housing prices as a function of population and income

$$log(p_H) = \frac{1}{\delta} log(\delta c_0) + \frac{\delta - 1}{\delta}(log(\alpha N W) - log(\bar{L})). \tag{3}$$

Now using the three optimality conditions 1, 2, 3, we have three equations with three unknowns, namely population, income and housing prices. Solving for these endogenous variables as functions of municipality-specific productivity A, amenities θ, and fixed supply of land $\bar{L}$, we have the following system of equations

$$log(N) = F_N log(A) + E_N log(\theta) + D_N log(\bar{L}) + I_N \tag{4}$$

$$log(W) = F_W log(A) + E_W log(\theta) + D_W log(\bar{L}) + I_W \tag{5}$$

$$log(p_H) = F_p log(A) + E_p log(\theta) + D_p log(\bar{L}) + I_p \tag{6}$$

where E, F, G, and I denote constant functions of the model's deep parameters and $F_N, F_W, F_p > 0$; $E_N, E_p > 0$; and $E_W < 0$. This shows another key intuition of the Rosen-Roback spatial equilibrium framework: that it is impossible to analyze income, population or prices separately or alone because there is a set of markets in which they all interact. "Population, wages, and rents are all increasing functions of the municipality-specific productivity parameter A. Intuitively, higher A allows firms to pay higher wages, which attracts households and bids up rents. Similarly, population and rents are increasing in the amenity parameter θ: better amenities attract households and bid up rents. Wages are decreasing in θ because firms prefer cities with higher production amenities, whereas consumers prefer cities with higher consumption amenities, and factor prices - W and p_H - strike the balance between these conflicting location preferences." (Harari 2018)

Now consider a geography-based exogenous shifter of income, population, and housing prices. Assume that for this geographic exogenous shifter, denoted G,

$$log(A) = I_A + \lambda_A G + \mu_A \tag{7}$$

$$log(\theta) = I_\theta + \lambda_\theta G + \mu_\theta \tag{8}$$

$$log(\bar{L}) = I_L + \lambda_L G + \mu_L \tag{9}$$

where I_i are constants, λ_i are coefficients, and μ_i are error terms $\forall i \in \{A, \theta, L\}$. Since A and θ are unobservables, we substitute these back into equations 4, 5, and 6, which then imply

$$log(N) = \kappa_N + \frac{(\alpha+\gamma-\alpha\gamma)\lambda_A + (1-\gamma)(\delta\lambda_\theta + \alpha(\delta-1)\lambda_L)}{\delta(1-\beta-\gamma)+\alpha\beta(\delta-1)} G + \mu_N \tag{10}$$

$$log(W) = \kappa_W + \frac{(\delta-1)\alpha\lambda_A - (1-\beta-\gamma)(\delta\lambda_\theta + \alpha(\delta-1)\lambda_L)}{\delta(1-\beta-\gamma)+\alpha\beta(\delta-1)} G + \mu_W \tag{11}$$

$$log(p_H) = \kappa_p + \frac{(\delta-1)(\lambda_A + \beta\lambda_\theta - (1-\beta-\gamma)\lambda_L)}{\delta(1-\beta-\gamma)+\alpha\beta(\delta-1)} G + \mu_p \tag{12}$$

where κ_i are the constants independent of G and μ_i error terms independent of G, $\forall i \in \{N, W, p\}$.

Now we could use some geography-based shifter G that is connected with prices, population, and income, given plausible values for α, β, γ, and δ, to provide estimates of λ_A, the marginal productivity impact of G, λ_θ, the marginal willingness to pay for G, and λ_L, the welfare impact of G. Denote by $\hat{B}_N$, $\hat{B}_W$, and $\hat{B}_p$ the estimated reduced-form coefficients of the geography variable G impact on the population, price, and income regressions.

