Long-Distance Trade and Long-Term Persistence*

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Abstract

The spatial distribution of economic activity depends largely on market access and history, but countries differ greatly in the extent to which their geography reflects these determinants. What explains these differences? This paper explores this question using a staggered lifting of restrictions on direct trade with Europe across the Spanish Empire. I combine a difference-in-differences approach with a dynamic spatial equilibrium framework and detailed georeferenced data on maritime travel from historical logbooks to examine this issue. I show that the increase in market access induced by the reform led to a reconfiguration of the economic geography in places that were initially less densely settled. Moreover, I show that modern-day settlement patterns depend less on historical settlement patterns and more on coastal access in areas subjected to the reform. Taken together, the findings provide evidence that a key determinant of persistence of historical settlement patterns in a country is the level of urban development as it experiences changes in the trading environment.

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1 Introduction

The spatial distribution of economic activity is shaped by market access and history. However, countries differ substantially in the extent to which their economic geography reflects these determinants. The location of trading opportunities is particularly important for city location in the United States; this is evident when one considers that the two largest cities are also the two largest international ports (New York and Los Angeles). Other urban systems, sometimes with cities centered around former imperial capitals (e.g., Rome, Beijing, or Delhi), reflect historical precedent to a much larger degree. What explains the relative importance of market access versus historical precedent in determining the spatial distribution of economic activity? Do urban systems adapt to changes in the trading environment? If so, under what conditions?

To study these questions, I exploit a large-scale historical experiment: the expansion of direct trade with Europe in the Spanish Empire. Early Spanish commercial policy restricted the direct trade of goods with Europe. However, driven by political developments in Europe and dynastic changes in Spain, these restrictions were gradually lifted in the second half of the 18th century. While only four ports were permitted to trade goods directly with Europe in 1765, this number had increased to 45 by the beginning of the 19th century. By this time, no major ports in the empire were subjected to restrictions on the direct trade of goods with Europe (see Figure 1). The reform reduced trade costs in different years and different locations, generating variation that is well suited to study the impact of trade costs for several reasons. First, while I show that the reform caused large and spatially heterogeneous variation in international trade costs, these changes were limited to the costs of trading goods. Second, the geographic scope of the reform allows us to consider its heterogeneous effects while keeping formal institutions and legal origins fixed. Finally, compared to studies of single countries or regions, the geographic scope of this setting is compelling in terms of external validity.

I study the long-run impact of the reform in three steps. First, I construct a comprehensive panel dataset of population and trade for the Spanish Empire in the 18th century. To quantify how the reform affected empire-wide bilateral shipping times, I construct a grid of $0.5° \times 0.5°$ covering the full extent of the Spanish Empire in the 18th century. On this grid, I construct a directed network of bilateral trade costs between all adjacent cells, accounting for shipping on land and sea. For maritime shipping, I estimate accurate sailing speeds from historical maritime logbooks and georeferenced wind data. Travel on land accounts for various geographic features that determined mobility, such as elevation and landcover, as well as infrastructures, such as roads and ports. I validate the resulting shipping times with various historical and contemporary sources, confirming the accuracy of my approach. As there are many potential routes between any two cells, I use the route that minimizes shipping cost, subject to the restrictions on direct trade with Europe that were in place in a given decade. This results in bilateral shipping time matrices for each decade between 1710 and 1810. These time-varying measures of bilateral shipping times are then matched with data on geographical characteristics, agricultural productivity, urban populations, and the locations of settlements to construct a balanced panel covering Spanish America between 1710 and 1810.

I use this dataset to study the reduced form effect of lower international trade costs on the formation of new settlements and population growth. At the heart of the research design is a difference-in-differences approach, which compares changes in the prevalence of settlements and population growth in localities where trade costs changed differentially because of the reform. The identification assumption is that changes in population growth in such localities would have been the same in the absence of the reform. Pre-trend checks and several robustness exercises support a causal interpretation of the estimates. I find that the reform improved market integration between Europe and America. While the shipping time was 6 days lower on average, the decrease ranges from 27 days to no changes for several locations.[1] Consistent with the reform inducing lower trade costs, I also provide evidence of increases in the value of trade and price convergence for traded commodities. This improved market integration in turn affected population growth and the formation of new settlements. In the preferred specification, a one standard deviation reduction in the shipping time (6.5 days) increases the urban population by around 8 percent. The effects are concentrated in cities with smaller initial population sizes. Consistent with these patterns, I show that the correlation between historical and contemporary population density is lower in areas more intensively treated by the reform. Taken together, the findings provide evidence that the opening of trade had large and persistent effects on urban growth in smaller cities, which weakened the persistence of historical settlement patterns in these locations.

To explore the mechanisms and provide a quantitative explanation of the reduced form findings, I interpret the findings through the lens of a parsimonious dynamic spatial general equilibrium model building on the work of Allen and Arkolakis (2014).[2] In this model, regions with heterogeneous productivities, endowments of arable land, and initial endowments of workers are linked through costly migration and trade. Mobile workers choose where to live subject to migration frictions, and the utility derived from each location depends on locational fundamentals, agglomeration, and congestion forces in the form of prices for food that is non-traded and sourced from the immediate hinterland. To accommodate the long adjustment process documented in the reduced form, agglomeration forces are dynamic and depend on both contemporaneous and historical population density following (Allen and Donaldson, 2020). The key parameters of the model are chosen to match the model simulated impact of the reform to the reduced form estimates. The identification of these parameters relies on the assumption that *changes* in the value of geographical fundamentals were uncorrelated with changes in population during the reform period, conditional on a large set of controls. While this is an untestable assumption in practice, the reduced form evidence, and in particular, the absence of pre-trends, provides support for it.

I find evidence of positive returns to scale in historical city population. Increasing the historical population size of the city by one percent increases the current productivity by 0.026 percent. As a result, the model can account for the reduced form findings. The reform increased population density in locations that experienced reductions in trade costs. However, the effect depends on the pre-reform market size of the city and had smaller effects on the cost of living in locations with a larger home market. Due to dynamic agglomeration economies, the effect of the reform is highly persistent. Furthermore, consistent with the reduced form findings, the model accounts for the

[1] The calculated travel times are validated with several historical and contemporary datasets. For example, I provide evidence that the calculated sailing times are highly correlated with mail dispatch times and recorded travel times in the 18th century.

[2] More generally, the model builds on recent quantitative models of trade and geography, which accommodate a large number of locations that are asymmetric in their locational characteristics and frictions to trade and migration (Redding and Rossi-Hansberg, 2017).

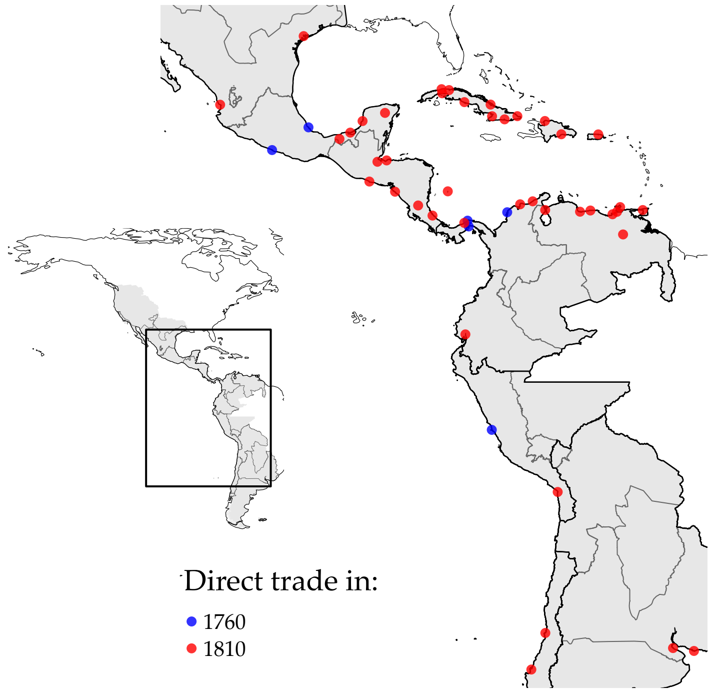

Figure 1: This map shows the extent of the territory claimed by the Spanish Empire in 1790 with its ports marked according to status. Ports marked in blue were licensed for long-distance trade prior to 1765 (Callao, Cartagena, Veracruz, Panama, and Acapulco), while those marked in red were licensed to trade with Europe in 1810. Callao, Cartagena, Veracruz, and Panama traded with Europe, while Acapulco was a hub for trade with the Philippines.

reform attenuating the relationship between historical and contemporary population density. Taken together, the model provides a novel mechanism linking international trade costs to differences in the persistence of historical settlement patterns. Since the effect of trade costs is larger for historically small locations, changes in trade costs attenuate persistence and induce reversals in the location of economic activity.

This paper contributes to the literature on the determinants of persistence in urban economics and economic geography. Persistence in the location of economic activity is consistent with both the importance of natural advantages (Davis and Weinstein, 2002; Maloney and Valencia, 2016; Bosker and Buringh, 2017; Alix-Garcia and Sellars, 2020) and multiple spatial equilibria (Krugman, 1991; Redding, Sturm and Wolf, 2010; Bleakley and Lin, 2012; Jedwab and Moradi, 2015). While persistence in the spatial distribution of economic activity remains well-documented, little is known about what drives the degree of persistence across locations. This is puzzling since Henderson et al. (2018) show that locational fundamentals associated with trade and agriculture differ substantially across countries. This paper contributes to the literature by establishing a relationship between persistence in the location of economic activity and changes in international trade costs. The paper therefore builds on a literature emphasizing the importance of international trade in shaping the economic geography within countries. Earlier contributions emphasized the role of trade openness in determining spatial concentration in stylized settings (Henderson, 1982; Rauch, 1991; Ades and Glaeser, 1995; Krugman and Elizondo, 1996), while later studies have explored the effect of trade on a range of outcomes in models accommodating rich geographies (Fajgelbaum and Redding, 2014; Coşar and Fajgelbaum, 2016; Nagy, 2018, 2020). This paper builds on this literature by exploring the effects of changes in the trading environment on the location of economic activity in the very long run and by quantifying the role of trade in shaping persistence in the location of economic activity.

This paper also contributes to the literature exploring the long-term economic impacts of historical institutions, (Acemoglu, Johnson and Robinson, 2001, 2002; Banerjee and Iyer, 2005; Dell, 2010) and the economic legacy of the Spanish Empire in particular (Grafe and Irigoin, 2006, 2012; Coatsworth, 2008; Bruhn and Gallego, 2011; Engerman et al., 2012). Acemoglu, Johnson and Robinson (2002) establish a negative relationship between population densities in 1500 and today at the country level. They argue that lower initial population density necessitated institutions that enabled broader participation in the economy. These institutions were in turn more compatible with modern economic growth, thus contributing to a divergence between areas with different population densities in 1500 starting in the second half of the 18th century. Other important contributions emphasize the role of migration from Europe in generating this reversal (Chanda, Cook and Putterman, 2014; Easterly and Levine, 2016). This paper complements these findings by highlighting the role of trade-related institutions. The results are consistent with the view that the *reversal of fortune* in the Americas is rooted in institutional change but also highlight the importance of the factors that shaped institutions governing trade, such as the transition from Habsburg to Bourbon rule in Spain, in addition to property rights, of which Acemoglu, Johnson and Robinson (2002) emphasize the importance. More broadly, this paper provides evidence of the impact of trade-related institutions on long-run economic development, which has received little attention in the literature (Jha, 2013; Jia, 2014; Alvarez-Villa and Guardado, 2020).