Totally differentiating the indirect utility of consumers, equation 1, with respect to G yields

$$\frac{\partial log(\theta)}{\partial G} = \alpha\frac{\partial log(p_H)}{\partial G} - \frac{\partial log(W)}{\partial G} \tag{13}$$

thus λ_θ can be estimated as

$$\hat{\lambda}_\theta = \alpha\hat{B}_p - \hat{B}_W. \tag{14}$$

Totally differentiating the zero-profit condition of the production sector, equation 2, with respect to G yields

$$\frac{\partial(A)}{\partial G} = (1-\beta-\gamma)\frac{\partial log(N)}{\partial G} + (1-\gamma)\frac{\partial log(W)}{\partial G} \tag{15}$$

thus λ_A can be as estimated as

$$\hat{\lambda}_A = (1-\beta-\gamma)\hat{B}_N + (1-\gamma)\hat{B}_W. \tag{16}$$

Finally, totally differentiating the zero-profit condition of the construction sector, equation 3, with respect to G yields

$$\frac{\partial log(\bar{L})}{\partial G} = \frac{\partial log(N)}{\partial G} + \frac{\partial log(W)}{\partial G} - \frac{\delta}{\delta-1}\frac{\partial log(p_H)}{\partial G} \tag{17}$$

which suggests that the estimation of λ_L is connected to the other variables in the following manner

$$\hat{\lambda}_L = \hat{B}_N + \hat{B}_W - \frac{\delta}{\delta-1}\hat{B}_p. \tag{18}$$

Since θ and A is unobserved, we can back out $\hat{\lambda}_\theta$ and $\hat{\lambda}_A$ by using $\hat{B}_N$, $\hat{B}_W$, and $\hat{B}_p$. In our application, $log(p_H)$ is also unobserved, thus we can directly estimate λ_L since the variable $\hat{L}$ is constructed based on geography and we can then back out $\hat{B}_p$ using $\hat{\lambda}_L$, $\hat{B}_N$, and $\hat{B}_W$. The next sections implement the model.

4 Empirical strategy

4.1 Data sources and variable construction

Working with data referent to the XIX century in Brazil has certain limitations. The first nation-wide representative census was only in 1872 and did not contain any mention of income or wages, being mostly about demography and occupations. The demographic data on working population and slaves is thus from the 1872 Census (Brasil 1876), in a version worked out by Cedeplar. Data on incomes is collected from the wages of municipal civil servants in 1876 published by the Statistical Report of the Empire in 1878 (Brasil 1878).

The data on terrain ruggedness is constructed using GIS and the SRTM digital elevation data produced by NASA and revised and distributed by CGIAR (Jarvis et al. 2008). Specifically, we use the DEM with 250m resolution at the equator. Climate data is calculated using the Bioclim dataset from WorldClim (Fick and Hijmans 2017) with a 1km resolution at the equator and soil suitability is calculated using the FAO GAEZ database (IIASA/FAO 2012) and has a resolution of 10km at the equator.

The construction of the variable for $\bar{L}$, the short-run exogenous amount of land available for development, is done using GIS with the following procedure. First, 10km[7] geodesic

[7] A radius of 10km is a realistic distance for the time where most of transportation was done by foot or

buffers are created around the coordinates for the municipality seat according to IBGE (note that this is not the centroid of the municipality shape, but the actual municipality downtown center), then all water bodies, made available in shapefiles by IBGE, are removed. Then these buffers are intersected with municipality shapes so the buffer only covers the actual municipality territory, avoiding its extension into neighboring municipalities. Next a slope raster is calculated using the STRM digital elevation model. Finally, the total area within the buffer that is not covered by water bodies or does not have slope greater than 15% can be calculated. This is illustrated in Figure 1 for the region of the Empire capital. Figure 2 shows the whole country. Thus we have data for W, N and $\bar{L}$, which leads us to the following strategy.

4.2 One direct test of the model

One fact that could support the relevance of the spatial equilibrium approach in this setting is to see if there is correlation between area prices and area income. Since we still do not have data for local prices at this time in Brazil, we use our constructed variable of land available for development as proxy for area prices. The reasoning is simple: places with less area available for development tend to have higher housing and land prices because of the short supply in relation to places with less constraints.

Figure 3 displays the correlation between the variables. There is no sense of what is causing what because the model treat both variables as endogenous, still the link is valid to see the fit of the model. The correlation shown is

$$log(Income) = 13.24 - 0.23 \text{ x } log(\bar{L})$$

with a r-squared of 0.011 and a robust standard error of 0.101. This relationship appears to support the assumption that high wages are compensated by higher land prices. Glaeser 2008 shows based on current surveys in the US that the average family spends about 30 percent of its income on housing, which would equal a coefficient of 0.3 in the regression. Our coefficient being 0.23 shows that we could consider the housing share between 0.13 and 0.33 to be very plausible values for Brazil in the late XIX century. This also shows a remarkable well fit for the Cobb-Douglas assumption of this model.

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horses and mules.

4.3 Estimating the impact of exogenous shifters

Now we turn to properly estimating the model with exogenous geographic shifters. We estimate a version of equations 9, 10, and 11

$$log(\bar{L}) = K_L + \hat{\lambda}_L geography_i^k + \mu_L \tag{19}$$

$$log(N) = \kappa_N + \hat{B}_N geography_i^k + \mu_N \tag{20}$$

$$log(W) = \kappa_W + \hat{B}_W geography_i^k + \mu_W \tag{21}$$

where $geography_i^k$ is a different variable k for each municipality i. The models are estimated for k equal to terrain ruggedness, average annual temperature, and soil suitability for sugarcane, maize and cassava.

5 The marginal impact of geography on municipality-specific welfare and productivity and the role of slavery

5.1 The case of "bad geography"

Terrain ruggedness can be considered "bad geography", due to its detrimental effect in the long run (Nunn and Puga 2012). It has negative effects because it most likely hurts productivity due to difficulties created for market access and in transporting goods[8]. Note, however, that market access is more conditioned by distance to market centers or by ruggedness in the roads to market centers than by local ruggedness itself. Most importantly, in agrarian contexts, ruggedness creates difficulties for the cultivation of agricultural crops caused, in particular, by leaching. In urban contexts, the difficulties are related to the construction of housing but, in the ancient city, ruggedness have substantial advantages in what concerns sanitary and security conditions. There is also difficulties in commuting within the city, problems that are aggravated in peripheral countries that do not have the resources to invest in proper transportation systems.

The reduced-form results of the regressions of ruggedness on income, land available for development, and population are presented in Table 1. Using plausible values for α, β, γ, and δ, we can analyze the reduced-form results through the lens of the spatial equilibrium

[8] As explored by Nunn and Puga 2012, ruggedness has positive effects on long-run development only in Africa because it facilitated for populations to hide from the slave trade.

framework. Suppose the value of $\delta = 1.5$, which is a standard value for the elasticity of housing supply in the literature. In combination with the reduced-form estimates $\hat{\lambda}_L = -0.004973$, $\hat{B}_N = 0.005374$, and $\hat{B}_W = 0.004927$, the estimated value of the impact of ruggedness on $logp_H$ is $\hat{B}_p = 0.005091$. Assuming $\alpha = 0.2$, which we saw is a plausible value for the share of housing expenditure of consumers income, we have that $\hat{\lambda}_\theta = -0.003399$. This means that there is a negative welfare impact imposed by bad geography, a 10 point increase in ruggedness is worth the same as a 0.034 log point decline in income. This is not insignificant as the ruggedness scale in Brazil goes from around 2 (level terrain surface) to a maximum of 170 (intermediary rugged) and the standard deviation of log income is 0.8, thus a 30 point increase in ruggedness would be the same as if income goes down by a full standard deviation.

Now suppose that the value for the share of fixed capital in production is $(1-\beta-\gamma) = 0.1$, then we can analyze the role of slavery in this framework. Assume that slavery is a form of tradable capital and that only free labor constitutes the labor share. Looking at the 1872 Census there are only five municipalities with less than 50 slaves, which would mean a slave share less than 0.1. Overall the mean slave share is 0.3 with a standard deviation of 0.2 and a maximum of 0.9, meaning that there are municipalities with very little slavery, at least in the census, up to municipalities where slaves constitute 90 per cent of the factor share with only 10 per cent of free labor. Thus, for the empirical exercises we can look at the variation for γ, the slave share, from 0.1 to 0.9, with 0.3 as the most plausible value.