Finally, my findings contribute to the empirical literature on the effects of international trade on economic development. The literature using reduced-form approaches have documented sizeable impacts of trade on national income (Frankel and Romer, 1999; Feyrer, 2009, 2019; Maurer and Rauch, 2019), while papers relying on structural approaches find more modest effects (Arkolakis, Costinot and Rodríguez-Clare, 2012). Studying the diffusion of steamship technology, Pascali (2017) finds little evidence of improved trade integration on economic development on average. This is consistent with increased access to trade inducing some countries to specialize in sectors that have fewer growth-enhancing externalities (Grossman and Helpman, 1990), are more volatile (Blattman, Hwang and Williamson, 2007), have weaker economies of scale (Matsuyama, 1992; Krugman and Venables, 1995), or negative effects on institutions (Acemoglu, Johnson and Robinson, 2005; Puga and Trefler, 2014). The findings in this paper complement this literature by providing evidence that trade can promote economic development within countries even in contexts with highly extractive institutions. More broadly, the paper contributes to the debate on the sources of the growth of world trade in the 19th century (Estevadeordal, Frantz and Taylor, 2003). In particular, the paper provides empirical evidence on the importance of institutions and supports the idea that the relaxation of mercantilist policies contributed to market integration in the early 19th century (O'Rourke and Williamson, 2002; O'Rourke, 2006).

This paper is structured as follows. Section 2 presents the historical background. Section 3 presents the data sources. Section 3 provides details the calculation of trade costs. Section 5 elaborates on the reduced-form research design, results, and mechanisms. Section 6 presents the model and the results of the quantitative exercise. Section 7 concludes.

2 Historical Background

This section provides the historical background for the analysis. I discuss the background and the motivation for the trade reform as well as the historical relationship between trade and economic development within the Spanish Empire.

The Spanish Commercial System. A central aim of Spanish commercial policy was to promote state wealth acquisition through trade surpluses (Findlay and O'Rourke, 2007). To this end, several policies restricted Atlantic trade. First, points of entry and exit were restricted to four ports in the Americas (Cartagena de Indias, El Callao, Portobello/Nombre de Dios, and Veracruz) and only Seville/Cádiz in Europe. Further, the frequency of travel and the routes were restricted.[3] Third, participation in Atlantic trade was restricted to Spanish merchants. Finally, there were high tax rates on imports and exports.[4] Mercantilist restrictions and high trade costs ensured that trade was limited to non-competing goods with a high value-to-weight ratio. Important exports during the period beyond precious metals were hides, tallow, sugar, indigo, and cochineal (Rahn Phillips, 1990).[5]

These measures facilitated naval defense of convoys and limited imports to the Americas, thus limiting the flow of bullion to other places than the Iberian Peninsula while keeping prices for Spanish exports artificially high (Baskes, 2013). As a result, merchants' private remittances to Spain were substantially larger than remittances directly controlled by the crown (Cuenca-Esteban, 2008). While the system limited trade with Europe across large parts of the Spanish empire, there was still some long-distance trade occurring. Ships sailing under special permission of the crown (*registros*) supplied ports that were too remote relative to the large trade routes. However, this was never done at a sufficiently large scale (Walker, 1979) and increased the reliance on contraband trade which was sizeable (Christelow, 1942). While as a rule, there were no restrictions on inter-regional trade (Elliott, 2006, p. 111), a likely consequence of Spanish mercantilist policies before the liberalization in the late 18th century was the underdevelopment of peripheral areas in America (Fisher, 1997, p. 73).

Reforming Trans-Atlantic Trade. Beginning in the 18th century, Spanish policymakers were induced by geopolitical considerations, originating mainly in Europe, to overhaul the external trading system (Elliott, 2006). In the immediate aftermath of Spain's defeat in the Seven Years' War, a technical committee was appointed under Charles III to assess and reform the system. Drawing on ideas of reforming the system of government in America that had been circulating for a long time, the *junta de comercio* proposed the abolition of the Cádiz monopoly as well as the fleet system. Further, it

[3] Typically, only two fleets left Spain every year: the New Spain *flota* destined for Veracruz, and the *Tierra Firme galeones* destined for Cartagena and Portobello. In the Pacific, shipping was conducted by *Armada del Sur*, which carried goods from the trade fairs in Portobello to Pacific ports in South America (Walker, 1979). Moreover, the Manilla galleon would sail between Acapulco and Manilla. Official information was carried by *aviso* ships, which were light carriers operating separately from the commercial system and were not permitted or equipped to carry freight.

[4] The duties typically depended on the origin of the goods, with lower rates on goods originating from Spain.

[5] The slave trade was subject to different rules. Trade in slaves was allowed for British ships from early to the mid 18th century as a result of the treaty of Utrecht, the *asiento* (Walker, 1979).

proposed opening 14 ports on the Iberian Peninsula as well as 35 ports in the Americas (Fisher, 1997).[6] Several ports in the Caribbean were opened already in 1765 (see Table 3).[7] The liberalization measures culminated in the decree of free trade in 1778, which opened several of the remaining ports.[8] In the 1780s, the remaining ports followed. While the reform reduces trade costs, the terms of trade in many ports presumably remained depressed (Francis, 2017). However, Spanish communication with the Americas was disrupted during the Napoleonic wars (O'Rourke, 2006). Out of necessity, trade with neutral nations was therefore allowed. This marked the end of Spain's ability to enforce protected trade with the colonies. By the beginning of the 19th century, Spanish America enjoyed *de facto* although not *de jure* unrestricted trade with foreigners (Fisher, 1998). As a result, direct trade with Britain, not mediated through Spain, grew in importance (Prados de la Escosura and Casares, 1983). Independence was mostly followed by high tariffs, mainly driven by the revenue needs of post-independence governments (Coatsworth and Williamson, 2004).

The historical literature emphasizes the role of European interstate competition and the resulting increased need for a modernized imperial defense as motivating the reform. Thus, the drive to reform the Spanish commercial system can be understood as being motivated by the intense interstate competition between the European states of the 18th century (Kuethe and Andrien, 2014). Highlighted in the historical literature as an important impetus for the reform was the "humiliating" capture of Havana and Manila by the British during the Seven Years' war. This opened a window of opportunity for reform-minded policymakers in Spain who now could justify reforming the commercial system with concerns about the territorial integrity of the empire. As a result, the reform was implemented rapidly after the Seven Years' War (Fisher, 1997). Therefore, the timing of the reform is mainly driven by intensified interstate competition in Europe, rather than economic development in the Americas directly. Moreover, the reform was implemented from above, and no significant ports in which the policies were applied were excluded. This is also apparent from the fact that the policies were resisted by several actors in the Spanish Empire (Baskes, 2013). Finally, the policies undoubtedly broadened access to international trade across the Spanish Empire, which is apparent in trade statistics (Fisher, 1985; Cuenca-Esteban, 2008).

"Free Trade" and Economic Development. The reform affected economic growth in different regions. Formerly neglected regions such as *Rio de La Plata*, Venezuela, and Cuba became more important exporters of primary commodities. Lower trade costs induced by unrestricted sailing potentially allowed for specialization in a wider range of commodities, such as more perishable goods. However, bullion remained an important export commodity (Fisher (1997), p. 38). Fisher (1993) provides data on the composition of Spanish imports from Spanish America between 1782 and 1796 for the ports of Cadiz and Barcelona (which accounted for around 88 percent of imports from Spanish America). Precious metals still accounted for 56.4 of imports through this period. The other commodities were

[6] The ports that were opened on the Iberian peninsula in this period was Malaga, Almería, Cartagena, Alicante, Tortosa, Barcelona, Santander, Gijón, La Coruña, Palma de Mallorca, Santa Cruz de Tenerife. While the reform is believed to have a role in promoting the rise of the Barcelona textile industry, in the early 19th century, around 80 percent of Spanish trade with the Americas still went through the port of Cádiz (Fisher, 1997).

[7] Santo Domingo, Puerto Rico, Margarita, and Trinidad were opened for direct trade with Spain in 1765.

[8] This was with the exception of the Captaincy Generalacy of Venezuela (Caracas), where it was believed the Caracas companies tobacco monopoly was worth protecting, and New Spain (Campeche), where it was believed it would have diverted too much trade away from other regions (Fisher, 1997). Even so, especially Veracruz was affected by the changes before the late 1780s due to the abolition of the convoy system and the increased prevalence of *registros*.

typically high-value agricultural commodities (tobacco 13.6, cacao 7.8, sugar 5.5, indigo 5.2, cochineal 4.2, hides 3.4 and cotton 0.4 percent) (Fisher, 1993).

While it is generally agreed upon that the reform had large effects on trade volumes, the magnitudes are disputed (Cuenca-Esteban, 2008). Colonial imports to Spain increased tenfold and exports from Spain to the colonies fourfold according to Fisher (1985), while more modest estimates are found in Cuenca-Esteban (2008), also suggesting large effects (see Figure 2). However, there is little doubt that trade increased substantially during the period. Presumably, as a result of these developments, several marginal areas in the Spanish empire became important economic regions. "...for the first time, the metropolis succeeded in unleashing the agricultural potential of its American possessions whilst also promoting the continued expansion of mining production. The relationship between this economic growth and the liberalization of trade is abundantly clear", (Fisher, 1997, p. 197). Moreover, it has been argued that the population and economies of previously stagnant peripheral colonies in Spanish America grew rapidly (Bulmer-Thomas, 2003; Mahoney, 2010).[9] In summary, the historical literature suggests the restrictions imposed on trade in goods with the Americas stunted economic development, and efforts induced by European interstate competition to relax these marked the beginning of a process that would have large effects on trade and regional development in the second half of the 18th century.

3 Data

To quantitatively assess the impact of the reform, I construct a dataset containing geographical, demographic, and economic data of the Spanish Empire in the 18th century.[10] The main dataset covers the 100 year-period 1710-1810, roughly corresponding to the Spanish Empire under the Bourbon dynasty. Summary statistics of the main variables can be found in Table 1 and 2.

Population. As a starting point, I use city-level population data from Buringh (2013). Following Vries (1984) and Bairoch (1988) they apply a threshold rule and collect data on cities with a population exceeding 5,000 inhabitants. I restrict the sample to cities with more than 5,000 inhabitants in 1750, the last measurement before the reform, which constitutes 299 cities. Following Arroyo Abad and Zanden (2016), I supplement and correct this data source by digitizing population data from the historical literature. Details on the sources and approach are provided in the Appendix. I further supplement the dataset territorial gazetteer of around 15,000 places that existed in the Spanish Empire during the 18th and early 19th-century. The dataset is based on official records as well as various secondary sources (Stangl, 2019*b*).[11] It contains the founding, legal status, position in the ecclesiastical

[9] Cadiz remained the dominant port for trade with Spanish America between 1778 and 1796 (76.4 percent of total exports and 84.2 percent of imports). The remaining important ports were Barcelona (9.6 and 3.8 percent), Malaga (4.8 and 1.3 percent), Santander (3.3 and 2.6 percent), and La Coruña (3 and 6.8 percent) (Fisher (1993) p.20 and p.25).

[10] The contemporary countries partly or entirely contained in the sample are Argentina, Brazil, Chile, Bolivia, Peru, Uruguay, Ecuador, Colombia, Paraguay, Venezuela, Panama, El Salvador, Honduras, Costa Rica, Guatemala, Mexico, Nicaragua, Cuba, the United States, and the Dominican Republic.

[11] "Sources include archival material like census tables, mission reports, visitations of dioceses and provinces, but also more ephemeral documents like petitions of some city council which was mostly not written for giving geographic information but may touch one specific detail or incidentally exposes some relevant information. Non-archival contemporary sources include mostly highly systematic sources for information like so-called "Foreigner Guides" (printed calendar-manuals which included also lists of office holders of many parts of the Empire), maps, or geographical descriptions both printed and manuscripts."

hierarchy, as well as the longitude and latitude of each settlement. In the main analysis, I restrict the sample to places with the status of city, town, or village to capture the location of population centers.[12] The status of city was the highest legal status afforded a population center in Spanish America and was typically granted by the crown. Below the city in the hierarchy was the town (*villa*). In some cases, settlements were abandoned (such as Buenos Aires) or moved (such as Guatemala). In these cases, the date of founding is the founding of the first city in both cases. The location of the place is determined by the functional center.[13] Altogether, the final dataset contains 2,125 places spanning 1710 and 1810, and henceforth, I refer to these as settlements. Data on pre-colonial population density is from Denevan (1992), which combine the most recent available geographical, anthropological, and archaeological findings (Maloney and Valencia, 2016).[14] For New Spain and Peru, more detailed data is available for the colonial period. For these locations, I digitize data on population and tributary density from Gerhard (1993*a*,*b*,*c*) and Cook (1982). Finally, I include data on contemporary population density is from the Gridded Population of the World, which is distributed by the (CIESIN) at Columbia University.

Sailing and trade. To estimate the sailing speeds, I combine information on maritime logbooks with data on wind patterns. To calculate average sailing speeds I use logbooks from the CLIWOC database (Climatological Database for the World's Oceans) (García-Herrera et al., 2005). The data was originally compiled for studying historical oceanic climate conditions and contains around 280,000 logbook entries for Spanish, Dutch, French, English, and Swedish ships between 1750 and 1850. The logbook entries contain the daily longitude and latitude, wind speed and direction as well as several voyage-level characteristics such as the ship name, origin, and destination, captain name, and ship type.[15] Information on the average velocity and direction of the sea-surface winds by $0.5° \times 0.5°$ cells for each week between 2011 and 2017 is from the US National Oceanic and Atmospheric Administration (NOAA).[16] Data on trade flows come from two separate sources. First, data on trade between Spain and America at the port-level between 1797-1820 is from Fisher (1993). These data have been compiled from primary sources, mainly from the General Archive of the Indies in Seville. It contains data on the share of Spanish foreign exports to the 19 largest American ports as well as the total value (measured in *reales de vellón* in constant prices). Moreover, it contains estimates of the composition of trade. Second, I use data on bilateral trade flows at the country level (Fouquin and Hugot, 2016). I restrict this dataset to be between 1820 and 1870 which roughly corresponds to the period before the diffusion of the steamship. I digitize data on prices in Spain (Castille) using data from Hamilton (1947) and use price data from GPIH.[17] Information on urban nominal wages (measured in grams of silver) is from Arroyo Abad, Davies and van Zanden (2012).

Geography and infrastructure. I use high-resolution data on agricultural suitability measures from FAO's Global Agro-Ecological Zones under rain-fed, low-input agriculture for six important crops.

(Stangl, 2018).

[12] This avoids common pitfalls associated with using population thresholds for defining a settlement.

[13] For example, a place served as a marketplace, the dataset includes the location of the marketplace. A place with a primarily religious function records the location of the church and so on.

[14] The data used in this paper have been made available by Bruhn and Gallego (2011) and Maloney and Valencia (2016).

[15] In the case of Spanish ships these are *paquebote*, *fregata*, and *navio*.

[16] For cells covering land, the wind speed is set to zero to prevent routes from crossing land.

[17] Available at `https://gpih.ucdavis.edu/`.

The staple food in Mexico and the Andean countries was maize while wheat was the important staple in Chile and Argentina (Arroyo Abad, Davies and van Zanden, 2012). Important export crops were cotton, tobacco, sugarcane, and cacao which constituted around 27.3 of total exports from Spanish America to Spain in this period (Fisher, 1993). I supplement these data with the maximum attainable caloric yield using data from Galor and Özak (2015, 2016). The potential caloric yield is chosen because the relative caloric content is economically important in a pre-industrial context, moreover it isolates features of the natural environment affecting attainable yields, but that are exogenous to human intervention. Furthermore, I calculate the terrain ruggedness index, average slope, and elevation. Information on climatic variation is from Hijmans et al. (2005).

I collect data on the location and trading status of each port is from the decree *Reglamento y aranceles reales para el comercio libre de España a Indias de 12. de octubre de 1778* (Ramíres Bibiano and Ortíz de la Tabla, 1978), as well as Fisher (1997). I validate these sources with various other secondary sources. The list of ports can be found in Table 3. Further, I include the location of the principal mining centers (*Reales de Minas*) in the 18th century from Fisher (1997).[18] Together, mining, cotton, tobacco, sugarcane, and cacao exports make up around 83.7 of all exports from Spanish America to Spain in the period. Finally, I use mail routes to proxy for the location of roads (Stangl, 2019*a*). I include controls on potential vegetation to proxy for different geographical fundamentals as well as using landcover to calculate travel speeds (Ramankutty and Foley, 1999). Navigable rivers played a less important role in trade than in Europe and the United States. Therefore, I only control for time-varying effects of distance to waterways and fresh-water access by using data from Natural Earth.

4 Shipping Times and Trade Costs

To estimate the impact of the reform, I compute trade costs between locations in the Spanish Empire in the 18th century. While trade costs in this context are a function of a range of factors, I exploit that trade costs have been widely documented to be affected by distance both in contemporary and historical settings (Flückiger et al., 2019; Barjamovic et al., 2019). I leverage this by constructing a directed graph, where nodes denote localities and edges the shipping times to all adjacent localities (measured in days). Shipping times are calculated based on predetermined first-order determinants of mobility in the context, such as wind patterns, elevation, and infrastructure constructed before the reform. Using the graph, I calculate time minimizing trade routes, accounting for which ports were allowed to trade directly with Europe by decade. This section further elaborates on the procedure.

4.1 Estimating Trade Costs

Maritime transportation. I estimate the sailing speed by using information from maritime logbooks in the 18th and early 19th centuries. From each logbook entry, I extract information on recorded wind speed, wind direction as well as travel direction. I follow Kelly and Ó Gráda (2019) and remove observations for which either the inferred speed is implausibly high (above 10 knots), or are located

[18] I identify in total 78 locations across the Spanish Empire mined for silver, mercury, gold, salt, emeralds, copper, platinum, or iron.

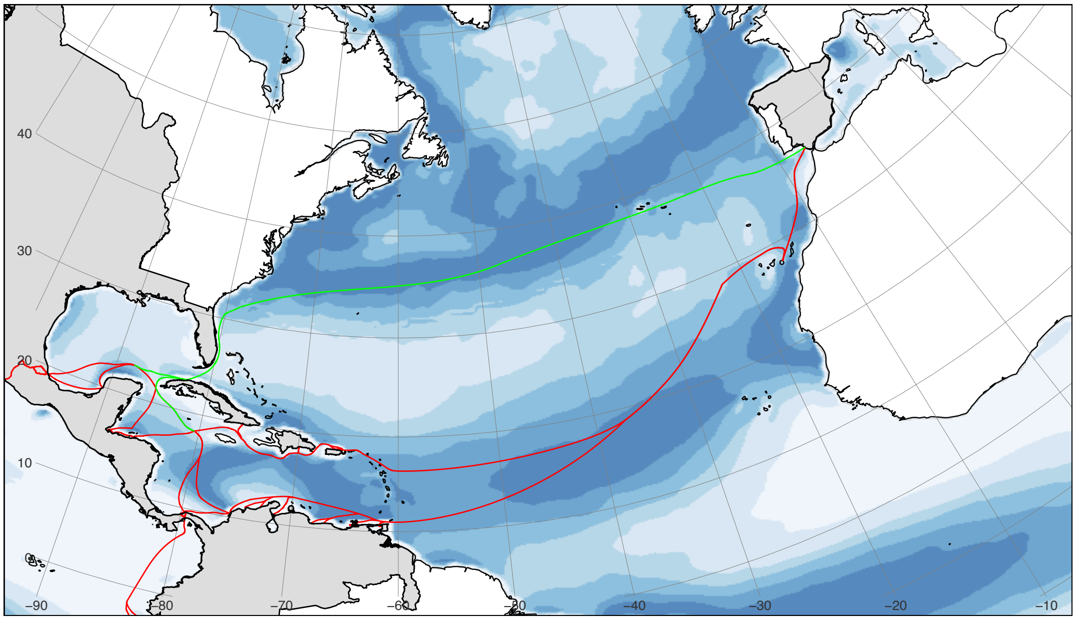

Figure 3: The figure shows the cost surface of maritime travel between 1750 and 1850. The map plots the average cost for each $1° \times 1°$ grid-cell where darker colors indicate that the cell can be crossed at higher speed. Grey areas denote territory claimed by the Spanish Empire in 1790. The cost surface is calculated from predicting sailing speeds from wind direction and speeds. The estimated relationship is the extrapolated on gridded data of wind direction and wind speeds covering the world oceans. The red and green lines denote historical trade routes. Red denotes the westward journey while green denotes the eastward journey. Source: NOAA and CLIWOC.

in coastal areas. Figure 4 panel (a) shows the distribution of recorded wind directions and panel (b) travel speeds. The figure shows that the average sailing speed was around 5 knots and that most sailings took place in the direction of the wind or at 90 degrees where sails work most efficiently (Pascali, 2017; Kelly and Ó Gráda, 2019). To estimate the relationship between wind direction, wind speed, and sailing speed, I consider the following equation,

$$S_i = e^{f(\theta_i, s_i) + \epsilon_i}, \tag{1}$$

where s_i measures the wind speed in grid-cell i, θ_i measures the deviation of the angle between the wind direction and direction of travel, and S_i denotes the sailing speed. Given a large number of features, Equation 1 is estimated using an elastic net where tuning parameters are chosen optimally using 10-fold cross-validation (Zou and Hastie, 2005). The full sample ($N = 37,141$) is then split into a training sample (80 percent of the sample) and a validation sample. I fit the model on a training sample and then test its performance in a validation sample. The model predicts sailing speed accurately (with a mean absolute error of 1.48 in the preferred model). Next, I average weekly high-resolution data on wind speed and wind direction from NOAA over the period 2011-2017. For every node in the graph, I then calculate the wind speed and wind direction between all adjacent nodes and use $\hat{S}_i$ to calculate the predicted sailing time.[19]

[19]The graph is weighted again to account for the fact that the distance between the nodes of the graph varies due to their relative position as well as the curvature of the earth.

Overland transportation. Long-distance transportation on land relied on pack animals at least until the second half of the 19th century. I calculate the costs faced by shipping with pack animals using geographical features, drawing on least-cost analysis tools from archaeology (White, 2015). The pace will depend on whether travel occurs on the road, the slope of the terrain, the elevation, and the land cover. The predicted speed of travel between node i and j is given by W_{ij} and based on the Tobler function (Tobler, 1993),

$$W_{ij} = \kappa_i \times 6.096 \times \mathrm{e}^{-3.5|\mathrm{slope}_{ij}+0.05|-\gamma \mathrm{elev}_i} \tag{2}$$

where $slope_{ij}$ measures the slope between cells i and j, κ_i is a coefficient determined by the landcover in cell i, and elev_i denotes the elevation in meters ($\gamma = -0.0001072$).[20] As a consequence, travel on flat terrain at sea level the predicted speed is around 5 kilometers per hour. To adjust for differences in landcover, I rely on coefficients from Weiss et al. (2018). Five terrain types have a natural mapping between historical land cover data and the terrain coefficients.[21] I rely on data on official routes for mail in the Spanish Empire during the Bourbon period to proxy the location of roads. Travel on a path is affected by the slope and elevation, but not the landcover. The walking speed is then used to construct the time required to travel between all nodes.[22]

Least-cost path problem. Once the duration of passing between all adjacent cells is known, I calculate the bilateral travel time between all cells by searching for the cost-minimizing route of getting from a cell i to any other cell j along the graph. Since there will be many alternative routes to ship a good between localities i and j, I assume goods shipping follows the time-minimizing route according to the Dijkstra algorithm (Dijkstra, 1959) (see Figure 5 for an example). Beyond sailing speed, the turnaround time in port shapes the total sailing time of a route. Since it is not clear whether turnaround times improved over time (Rönnbäck, 2012), I assume these are constant and zero as a starting point. Moreover, I model Europe as a point-like country centered on Cadiz containing the population mass of Spain, the United Kingdom, and France in 1700. I choose Cadiz because the majority of legal trade with Europe was channeled through this port throughout the period.[23] This approach results in a $R \times R$ dimensional matrix of bilateral travel times between all the cells, $\mathbf{T}_t[T_{ij} \geq 1]$. I calculate one matrix for every decade, accounting for which ports were open to direct trade with Europe in a given decade, and I refer to $\mathbf{T}_t$ as the travel time matrix in decade t.[24]

Shipping time elasticity. Next, I calculate the elasticity of the value of trade with respect to shipping time. I estimate the following equation,

$$\ln X_{jt} = \alpha_r + \gamma_t + \beta \mathrm{T}_j + \epsilon_{jt}, \tag{3}$$

[20]While Equation 3 models walking speed, the use of pack-animals will not have affected the speed much since these were typically accompanied by humans on foot (Verhagen, Joyce and Groenhuijzen, 2019).