For the slave share equal to 0.1 we have $\hat{\lambda}_A = 0.0049$, for the slave share equal to 0.3, $\hat{\lambda}_A = 0.0039$, and for the slave share equal to 0.3, $\hat{\lambda}_A = 0.00103$. For example, take the mean value for the slave share, this suggests that a 10 point increase in ruggedness is worth the same as 0.039 increase in city-specific productivity. This is an unexpected result. Of course this is not the causal impact of ruggedness on productivity, as there might be uncontrolled for factors associated with productivity ruggedness that are positively correlated with ruggedness. What this could be pointing to is that most of economic activity at this time in Brazil was concentrated along the coast line and states such as Minas Gerais which is naturally more rugged because of a very large relief difference in the Southwest region, where going 100km inland often means going up 1000m, which can be noted in Figure 2, thus ruggedness could be correlated with some economies of density that are driving the result. Other interesting fact is that the greater the free labor share in the model, the greater is the exchange between bad geography and productivity. Together this shows the contradictory nature of Brazil's initial development, where places with less slavery bad geography is connected to more productivity.

5.2 The case of climate

Other issue of debate is the role of climate in Brazil's development. Table 2 shows the regression of annual average temperature on land available for development, population of workers and income, where we see that higher average temperatures throughout the year are correlated with both lower levels of working population and income. Assuming the same values as above for housing share and the elasticity of housing supply, we have that $\hat{\lambda}_\theta = 0.0293$. This means that an increase in 10 degrees Celsius is worth the same as a 0.293 log point increase in income. Thus it appears that warm weathers offset lower wages.

Turning to productivity, the predicted value of $\hat{\lambda}_A$ lies between -0.099 and -0.0489 for the lower and higher bonds of the slave share. Taking the mean slave share, then $\hat{\lambda}_A = -0.0865$, which means that higher temperatures are depressing productivity. Again, this is surely not the causal impact, however there is some correlated factor with temperature that is driving productivity down.

5.3 The case of soil suitability

At last, Tables 3, 4, and 5 show the regression results for soil suitability for sugarcane, cassava, and maize, respectively. Sugarcane is a very important commodity in Brazil's history and cassava and maize are two staple foods widely consumed throughout the country.

First, in relation to sugarcane, we see in Table 3 that a municipality having more soil suitable for sugarcane is correlated with higher levels of income but there is no effect on working population. Again, assuming the same parameter values for the elasticity of housing supply and the housing share, the results for sugarcane show that $\hat{\lambda}_\theta = -0.0724$. This is also an unexpected result, a 10 percent increase in sugarcane suitability depresses welfare in 0.7 percent, but consumers appear to be paying in the form of higher prices ($\hat{B}_p = 0.01163$) rather than lower wages. In relation to productivity, the estimate value of $\hat{\lambda}_A$ varies between 0.0673 for the lower bound of the slave share to 0.00748 to the higher bound. This shows that sugarcane suitability is positively correlated with productivity and that this correlation decreases with higher levels of the slave share.

Second, in relation to the staple foods, we see in Tables 4 and 5 that both staples are positively correlated with working population and negatively correlated with income. Since the results for both cassava and maize run in the same direction it suffices to further discuss only one of them. Take, for instance, cassava, the estimated value for $\hat{\lambda}_\theta$ is 0.0655. This means that a 10 percent increase in the soil suitability for cassava is worth a 6.5 percent increase in welfare. However, this increase in welfare does not seem to come from higher wages, but from lower prices ($\hat{B}_p = -0.0178$). In relation to productivity, the predicted value

$\hat{\lambda}_{\theta}$ lies within -0.055 for the lower bound and 0.00026 for the higher bound of the slave share. Looking at the mean value of the slave share, $\hat{\lambda}_{\theta} = -0.0412$, thus higher soil suitability for cassava ceases to depresses productivity only with high factor shares of slavery.

6 Conclusion

This paper has shown that the spatial equilibrium framework has a good fit for municipalities in late XIX century Brazil. In taking a step to understand some puzzles related to Brazil's position in the wealth of nations we first turn to understand heterogeneity in prices, income and population levels in municipalities. Combining archival resources to build income data for the late 1870s with the first census in history and GIS-derived data it is possible to generate great insight driven by theory and facts in a otherwise context of poor data that usually led only to subjective interpretations. Specifically, we have shown that the initial spatial equilibrium in Brazil worked in perverse ways that is sometimes amplified by the factor share of slavery. Future research could more exogenous variables and predict how income behaves at the municipality and more aggregate levels.

7 Tables and Figures

Figure 1: Cities of the Empire in the Rio de Janeiro region and land available for development. The dots represent the downtown center. The light green dot represents Rio de Janeiro, the Empire Capital. The dark green lines represents a maximum of 10km buffers around the downtown center which do not contain water bodies and that do not transverse into territories of other municipalities. The yellow area represent land that is above 15% of slope. The gray area represents all other land. Thus, the area available for development in the short run ($\bar{L}$) is the grey area within the green buffer.