[21]These are tropical forests, temperate forests, desert, savanna, and shrubland. The terrain factors are 0.324 in a tropical forest, 0.648 in a temperate forest, 0.97 in a savanna, 0.6 in shrubland, and 0.6 in deserts. Inland water can be crossed at half the speed (Herzog, 2014).

[22]Özak (2018) develops a *Human Mobility Index* to calculate pre-modern travel times. This measure is not appropriate in this context because I use context-specific features such as the location of paths and maritime technology available during the period.

[23]For the case of Great Britain the share of direct trade with Latin America became the most dominant towards the end of the colonial period, starting in the early 18th century (Prados de la Escosura and Casares, 1983).

[24]In the baseline case R = 5,573.

where X_{jt} is the value of exports from Spain and port j in year t. α_r accounts for regional heterogeneity that is unlikely to be driven by shipping time, for example route-specific factors such as risk caused by weather variability or privateering along the route.[25] Finally, γ_t accounts for year-specific factors affecting trade during the period, such as interstate conflict. A challenge is that missing data on bilateral trade between American ports prevent me from fully accounting for multilateral resistance terms, which arise in a large class of trade models (Anderson and Wincoop, 2003). However, since trade in this context was a closed system, trade with third countries is less of a concern in the current context.

4.2 Assessing the Shipping Times

How plausible are these estimates? First, I find a close correspondence between predicted trade routes and the location of known historical trade routes.[26] Next, I quantitatively assess the quality of the estimates in three ways. First, I compare the results to measures sailing times according to a database of bilateral sailing times.[27] For each port, I calculate the sailing time from Europe (Cadiz) to all the ports in the dataset for which the website records information. The average speed of 5 knots is used, the average speed of Spanish freight ships in 1750 (Kelly and Ó Gráda, 2019). For shipping on land, I compare the calculated shipping times with walking times using the Human Mobility Index Özak (2018) as well as google maps. Finally, I assess the correlation between predicted travel time and the duration of mail dispatches between major ports in Spanish America (Baskes, 2013). Figure 6 shows that these alternative shipping time measures are highly correlated with the measure developed in this paper. Furthermore, I assess the correlation between historical and contemporary wind patterns. There is a strong correlation between wind speed and direction in these two datasets. A remaining concern is that changes in maritime technology changed the relationship between distance and trade costs over the period. However, improvements in maritime technology were unlikely to be the most important determinant of productivity gains in shipping before the 19th-century (North, 1968; Harley, 1988; Menard, 1991).[28] Since maritime productivity gains were limited, potential measurement error in travel times is unlikely to be changing over time. As a result, these are likely to be absorbed by year and location fixed-effects. Taken together, the exercises show that the determinants of trade costs emphasized in the estimation were important in the context.

5 Reduced-Form Evidence

In this section, I use the calculated changes in trade costs to examine the effects of trade on the location of economic activity and economic development. I document four facts.

[25]The decline in piracy and privateering has been highlighted as an important source of productivity growth in shipping in the first half of the 18th century (North, 1968). These factors had become less important towards the end of the 18th century (Hillmann and Gathmann, 2011).

[26]For example, Pacific and Atlantic ports are connected by the Panama isthmus, Mexico City is connected to maritime trade through Veracruz and Acapulco, and Potosi and Arica with Callao.

[27]A database of bilateral sailing times between major ports around the world. Data available at `seadistances.org`.

[28]This view has recently been challenged by (Kelly and Ó Gráda, 2019). However, they show that Spanish sailing speeds remained stagnant throughout the period of this study.

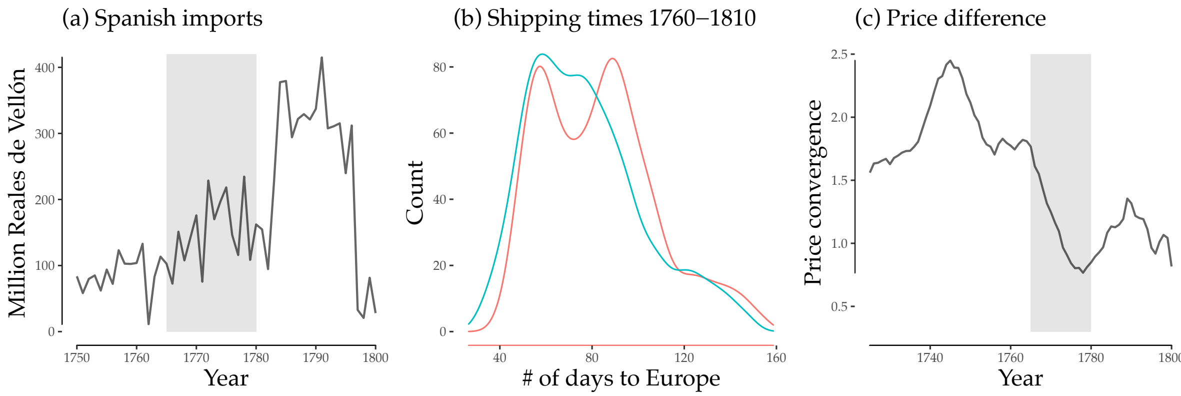

Figure 6: Panel (a) shows the value of non-bullion exports from Spain to American ports from 1750-1800. The shaded area denote the beginning and end of the main part of the liberalization. Data for 1780 is missing in the original data source (imputed with average). Data are from Cuenca-Esteban (2008). Panel (b) displays the number of days' travel from a grid-cell to Europe in 1760 (red) and 1810 (green) for the grid cells in the sample. Panel (c) shows the average price dispersion for commodities (salt, sugar, cinnamon) in Spain (Castille) and cities in Spanish America (Buenos Aires, Potosí, Lima, Bogotá, Santiago de Chile, Mexico City) calculated with a few year rolling window.

5.1 Results

Fact 1: *Lower shipping times promoted market integration.* To assess the effect of the reform on market integration, I first consider the evolution of trade volumes. The value of Spanish non-bullion imports from the Americas is shown in Figure 2a. While there is no secular increase in imports before 1765, we see a positive trend coinciding with the reform. After the largest wave of port openings in 1778, the value of trade increased nearly fourfold. The slightly delayed response is explained by the Spanish involvement in the American Revolutionary War which disrupted trade. This rapid increase in imports coinciding with the timing of the reform is consistent with improved market integration, but ultimately it remains a theoretical possibility that the growth is partly driven by increases, income, or productivity that happens to coincide with the reform.

Figure 2b presents the change in shipping time between 1760 and 1810 induced by opening ports for direct trade with Europe. The red curve denotes the shipping times in 1760, while the green curve the distribution of shipping times in 1810. As can be seen from the figure, there is an overall shift to the left in the distribution of shipping times. The shipping time is 6 days lower on average. The reduction ranges from 27 days shorter shipping to no changes for several locations. These reductions are relative to a pre-reform average of around 83 days. As a result, the reductions in shipping time and trade costs induced by the reform are economically significant. Figure 7 shows the spatial distribution of the changes in trade costs. Tables 4 shows the relationship between shipping times and the value of exports from Spain between 1797 and 1820. Across all the specifications, there is a negative relationship between the shipping time and the value of trade. As a result, the reductions in travel time induced by the reform had a positive effect on trade with Europe. To further corroborate that improved market integration was responsible for the growth in trade, I leverage information on price differentials for various commodities (salt, sugar, cinnamon) in Spain and various cities in Spanish America. Figure 2c shows the average log price differential calculated in five-year periods over the 18th century. For these commodities, there is a reduction in the price differential also coinciding with the reform. A t-test for the average price differentials being different before and after 1765 rejects the equality at conventional levels of significance. Taken together, increases in trade coinciding with a substantial reduction in trade costs, provide evidence that the reform promoted market integration.

Fact 2: *Lower shipping times induced urban growth.* Next, I explore how the change in shipping time to Europe affected urban population growth. I consider a specification of the following form,

$$\ln L_{it} - \ln L_{it'} = \gamma_t + \beta \Delta T_i + \phi x_{it} + \epsilon_{it}, \tag{4}$$

where L_{it} is the population in city i at time t , ΔT_i measures the change in the number of days of travel from the city to Europe, x_{it} controls for geography, climatic characteristics, disease environment, and historical resource availability of a given location, and ϵ_{it} is an error term potentially spatially correlated across nearby locations. To control for potentially mean reversion and differences in population growth depending on city size (Duranton and Puga, 2014), I control for the initial population in some of the specifications.[29] In the baseline specification, standard errors are clustered at the level of the closest port.[30] The coefficient β captures the effect of a one standard deviation change in ΔT_i on the population growth in city i. The key identification assumption is that *changes* population growth in locations with different *changes* in trade costs would have been the same in the absence of the reform. I challenge this assumption in several ways below. Furthermore, proxying 18th and 19th-century geographical characteristics with contemporary data sources requires further assumptions. Throughout, I assume that the variables have remained fixed or changed with the same factor across different locations. While measurement error in the outcome variable remains a possibility, classical measurement error does not lead to bias in the estimate of β. To account for non-classical measurement error that potentially varies across time and location, I include various location fixed-effects as robustness checks.

Table 5 shows the relationship between shipping times and city growth. Panel (a) presents the effect of changes in shipping time on population growth between 1750 and 1800. Across a wide range of specifications, there is a negative relationship between shipping time to Europe and population growth. Cities with larger reductions in shipping time grow faster on average. In the preferred specification in Column (3), containing both viceroyalty fixed effects in addition to the full set of controls, I find that one standard deviation larger reduction in the shipping time to Europe (6.5 days) leads to an around 9 percentage point increase in urban population growth ($\beta = 0.09$). The estimated coefficients range from 0.05 and 0.1. Panel (b) shows the estimates for the 1750 to 1850 period for which the estimates are nearly twice as large. Reassuringly, the estimates for 1700 to 1750 are significantly smaller and statistically insignificant.

[29] To proxy for the disease environment, I construct an indicator variable that takes the value 1 if the average elevation is below 1500m and control for distance to the coastline. There is no data on the disease environment at high geographical resolution available for Spanish America in the 18th century. However, as pointed out in Bruhn and Gallego (2011), Hong (2007) shows that the main predictors of deaths due to malaria in North American frontier forts in the 19th century are variables related to climate and elevation, which I do control for in a flexible manner.

[30] I also account for spatial dependence in the error term by explicitly allowing for spatial correlation (Conley, 1999). The distance kernel chosen has a cutoff of 5,000km. This correction matters little for the size of the standard errors, as can be seen in the appendix.

Table 5: Shipping time and settlements

Dependent variable:	City population growth: $\ln L_{it} - \ln L_{it'}$			
	(1)	(2)	(3)	(4)
Panel (a): Population growth 1800-1750				
Change in shipping time	0.100***	0.085**	0.091**	0.051
	(0.037)	(0.042)	(0.038)	(0.036)
N	299	299	299	299
R^2	0.038	0.049	0.052	0.231
Panel (b): Population growth 1850-1750				
Change in shipping time	0.227***	0.190***	0.189***	0.121***
	(0.044)	(0.048)	(0.051)	(0.040)
N	299	299	299	299
R^2	0.078	0.099	0.124	0.334
Panel (c): Population growth 1750-1700				
Change in shipping time	0.060	0.052	0.047	0.046
	(0.037)	(0.038)	(0.034)	(0.033)
N	246	246	246	246
R^2	0.020	0.044	0.076	0.077
Controls		✓	✓	✓
Viceroyalty FE			✓	✓
Population (1750)				✓

Note: Shipping time is standardized. The unit is a city. **Dependent variable:** Population growth. **Controls:** Elevation, crop suitability, the location of active mines, distance to the coastline. **Standard errors:** Clustered at the level of the closest port. ***p < .01, **p < .05, * p < .1

Did the changes in shipping time also induce growth on the extensive margin? To explore this I estimate Equation 4 with the number of settlements as the per grid-cell as the dependent variable. Aggregating the number of settlements by the grid-cell reduces measurement error in the recorded location and makes the variable less sensitive to the grid-cell size. Table 6 shows the relationship between shipping times and the formation of new settlements. Panel (a) presents the results estimated between 1750 and 1800. The estimates are positive and significant but smaller in magnitude than the effect on city growth. One standard deviation higher reduction in the sailing time increases the number of settlements in a grid-cell by 0.044 in the baseline specification. Again, it is reassuring that the change between 1700 and 1750 is unrelated to the change in sailing time which is consistent with the identification assumption. Taken together, the estimates are consistent with cheaper access to goods produced in other locations and better export opportunities, increasing the attractiveness of settling in a new location.

Fact 3: *Lower shipping times induced less urban growth in larger cities.* The change in trade costs induced by the reform affected cities that differed substantially in terms of population size. In smaller cities, the own market is potentially less important relative to markets in other cities and as a result, the change in external trade cost has a larger impact in smaller cities (Redding and Sturm, 2008). To explore this, I interact the initial population size with the change in trade costs using the baseline specification in Equation 4. The results are presented in in Table 6. Across all specifications, the interaction between changes in shipping time and the pre-reform city population is negative and statistically significant. While there is a positive effect of lower shipping time for the cities with the average population size, a one standard deviation increase in the population size, reduced the marginal impact of a change in the shipping time to zero. I find no effect of the interaction with growth on the extensive margin.

An alternative interpretation could be that the resource availability is more constrained in larger cities, therefore limiting how much the population size adjusts to lower trade costs. However, in Columns (2)-(3) I control for different measures of the local resource availability. Since the negative interaction remains across these specifications the findings are not consistent with this mechanism. Measurement error in the city population size is a concern when population size enters as an explanatory variable. To address this, I use a more stringent fixed effect specification in Column (4) which also controls for unobserved time-variant heterogeneity at the *audiencia* level. Also, in this specification, the estimated coefficient between changes in shipping time and the population size is negative and significant. Finally, it is reassuring that there is no effect on population growth, both for the interaction and the un-interacted terms, for the period 1700 to 1750. This is again consistent with the assumptions underlying the causal interpretation of the estimates. In sum, the result is therefore consistent initial population size being important in mediating the effect of the change in trade costs induced by the reform.

Fact 4: *There is a high degree of persistence in historical settlement patterns, but it is lower in areas exposed to the reform.* To explore the persistence of historical settlement patterns, I compare the contemporary population density across places with different historical density. I estimate the following equation,

$$\mathrm{d}_{it} = \alpha_c + \beta \mathrm{d}_{it'} + \phi x_i + \epsilon_{it}, \tag{5}$$

where d_{it} denotes contemporary population density, $\mathrm{d}_{it'}$ the population or tributary density at time t', x_i a vector of control variables, and ϵ_{it} is an error term potentially correlated across nearby locations. Standard errors are therefore clustered at the country level in the main specifications.[31] There are differences across regions in the degree of certainty of historical population density in the data from Denevan (1992). To account for this all specifications contain country fixed-effects as captured by α_c. β is the reduced form persistence elasticity or the elasticity of contemporary density with respect to historical population density. To explore the role of the reform in affecting the persistence of historical settlement patterns, I estimate Equation 5 separately for locations that were differentially exposed to the reform. I therefore make the assumption that the locations that experienced different changes in shipping time would have had similar reduced-form persistence elasticities β in the absence of the reform.

Figure 8 shows the relationship between pre-colonial population density and the current population for the different samples. Figure 8a shows the correlation for all regions in the study region. Consistent with Maloney and Valencia (2016), there is a strong persistence as measured by the positive

[31] To address concerns about spatially correlated errors, I also calculated the Conley standard errors (Conley, 1999).

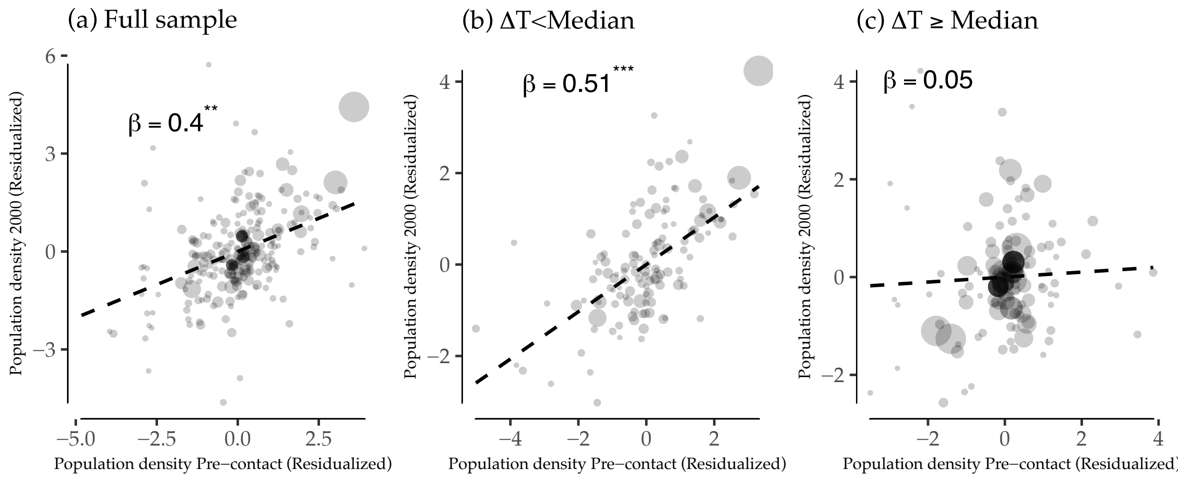

Figure 7: The figure shows the relationship between pre-contact population density and the population density in year 2000 at the level of the province. The left figure shows the relationship for the full sample. The middle figure shows the relationship for provinces with below median change in the distance to Europe between 1760 and 1810. The right figure shows the relationship for the sample above median reduction in shipping time to Europe between 1760 and 1810. Pre-colonial population density is the number of people per square kilometre pre-contact. The dependent variable is the log of people per square km in 2000. The full sample contains 337 observations. **Geographical controls:** Altitude, ruggedness, rainfall, and inverse distance to the coast (see Maloney and Valencia (2016) for details). **Standard errors** are clustered at the country-level.

relationship within-country between pre-colonial population density and population density in 2000. This is confirmed using data on tributary counts from Gerhard (1993*a*,*b*,*c*) and Cook (1982). Figure 8b shows the relationship between the two variables for the sample of provinces that experienced low changes in shipping costs after the reform. The figure shows that persistence is more pronounced for this subsample. Finally, Figure 8c shows the relationship to be weak in the subsample of provinces that experienced large changes due to the reform. Table 7 and Figure 8 shows that the pattern is robust across several specifications. Moreover, I find that these areas are substantially more concentrated in coastal areas today. Table 8 uses the same approach to compare the differences in coastal access for areas more or less intensively treated by the reform. The table shows that the distribution of the population is more spatially clustered in coastal areas for places more intensively treated by the reform. In sum, the results from Table 8 support the interpretation that the changes in trade costs induced urban growth increased the coastal population density, and attenuated the persistence of historical settlement patterns.

5.2 Assessing the Research Design

The key identification assumption in the reduced form is that urban population growth would have happened at an equal rate in areas with different reductions in shipping costs in the absence of the reform. To assess the plausibility of this assumption, I consider the dynamic version of Equation 4 where the change in shipping time is interacted with decade indicators. In particular, I estimate the following model

$$\ln L_{it} = \alpha_i + \tau_t + \sum_{s=1710}^{1810} \mathbb{1}[t = s]\Delta T_i \times \tau_s + \phi x_{it} + \epsilon_{it}, \tag{6}$$

where the variables are defined as in Equation 4. Figure 8 shows the estimated coefficients using the baseline specification for both population growth and the formation of new settlements. The plotted coefficients give the estimated difference between differentially exposed localities in year j relative to 1760, which is the last year prior to the reform. Consistent with the identification assumption, Figure 8 shows that there is no significant difference in the change of settlement in areas with high or low exposure to the reform before the reform for either outcome.[32] Table 9 summarizes several alternative specifications.

Did other policies change at the same time that could explain the timing of the effect? In the second half of the 18th century, other administrative, ecclesiastical and military reforms were conducted in Spanish America. One potential concern is the effect of a territorial reorganization that was implemented in the 18th century. The Viceroyalty of *Rio de la Plata* was separated from the Viceroyalty of Peru in the second half of the 18th century. It remains a possibility that this induced economic growth to be reoriented towards Buenos Aires in a way that was correlated with the reduction in travel times. However, when dropping cells in the Viceroyalty of *Rio de la Plata* the estimated coefficients are similar.[33] To further account for unobserved regional heterogeneity, I use viceroyalty and *audiencia* borders between 1710 and 1750 as additional controls as well as virtual country fixed effects. Even though all large ports were eventually allowed to trade directly with Europe, it cannot be ruled out that the timing of which ports opened was driven by commercial potential. To mitigate this concern, I restrict the sample to only include areas far away from ports in the estimation, which were unlikely to be targeted by the policy. Finally, Kelly (2019) shows that in studies with spatially correlated treatment variables, p-values of statistical tests can be biased downward. I therefore use standard errors accounting for spatial correlation in line with Conley (1999). Taken together, these exercises provide support for the causal interpretation of the estimates.

6 A Model of Trade and Urban Growth

In this section, I develop a general equilibrium framework of trade among cities in the presence of trade costs. The model provides a parsimonious framework that accounts for the reduced-form results and sheds light on the mechanisms.

6.1 Theoretical Framework

Geography. The model consists of R cities indexed by i. Cities differ in their productivity A_i and their availability of arable land H_i. The availability of land suitable for agriculture constrains city

[32] I conduct a formal test of the joint significance. In all specifications, the hypothesis that the pre-trend coefficients are zero cannot be rejected.

[33] Moreover, I exploit the fact that the Viceroyalty of *Nueva Granada* with the capital in Bogota separated from the Viceroyalty of Peru already in 1717. I do not find evidence that this reform affected settlement patterns in a similar as the change in trade costs.