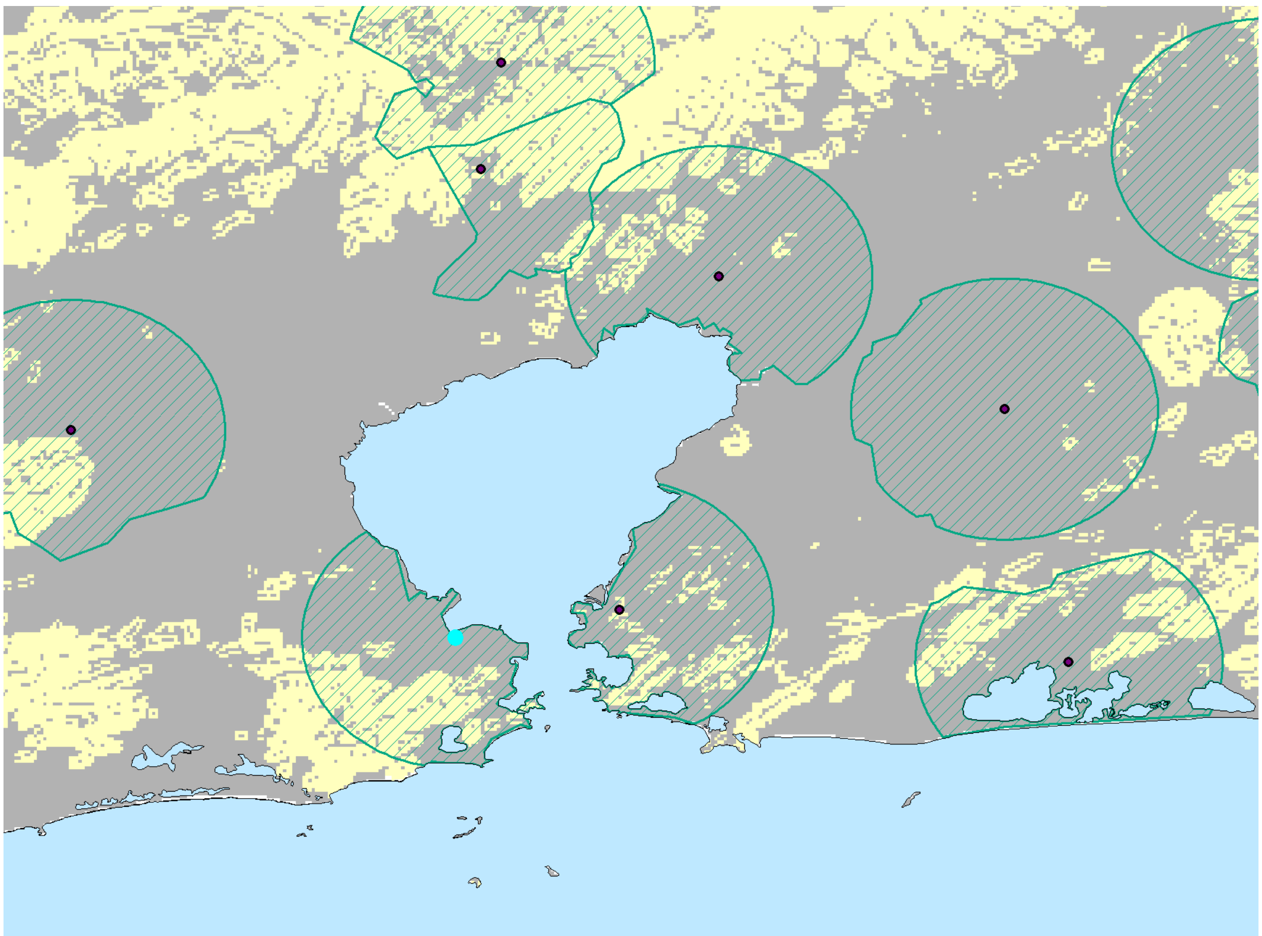

Figure 2: Buffers zones and 15% slope raster for Brazil. The dark green circles represents a maximum of 10km buffers around the downtown center which do not contain water bodies and that do not transverse into territories of other municipalities. The yellow area represent land that is above 15% of slope. The grey area represents all other land.