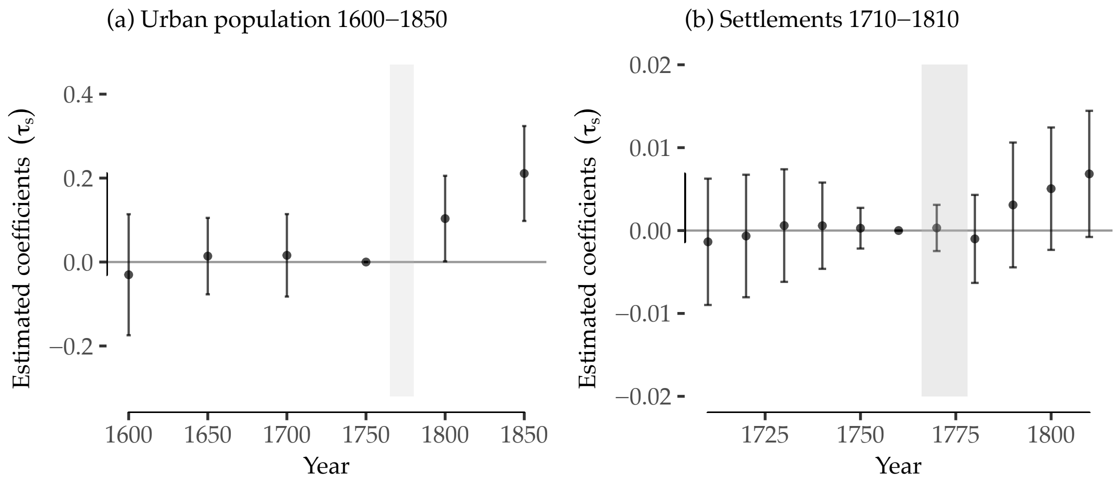

Figure 8: The figure shows the estimated coefficients of the difference in population growth the number of settlements according to the reduction in shipping times to Europe induced by the reform. **Dependent variable:** In panel (a) city population growth. In panel (b) number of settlements in grid-cell. **Observations:** Panel (a) 299 cities. In panel (b) the unit of analysis is at a 0.5°×0.5° grid-cell. The dataset is a balanced panel at a 10-year frequency for the period 1710-1810 for 5,573 grid cells. The full dataset thus contains 11 × 5,573 = 61,303 observations. **Controls:** The geographical controls contain elevation, crop suitability, the location of active mines, (log) distance to the coastline, and terrain ruggedness. **Standard errors:** Clustered at the port-level.

growth by leading to higher prices for food (which is non-traded) for a given population size (Bairoch, 1988; Duranton, 1999). Inhabitants in each city can trade with and migrate to all other cities subject to a cost. Locations therefore also differ in how well connected they are to other locations. Let τ_{ij} and m_{ij} denote the trade and migration cost respectively. Europe enters the model as a point-like country centered on Cadiz and contains the population mass of Western Europe for each decade. Moreover, I assume that the productivity of Europe is the average of the full sample.

Preferences. An individual has a Cobb-Douglas utility function defined over a composite of location-specific traded goods (Armington, 1969) and a non-traded good (food). This captures the fact that trade during the 18th century was limited to non-competing goods (Findlay and O'Rourke, 2007). The welfare derived from consumption for an individual living in location i is therefore given by,

$$V_i = \frac{w_i}{P_i^{\mu} r_i^{1-\mu}}, \tag{7}$$

where μ is the share of expenditure of the traded good, P_i is the price index, w_i is the nominal wage, and r_i is the price of land. Consistent with evidence that real wages responded to market conditions in the context of colonial Mexico and Peru Allen, Murphy and Schneider (2012); Arroyo Abad, Davies and van Zanden (2012), I assume that to a first-order approximation, labor markets were competitive. As a consequence, each household supplies labor inelastically.

Production. Production takes place under perfect competition. As a result, the price of the location-specific traded good in location i is given by $p_i = w_i \,/\, A_i$. Since there are iceberg transportation costs, the price faced by an individual in location i is given by $p_{ji} = \tau_{ij} p_i$. Agriculture was the largest sector of the economy (Arroyo Abad and Zanden, 2016), and the availability of land and high trade costs played an important role in limiting urban growth.[34] To capture this, I include an agricultural sector producing staple crops. The sector uses only land in production and has constant returns to scale and I assume that one unit of land produces one unit of food. Since the market for land is competitive and supply exogenous, the price for land is pinned down by the demand function for F_i is given by $r_i = (1-\mu)Y_i \,/\, H_i$. Finally, income from land is allocated lump-sum to all inhabitants of the location.

Trade and migration. The model gives rise to a gravity equation for bilateral trade flows between cities. Using the demand function for the traded goods gives the value of trade from location j to location i by

$$X_{ji} = q_{ji}p_{ji} = p_{ji}^{1-\sigma}\mu Y_i P_i^{\sigma-1}. \tag{8}$$

The model also features labor mobility. Legal restrictions on labor mobility and coercive labor institutions had lost importance by the end of the 18th century (Arroyo Abad and Maurer, 2019). Moreover, pre-industrial city growth was mainly driven by migration (Jedwab and Vollrath, 2015; Jedwab, Christiaensen and Gindelsky, 2017). Motivated by this I assume individuals can migrate to other cities but are subject to a migration cost. In particular, the utility of an individual moving from region i to region j is given by $V_{ij} = V_j\epsilon_j \,/\, m_{ij}$ where ϵ_j is an iid draw from a Fréchet-distribution with shape parameter θ and captures individual-level heterogeneity in location preferences. Using the properties of the Fréchet-distribution, I show that this structure gives rise to a gravity equation for migration.

Scale economies. In the core areas of Spanish America, urbanization was relatively high in the 18th century, at times exceeding that of Spain (Arroyo Abad and Zanden, 2016). To capture this, the framework allows for increasing returns to scale at the level of the city. A variety of factors drove agglomeration for pre-industrial cities (Jedwab, Johnson and Koyama, 2020). For example, they could reflect factors such as knowledge spillovers, input sharing, or physical security, location-specific capital, or knowledge about the local environment. To incorporate persistence in the model, I follow Allen and Donaldson (2020) and allow the scale economies to feature dynamic agglomeration economies. In particular, the productivity of the city depends on the size of the city today and in the past with constant elasticities, $A_{it} = \bar{A}_i L_{it}^{\alpha_1} L_{it-1}^{\alpha_2}$. $\bar{A}_i$ is a locational fundamental that is exogenous to the population size.

General equilibrium and steady-state. Finally, I define an equilibrium and steady-state of this economy, given a geography that is made up of local fundamentals ($\bar{A}_i$ and H_i), trade costs (τ_i), migration costs (μ_i), and past population distribution L_{i0}. Within each location all firms and individuals optimize and markets clear. In addition, an equilibrium is given by $E_t = \{L_{it}, w_{it}, V_{it}, \Pi_{it}\}_{i\in R}$ such that in each region total sales equals the total income ($w_{it}L_{it}/\mu = \sum_{j\in R} X_{ijt}$), trade is balanced ($w_{it}L_{it}/\mu = \sum_{j\in R} X_{jit}$), the total population equals the population arriving at a location ($L_{it} = \sum_{j\in R} L_{jit}$), and the total population in the last period equals the number of people exiting a location between $t-1$ and t and ($L_{it-1} = \sum_{j\in R} L_{ijt}$). Moreover, a steady-state is an allocation such that $L_{it} = L_{it-1}$ for all cities i, hence a state in which the migration flows between cities cancel out.

[34] Mining only employed around 0.04 percent of the population at its peak in the late 18th century (Fisher, 1997, p. 64) (75,000 out of 17 million).

Intuitively, the existence of the equilibrium and steady-state depends on the strength of the agglomeration force (the local scale economies) relative to the dispersion force (the availability of arable land for food production). Formally, using results in Allen and Donaldson (2020) and Allen, Arkolakis and Li (2020), I provide proofs of existence and uniqueness of the equilibrium and steady-state in the Appendix. These conditions are satisfied for the baseline calibration of the model.

6.2 Estimation and Identification Strategy

The ability of the model to account for the reduced-form findings depend on the structural parameters. In this section, I therefore estimate the value of the parameters. The model is fully parameterized by seven structural parameters and a tupel of fundamentals given by,

$$\Omega = \left\{\sigma, \theta, \mu, \alpha_1, \alpha_2, \bar{A}_i, H_i, \tau, m\right\}. \tag{9}$$

The empirical strategy to estimate Ω proceeds in four steps. First, I match the trade and migration costs to corresponding reduced form estimates. Next, the equilibrium conditions are inverted to recover $\{p_{it}^{\sigma-1}, P_{it}^{\sigma-1}, V_{it}^{\theta}, \Pi_{it}^{\theta}\}_{i\in R}$. Third, I estimate the structural version of the reduced form equations. Then I choose the remaining parameters to make the model match the reduced form estimates of the reform. In a final step, productivities are calculated as the residuals of the estimated model. I further elaborate on the steps of this procedure as well as the underlying assumptions for identifying the parameters below.

External parameters. The first set of parameters are matched to parameters estimated without relying on the structure of the model. First, I match μ to the share of GDP derived from land for colonial Mexico and Peru (Arroyo Abad and Zanden, 2016). To the best of my knowledge, there are no estimates for how responsive migration flows are to differences in real wages across cities. I therefore use estimates available for developing countries which typically range between 2 and 4 (Morten and Oliveira, 2018; Bryan and Morten, 2019). Next, I parameterize the bilateral trade and migration costs to depend on travel time. In particular, $\tau_{ijt} = T_{ijt}^{\kappa}$ and $m_{ij} = T_{ijt}^{\lambda}$ where κ and λ are the elasticities of trade and migration costs to travel time respectively. I match the trade elasticity in the model $(1-\sigma)\kappa$ to the estimate in Table 4 and the migration elasticity $-\lambda\theta$ to the corresponding estimate in Table 4. H_i is calculated as the share of arable land within 100km of the city using data from Özak (2010, 2018).

Model inversion. Given information on the city population sizes and urban nominal wages, the endogenous variables that would rationalize the observed population and wages can be calculated. Inverting the equilibrium conditions gives the following system of equations,

$$p_{it}^{\sigma-1} = \sum_{j\in R} \hat{T}_{ijt} \left(\frac{Y_{jt}}{Y_{it}}\right) P_{jt}^{\sigma-1} \tag{10}$$

$$P_{it}^{\sigma-1} = \sum_{j\in R} \hat{T}_{jit} \left(p_{jt}^{\sigma-1}\right)^{-1} \tag{11}$$

Table 10: Model parameters

Parameter	Description
Panel (a): Spillovers	
$\alpha_1 = 0.074^{***}$	Productivity spillover
$\alpha_2 = 0.026^{**}$	Historical productivity spillover
Panel (b): Trade and migration costs	
$\kappa(1-\sigma) = -3.13^{**}$	El. of trade wrt. time
$-\lambda\theta = -2.8^{*}$	El. of migration wrt. time
Panel (c): Preferences and technology	
$\sigma = 10.8$	El. of substitution.
$\theta = 3$	Migration el. $\theta \in [2,4]$
$1-\mu = 0.55$	Share of income from agriculture

Note: The table shows the parameters baseline calibration of the model. α_1, α_2, and σ are estimated directly from the data the 299 cities in the main sample. μ, and θ are taken from the literature. **Controls:** Elevation, crop suitability, the location of active mines, and distance to the coastline, and terrain ruggedness. **Standard errors:** Clustered at the level of the closest port. ***p $<$ .01, **p $<$ .05, * p $<$ .1

$$V_{it}^{-\theta} = \sum_{j\in R} \hat{M}_{jit} \left(\frac{L_{jt-1}}{L_{it}}\right) \Pi_j^{-\theta} = 0 \tag{12}$$

$$\Pi_i^{-\theta} = \sum_{j\in R} \hat{M}_{ijt} V_{jt}^{\theta} \tag{13}$$

where $\hat{T}_{ij} = T_{ij}^{\kappa(1-\sigma)}$ and $\hat{M}_{ij} = T_{ij}^{-\lambda\theta}$. It follows from Allen and Donaldson (2020) that given data on $\{L_{it}, L_{it-1}, w_{it}\}_{i\in R}$, the system uniquely solves for the endogenous variables $\{p_{it}^{\sigma-1}, P_{it}^{\sigma-1}, V_{it}^{\theta}, \Pi_{it}^{\theta}\}_{i\in R}$.

Estimating the scale elasticities. The historical scale elasticity can be identified using the equilibrium conditions. Combining the equilibrium conditions, then taking logs and first differences gives,

$$\Delta \ln L_{it} = -\sigma \Delta \ln \Lambda_{it} - \mu(2\sigma - 1)\Delta \ln P_{it} + \alpha_2 \mu(\sigma - 1)\Delta \ln L_{it-1}. \tag{14}$$

Taking first differences removes differences in locational fundamentals and time-invariant factors. An important assumption is therefore that changes in locational fundamentals are small throughout the reform period, and can therefore be differenced out. Under this assumption, $\alpha_2\mu(\sigma-1)$ can be recovered from estimating the equation using ordinary least squares. To explore the validity of the underlying assumption, I explore the stability of the estimated coefficient to the inclusion of the controls used in the reduced form analysis (which flexibly control for time-varying changes in the value of locational fundamentals). Finally, I leverage the market clearing condition for the traded good to identify $(1-\sigma)\alpha_1$. Next, σ is identified by simulating the model and matching the impact of the reform to the effect documented in the reduced form exercise. Finally, again using the market clearing condition for the traded commodity, $\bar{A}_i$ is recovered as the residual from that regression.

Results. Table 10 contains the parameters in the baseline calibration of the model. The contemporaneous and lagged agglomeration spillovers, α_1 and α_2 are found to be 0.074 and 0.026 respectively and estimated precisely. As a result, a one percent increase in the contemporaneous population size, increases the productivity of the location by 0.074 percent, while an increase in the historical population size increases the productivity of the location by 0.026 percent. This is similar to the agglomeration elasticities at the city level documented in the literature (Combes and Gobillon, 2015). The travel time elasticities of trade and migration are also found to be in line with estimates in the literature and are precisely estimated. A one percent increase in the travel time reduces the value of bilateral trade by around three percent and bilateral migration flows by around 2 percent. Finally, for the model to reproduce the impact of changes in trade costs documented in the reduced form, the elasticity of substitution is found to be 10.8 (this can be seen in Figure 9). The estimated value of σ is high but not uncommonly so. For example, Eaton and Kortum (2002) find values between 3 and 12. Given this calibration of the model, there exists a unique equilibrium and steady-state of the model.

6.3 Long-Distance Trade and Long-Term Persistence

In this section I state how the model can be used to explain the reduced-form findings. To this end, I use the theoretical framework can be used to derive structural versions of Equation 4 and 5. Using the indirect utility function, market clearing conditions, and assuming that trade costs are quasi-symmetric, it follows that the equilibrium population size of city i is given by,

$$\nu \ln L_i = \kappa' - \sigma \ln \Lambda_{it} \ln \mu(\sigma-1) \ln \bar{A}_i - \alpha_2 \mu(\sigma-1) \ln L_{it-1} + \mu(1-2\sigma) \ln P_{it} + \ln \sigma(1-\mu) H_i, \quad (15)$$

where $\nu = \mu + \sigma(1-\mu) + \frac{\sigma}{\theta} + \alpha_1 \mu(1-\sigma)$. Equation 15 can be interpreted as the structural version of Equation 4. It shows that the equilibrium population size of city i is larger if the factor productivity ($\bar{A}_i$) of the location is larger, the historical population size is larger (L_{it-1}), and arable land is more abundant H_i. Moreover, is shows that the local price index is a sufficient statistic for the effect of trade costs. Lower trade costs with Europe, will increase the equilibrium size of the city. Furthermore, changes in trade costs to Europe, will have a smaller marginal impact on the population size of the city the higher the past population size. Taken together, the framework therefore accounts for the reduced form findings through the mechanisms highlighted in the model.

By iterating Equation 15 backward, it is possible to derive a structural version of Equation 5. This gives,

$$\begin{aligned} L_{it} = \kappa_i' + \left(\frac{\alpha_2 \mu(\sigma-1)}{\nu}\right)^T L_{i0} - \frac{\sigma}{\nu} \sum_{k=0}^{T-1} \left(\frac{\alpha_2 \mu(\sigma-1)}{\nu}\right)^k \Lambda_{it-k} \\ - \frac{\mu(2\sigma-1)}{\nu} \sum_{k=0}^{T-1} \left(\frac{\alpha_2 \mu(\sigma-1)}{\nu}\right)^k P_{it-k}. \end{aligned} \quad (16)$$

Equation 16 can be interpreted as the structural version of Equation 5. It shows that the equilibrium population size is a function of the historical size as well as the whole path of migration and trade market access for the location. As a result, the model accounts for the degree of persistence in economic activity documented in the reduced-form exercise. Moreover, the model explains the high degree of persistence in the effect of the shock on city growth. Since the effect of changes in trade costs (as mediated by the lagged price index P_{it-k}) is smaller for larger locations, the model also accounts for the higher degree of persistence in locations experiencing lower trade costs shocks. Taken together, the model therefore accounts for all the facts documented in the reduced form exercise. Details on the derivations can be found in the Appendix.

The model can be used to make a more general point about the relationship between the persistence of historical settlement patterns and trade costs. Typically, one is interested in estimating the effect of L_{i0} on L_{it}. This is of interest since the coefficient $\alpha_2\mu(\sigma-1)\ /\ \nu$ is informative about whether the equilibrium spatial distribution of economic activity is uniquely pinned down by locational fundamentals (in which case shocks to L_{i0} will dissipate over time) or whether there are multiple equilibria (in which case shocks to L_{i0} will accumulate over time). Equation 16 shows that to recover this parameter, the whole historical path of market access needs to be controlled for. However, these variables are always unobserved. Moreover, since the time horizon is often long, there are often substantial changes in trade costs between the two periods. In the best-case scenario, changes in trade costs are orthogonal to the historical population distribution. However, since changes in trade costs have larger effects in smaller locations, this creates a correlation between the effect of changes in trade costs and the historical population size. As a result, the value of $\alpha_2\mu(\sigma-1)\ /\ \nu$ cannot be recovered and the estimated value will be biased towards zero. Taken together, since the effect of trade costs is larger for historically small locations, changes in trade costs attenuate the persistence in the location of economic activity. This also implies that in general changes in trade costs are a force pushing towards a reversal in the location of economic activity by having a larger effect on economic growth in smaller locations.

7 Conclusion

What explains variation in the persistence of historical settlement patterns across different places? I calculate the changes in travel times to Europe induced by the reorganization of long-distance trade during the second half of the 18th century. Using a difference-in-differences design that relies on comparing areas within the same region that differentially reduced its trade costs with Europe, I estimate the impact of lower trade costs on the location of settlements and population growth. I find that a statistically and economically significant positive effect on population density is associated with reduced shipping times to Europe. To explore the mechanisms, I build a spatial general equilibrium model that I take to the data. Consistent with the reduced-form evidence, the model shows that the opening of direct trade with Europe increased urban growth and more so in smaller cities. The findings show that the combination of low initial population density and significant changes in trade costs initiated a dispersal of economic activity and growth in the fringes of the Spanish Empire. Taken together, the findings show that changes in trade costs can attenuate the persistence of historical settlement patterns by having a larger effect on economic growth in smaller locations.

Both the quantitative and reduced-form evidence shows that changes in trade costs can overcome spatial persistence and have significant effects on the spatial distribution of economic activity, especially when the trade cost shock is large or the initial population density is low. More broadly, the findings point towards the conclusion that what determines the relative weight of history versus market access in the locations of population agglomerations is the sequencing with which a country achieves a high population density versus low trade costs. History will tend to explain the population distribution in places that attain high population density earlier in history, while market access will explain the population distribution in areas that had low density before opening up to trade. Thus, the findings highlight the role of history in shaping the population distribution in places that attained population densities early and show that market access is more important in places that attained high population densities after the large reductions in trade costs in the 19th century, such as the United States and Argentina. In light of the importance of access to water for European urbanization, the findings presented in this paper suggest that a poor geographic adaption to maritime trade is a cost of reaching high population density early in history.

Finally, the empirical setting provides a unique setting to study the long-term adjustment to changes in trade costs but also has important limitations. First, the estimation of causal effects relies on sizeable and abrupt changes in trade costs which may induce different adjustment processes than more gradual changes. Second, the context is largely pre-industrial. Naturally, other effects and magnitudes are possible in more industrialized contexts with an overall higher population concentration. These issues are potentially interesting avenues for future research.

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8 Tables

Table 1: Summary statistics of the city-panel

Statistic	N	Mean	St. Dev.	Min	Median	Max
Population	1,575	6,433.14	14,458.33	400.00	2,000.00	205,000.00
Shipping time 1760 (days)	1,794	59.54	18.32	35.49	54.15	138.68
Shipping time 1810 (days)	1,794	54.72	17.81	27.50	51.71	136.59
Δ Shipping time (days)	1,794	4.82	6.45	0.00	2.22	27.32
Elevation	1,794	0.24	0.43	0	0	1
Terrain ruggednes	1,794	262.43	221.50	2.04	215.08	1,033.84
Average crop suitability	1,794	0.00	1.00	−1.53	−0.11	2.77
Mining center	1,794	0.07	0.26	0	0	1
Average Temp. (Celsius)	1,794	20.97	4.89	4.52	21.92	28.49
Precipitation (mm.)	1,794	1,402.43	1,221.30	3.06	1,088.19	7,292.16
Coffee	1,794	6.76	1.22	3	6.8	8
Tobacco	1,794	6.30	1.17	2.69	6.22	8.08
Cotton	1,794	6.35	1.32	1	6.3	8
Wheat	1,794	6.83	1.49	2.51	7.67	8.18
Maize	1,794	5.73	1.34	2	5.8	8
Sugar cane	1,794	6.65	1.30	3	6.8	8
Dist. Coast (km)	1,794	175.66	189.64	2.02	100.89	988.70
Dist. River (km)	1,794	457.75	339.63	1.19	381.30	1,303.24
Dist. Port 1750 (km)	1,794	304.05	369.66	5.45	193.37	2,516.95
Decade	1,794	1,725.00	85.42	1,600	1,725	1,850

Note: The table shows the main key variables in the main dataset used in the analysis. The unit of analysis is the city. The dataset is a panel at a 50 year frequency for the period 1600-1850 for 299 cities. *Elevation* is an indicator variable equal one if the elevation is above 1500m. *Crop suitability* is the average suitability for tobacco, cotton, sugar cane, cacao, coffee (standardized).

Table 2: Summary Statistics of the grid-cell dataset

Statistic	N	Mean	St. Dev.	Min	Median	Max
#Settlements	55,154	0.21	0.84	0	0	25
Population 1760	55,154	2,098.00	5,707.89	0.00	165.76	118,175.10
Population 1810	55,154	2,469.52	6,824.08	0.00	234.46	142,383.30
Shipping time 1760 (days)	55,154	83.08	25.19	35.49	82.19	158.67
Shipping time 1810 (days)	55,154	77.06	25.04	26.46	73.58	151.90
Δ Shipping time (days)	55,154	6.02	7.68	0.00	4.35	27.32
Elevation	55,154	0.23	0.42	0	0	1
Terrain ruggednes	55,154	188.07	214.44	1.28	96.49	1,139.80
Average crop suitability	55,154	0.00	1.00	−1.86	−0.11	3.23
Mining center	55,154	0.03	0.18	0	0	1
Average Temp. (Celsius)	55,154	17.93	7.33	−2.12	19.03	28.83
Precipitation (mm.)	55,154	1,162.72	950.92	0.49	890.98	7,482.85
Coffee	55,154	7.02	1.36	2	8	9
Tobacco	55,154	6.67	1.33	2.00	6.78	8.75
Cotton	55,154	6.54	1.64	1	7.0	9
Wheat	55,154	6.64	1.61	1.02	7.31	8.75
Maize	55,154	6.16	1.66	1.00	6.13	8.75
Sugar cane	55,154	6.76	1.44	1	7.8	9
Dist. Coast (km)	55,154	412.17	317.95	0.19	336.61	1,471.73
Dist. River (km)	55,154	387.57	436.48	0.02	226.78	2,481.35
Dist. Port 1750 (km)	55,154	812.69	673.36	3.76	621.79	3,157.83
Decade	55,154	1,760.00	31.62	1,710	1,760	1,810

Note: The table shows the main key variables in the main dataset used in the analysis. The unit of analysis is at the grid-cell level. The dataset is a balanced panel at a 10 year frequency for the period 1710-1810 for 5,014 grid cells ($5,014 \times 11 = 55,154$). *Elevation* is an indicator variable equal one if the elevation is above 1500m. *Crop suitability* is the average suitability for tobacco, cotton, sugar cane, cacao, coffee (standardized).