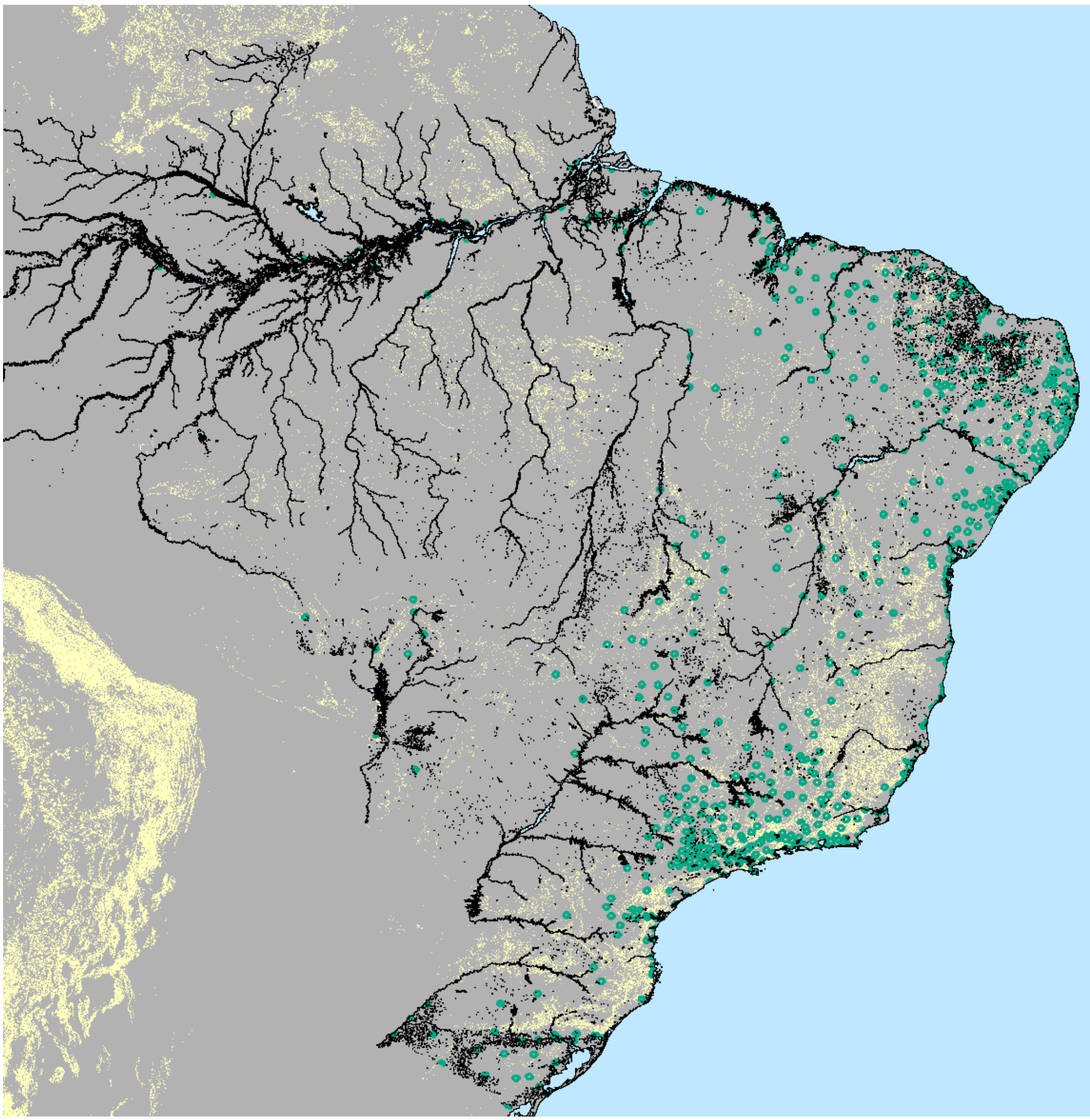

Figure 3: The correlation between log income and log land available for development.

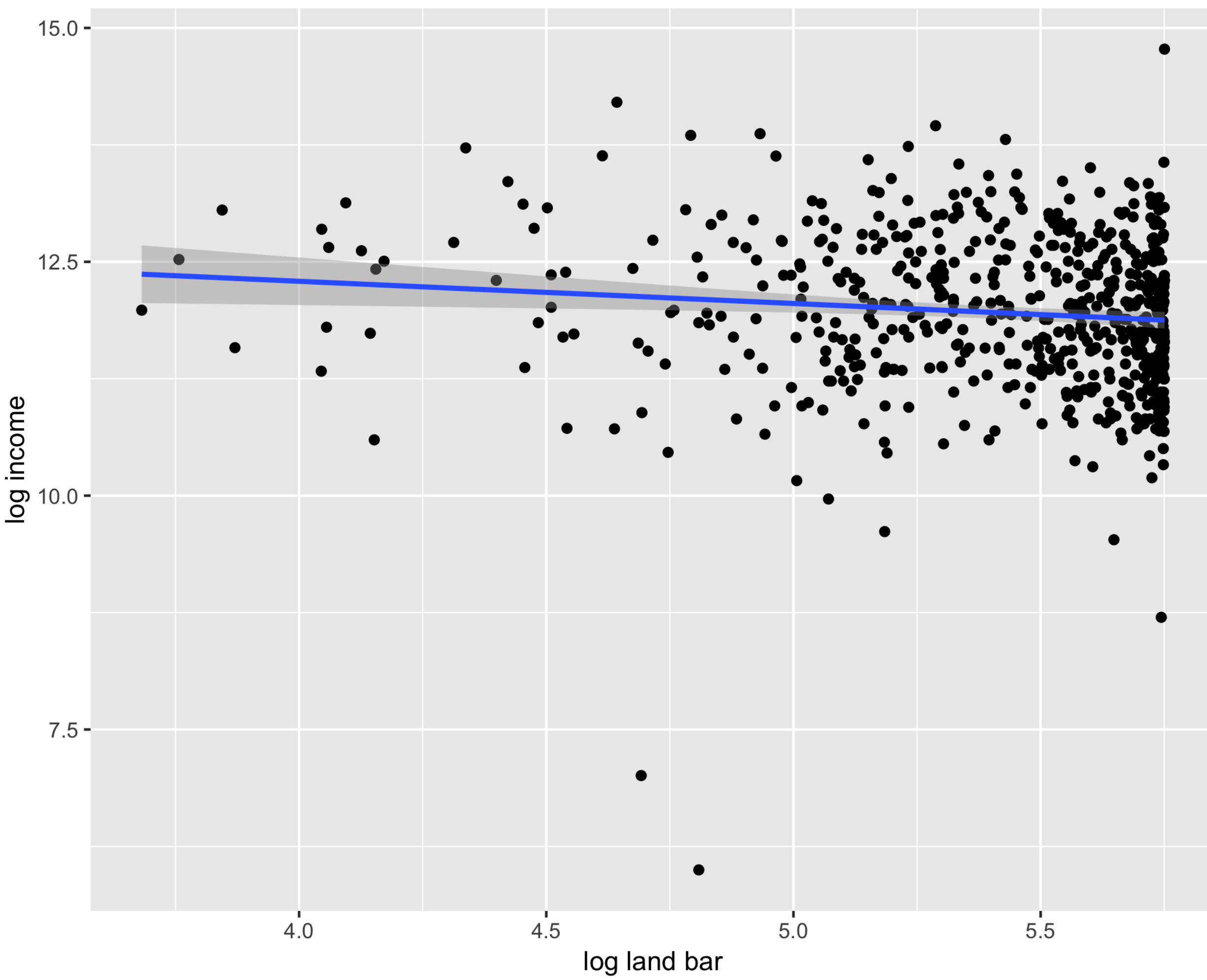

Table 1: The impact of ruggedness (the geographic exogenous shifter G) on land available for development, population of workers, and wages

	Dependent variable:		
	$log(\bar{L})$	$log(N)$	$log(W)$
	(1)	(2)	(3)
ruggedness	-0.004973^{***}	0.005374^{***}	0.004927^{***}
	(0.0005)	(0.001)	(0.001)
Constant	5.638^{***}	7.585^{***}	11.732^{***}
	(0.024)	(0.081)	(0.059)
Observations	641	641	619
R^2	0.160	0.020	0.032
Adjusted R^2	0.159	0.019	0.031
Residual Std. Error	0.346 (df = 639)	1.140 (df = 639)	0.826 (df = 617)
F Statistic	121.574^{***} (df = 1; 639)	13.085^{***} (df = 1; 639)	20.630^{***} (df = 1; 617)
Note:	Robust standard error in parenthesis. $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$		

Table 2: The impact of annual average temperature (the geographic exogenous shifter G) on land available for development, population of workers, and wages

	Dependent variable:		
	$log(\bar{L})$	$log(N)$	$log(W)$
	(1)	(2)	(3)
annual avg temperature	0.011357^{**}	-0.042634^{***}	-0.062721^{***}
	(0.005339)	(0.010370)	(0.011299)
Constant	5.153812^{***}	8.870669^{***}	13.385320^{***}
	(0.126037)	(0.239453)	(0.262699)
Observations	635	635	614
R^2	0.007753	0.020783	0.049136
Adjusted R^2	0.006185	0.019236	0.047582
Residual Std. Error	0.377315 (df = 633)	0.859434 (df = 633)	0.818632 (df = 612)
F Statistic	4.945740^{**} (df = 1; 633)	13.434810^{***} (df = 1; 633)	31.625060^{***} (df = 1; 612)
Note:	Robust standard error in parenthesis. $^{*}p<0.1$; $^{**}p<0.05$; $^{***}p<0.01$		

Table 3: The impact of sugarcane suitability (the geographic exogenous shifter G) on land available for development, population of workers, and wages

	Dependent variable:		
	$log(\bar{L})$	$log(N)$	$log(W)$
	(1)	(2)	(3)
log(sugarcane suitability)	0.039978**	0.026945	0.074869***
	(0.016233)	(0.022103)	(0.025776)
Constant	5.109590***	7.695602***	11.390940***
	(0.127208)	(0.161270)	(0.195399)
Observations	635	635	614
R^2	0.011051	0.000955	0.008094
Adjusted R^2	0.009489	−0.000623	0.006474
Residual Std. Error	0.376688 (df = 633)	0.868092 (df = 633)	0.836113 (df = 612)
F Statistic	7.073367*** (df = 1; 633)	0.605056 (df = 1; 633)	4.994156** (df = 1; 612)
Note:	Robust standard error in parenthesis. *p<0.1; **p<0.05; ***p<0.01		

Table 4: The impact of cassava suitability (the geographic exogenous shifter G) on land available for development, population of workers, and wages

	Dependent variable:		
	$log(\bar{L})$	$log(N)$	$log(W)$
	(1)	(2)	(3)
log(cassava suitability)	0.056160***	0.071774***	−0.069195***
	(0.018696)	(0.020218)	(0.021615)
Constant	4.972079***	7.336931***	12.498510***
	(0.151835)	(0.158293)	(0.174011)
Observations	635	635	614
R^2	0.038195	0.011867	0.012118
Adjusted R^2	0.036676	0.010306	0.010504
Residual Std. Error	0.371482 (df = 633)	0.863338 (df = 633)	0.834415 (df = 612)
F Statistic	25.137850*** (df = 1; 633)	7.601861*** (df = 1; 633)	7.507380*** (df = 1; 612)
Note:	Robust standard error in parenthesis. *p<0.1; **p<0.05; ***p<0.01		

Table 5: The impact of maize suitability (the geographic exogenous shifter G) on land available for development, population of workers, and wages

	Dependent variable:		
	$log(\bar{L})$	$log(N)$	$log(W)$
	(1)	(2)	(3)
log(maize suitability)	0.219559***	0.238882***	−0.182458***
	(0.059050)	(0.052487)	(0.063360)
Constant	3.695164***	6.031317***	13.383090***
	(0.468018)	(0.416890)	(0.502607)
Observations	635	635	614
R^2	0.093789	0.021118	0.013373
Adjusted R^2	0.092358	0.019572	0.011761
Residual Std. Error	0.360586 (df = 633)	0.859287 (df = 633)	0.833885 (df = 612)
F Statistic	65.512990*** (df = 1; 633)	13.656260*** (df = 1; 633)	8.295237*** (df = 1; 612)
Note:	Robust standard error in parenthesis. *p<0.1; **p<0.05; ***p<0.01		

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