Table 3: Ports 1700 - 1810

Port	*Country*	*Direct trade (decade)*	*Longitude*	*Latitude*
Cadiz	Spain	<1700	-6.28	36.53
Acapulco	Mexico	<1700	-99.91	16.85
Portobelo	Panama	<1700	-79.65	9.55
Panama	Panama	<1700	-79.53	8.95
El Callao	Peru	<1700	-77.15	-12.06
Cartagena de Indias	Colombia	<1700	-75.55	10.42
Veracruz	Mexico	<1700	-96.14	19.19
Batabano	Cuba	1765	-82.29	22.72
Isla de Trinidad	Trinidad and Tobago	1765	-61.51	10.65
Isla Margarita	Venezuela	1765	-63.85	10.95
La Habana	Cuba	1765	-82.35	23.14
Monte-Christi	Dominican Republic	1765	-71.64	19.85
San Juan de Puerto Rico	Puerto Rico	1765	-66.12	18.47
Santiago de Cuba	Cuba	1765	-75.82	20.022
Santo Domingo	Dominican Republic	1765	-69.94	18.48
Trinidad	Cuba	1765	-79.98	21.80
Campeche	Mexico	1770	-90.54	19.84
Arica	Chile	1778	-70.32	-18.48
Buenos Aires	Argentina	1778	-58.37	-34.61
Chagres	Panama	1778	-80.00	9.32
Concepcion	Chile	1778	-73.05	-36.83
Guayaquil	Ecuador	1778	-79.88	-2.19
Montevideo	Uruguay	1778	-56.20	-34.91
Nuevitas	Cuba	1778	-77.27	21.55
Omoa	Honduras	1778	-88.04	15.78
Riohacha	Colombia	1778	-72.91	11.55
Santa Marta	Colombia	1778	-74.21	11.24
Cumana	Venezuela	1788	-64.18	10.47
La Cruz	Venezuela	1788	-64.64	10.21
La Guaira	Venezuela	1788	-66.93	10.60
San Blas	Colombia	1789	-105.29	21.53
Maracaibo	Venezuela	1793	-71.62	10.65
Matanzas	Cuba	1793	-81.58	23.05
Villahermosa	Mexico	1793	-92.93	17.99
Acajutla	El Salvador	1796	-89.83	13.59
Isla de Carmen	Mexico	1796	-91.81	18.65
Puerto Cabello	Venezuela	1798	-68.01	10.48
El Realejo	Nicaragua	1796	-87.17	12.54
San Andres	Colombia	1798	-81.71	12.58
Santo Tomas de Castilla	Guatemala	1798	-89.00	15.64
Valparaiso	Chile	1798	-71.60	-33.05
Baracoa	Cuba	1803	-74.50	20.35
Manzanillo	Mexico	1803	-104.28	19.12
Sisal	Mexico	1807	-88.21	20.69
San Bernardo	United States	1808	-96.63	28.62
Matina	Costa Rica	1811	-83.29	10.08
Manta	Ecuador	Independence	-80.91	-0.97
Esmeraldas	Ecuador	Independence	-79.90	0.95
Trujillo	Peru	Independence	-79.00	-8.10
Huacho	Peru	Independence	-77.61	-11.11
Paita	Peru	Independence	-81.11	-5.09
Huarmey	Peru	Independence	-78.15	-10.07
Maldonado	Uruguay	Independence	-54.95	-34.90
Carupano	Venezuela	Independence	-63.25	10.67
Barcelona	Venezuela	Independence	-64.66	10.13
Barranquilla	Colombia	Independence	-74.80	10.96
Buenaventura	Colombia	Independence	-77.35	3.88
Puntarenas	Costa Rica	Independence	-84.83	9.98
Tela	Honduras	Independence	-87.46	15.76
Tuxpan	Mexico	Independence	-97.40	21.86

Table 4: The shipping time elasticity of trade 1797 - 1820

Outcome:	Value of exports (ln)			
	(1)	(2)	(3)	(4)
Panel (a): OLS Estimator				
ln Shipping time	-2.19^{*}	-3.30^{***}	-3.13^{***}	-2.87^{***}
	(1.17)	(0.97)	(1.03)	(1.11)
Panel (b): PPML Estimator				
ln Shipping time	-2.59^{*}	-3.34^{***}	-3.09^{***}	-3.22^{***}
	(1.17)	(0.86)	(0.83)	(0.86)
Observations	211	211	211	211
Year FE		✓	✓	
Region FE		✓	✓	✓
Viceroyalty FE			✓	
Region × Year FE				✓

Note: The table shows the relationship between shipping time and the value of exports from Spain. Shipping time denotes the shipping time from Spain. The value of trade is measured in *reales de vellón*. The sample contains ports with limited direct trade with Spain prior to the reform period. The data is from Fisher (1993). Robust standard errors in paranthesis. $^{***}p < .01$, $^{**}p < .05$, * $p < .1$

Table 6: Shipping time and settlements

Dependent variable:	Formation of a settlements: $S_{rt} - S_{rt-1}$			
	(1)	(2)	(3)	(4)
Panel (a): Settlement formation 1800-1750				
Change in shipping time	0.019	0.043***	0.044**	0.055***
	(0.016)	(0.014)	(0.018)	(0.016)
N	5,014	5,014	5,014	5,014
R^2	0.001	0.025	0.047	0.075
Panel (b): Settlement formation 1750-1700				
Change in shipping time	−0.016	0.012	0.005	0.024*
	(0.020)	(0.014)	(0.015)	(0.013)
N	5,014	5,014	5,014	5,014
R^2	0.001	0.045	0.078	0.152
Controls		✓	✓	✓
Viceroyalty FE			✓	✓
Population (1750)				✓

Note: Shipping time is standardized. The unit of analysis is at a $0.5° \times 0.5°$ grid-cell. **Dependent variable:** Number of settlements in a grid-cell. **Observations:** The dataset is a balanced panel at a 10 year frequency for the period 1710-1810 for 5,014 grid cells. The full dataset contains 11 × 5,014 = 55,154 observations. **Controls:** Elevation, crop suitability, the location of active mines, and distance to the coastline. **Standard errors:** Clustered at the level of the closest port. $^{***}p < .01$, $^{**}p < .05$, $^{*}p < .1$

Table 7: Spatial persistence in high and low exposure areas

Dependent variable:	Population density 2000 (log)			
	(1)	(2)	(3)	(4)
Panel (a): Full sample				
Population density 1500 (log)	0.378***	0.291***	0.498***	0.400**
	(0.102)	(0.101)	(0.140)	(0.137)
Panel (b): ΔT <Median				
Population density 1500 (log)	0.495***	0.412***	0.590***	0.495***
	(0.077)	(0.093)	(0.082)	(0.092)
Panel (c): $\Delta T \geq$Median				
Population density 1500 (log)	0.302***	0.198***	0.038	0.004
	(0.110)	(0.072)	(0.176)	(0.166)
Country FE			✓	✓
Controls		✓		✓
Observations	120	119	120	119
Adjusted R-squared	0.224	0.424	0.358	0.572

Note: Market access is standardized. The unit of analysis is at the province-level. Pre-colonial population density is the number of indigenous people per square kilometre before the arrival of Columbus from Maloney and Valencia (2016). The dependent variable is the log of people per square km in 2000. The full sample contains 258 observations. **Geographical controls:** Altitude, ruggedness, rainfall, and inverse distance to the coast (see Maloney and Valencia (2016) for details). **Standard errors** are clustered at the country-level. $^{***}p < .01$, $^{**}p < .05$, $^{*}p < .1$

Table 8: Coastal consentration in high and low exposure areas

Dependent variable:	Population density 2000 (log)			
	(1)	(2)	(3)	(4)
Panel (a): Full sample				
Distance to coast	-4.747^{***}	-3.700^{***}	-6.478^{***}	-5.801^{***}
	(1.321)	(1.333)	(2.103)	(1.736)
Panel (b): ΔT <Median				
Distance to coast	7.222^{***}	6.247^{**}	7.473^{**}	6.246^{**}
	(2.756)	(2.912)	(3.130)	(2.656)
Panel (c): ΔT ≥Median				
Distance to coast	-5.292^{***}	-3.960^{*}	-9.301^{***}	-9.702^{***}
	(1.834)	(2.046)	(1.645)	(1.530)
Country FE			✓	✓
Controls		✓		✓
Observations	124	119	124	119
Adjusted R-squared	0.267	0.352	0.525	0.565

Note: Market access is standardized. The unit of analysis is at the province-level. Pre-colonial population density is the number of indigenous people per square kilometre before the arrival of Columbus from Maloney and Valencia (2016). The dependent variable is the log of people per square km in 2000. The full sample contains 258 observations. **Geographical controls:** Altitude, ruggedness, rainfall, and inverse distance to the coast (see Maloney and Valencia (2016) for details). **Standard errors** are clustered at the country-level. $^{***}p < .01$, $^{**}p < .05$, $^{*}p < .1$

Table 9: Event-study specification

Dependent variable:	Indicator variable for grid-cell containing a settlement				
	(1)	(2)	(3)	(4)	(5)
Δ T $\times$ $\mathbb{1}$ (*year* = 1710)	−0.308	−0.308	−0.128	−0.090	−0.090
	(0.159)	(0.159)	(0.099)	(0.104)	(0.104)
Δ T $\times$ $\mathbb{1}$ (*year* = 1720)	−0.227	−0.227	−0.093	−0.060	−0.060
	(0.132)	(0.132)	(0.081)	(0.087)	(0.087)
Δ T $\times$ $\mathbb{1}$ (*year* = 1730)	−0.169	−0.169	−0.054	−0.020	−0.020
	(0.105)	(0.105)	(0.075)	(0.082)	(0.082)
Δ T $\times$ $\mathbb{1}$ (*year* = 1740)	−0.107	−0.107	−0.034	−0.011	−0.011
	(0.076)	(0.076)	(0.059)	(0.062)	(0.062)
Δ T $\times$ $\mathbb{1}$ (*year* = 1750)	−0.105	−0.105	−0.036	−0.025	−0.025
	(0.046)	(0.046)	(0.036)	(0.042)	(0.042)
Δ T $\times$ $\mathbb{1}$ (*year* = 1770)	0.082	0.082	0.034	0.034	0.034
	(0.051)	(0.051)	(0.028)	(0.033)	(0.033)
Δ T $\times$ $\mathbb{1}$ (*year* = 1780)	0.172	0.172	0.104	0.173	0.173
	(0.116)	(0.116)	(0.062)	(0.120)	(0.120)
Δ T $\times$ $\mathbb{1}$ (*year* = 1790)	0.320	0.320	0.217	0.316	0.316
	(0.128)	(0.128)	(0.101)	(0.146)	(0.146)
Δ T $\times$ $\mathbb{1}$ (*year* = 1800)	0.388	0.388	0.251	0.365	0.365
	(0.180)	(0.180)	(0.127)	(0.169)	(0.169)
Δ T $\times$ $\mathbb{1}$ (*year* = 1810)	0.502	0.502	0.320	0.454	0.454
	(0.240)	(0.240)	(0.140)	(0.193)	(0.193)
Audiencia FE		✓	✓	✓	✓
Audiencia × Decade FE			✓	✓	✓
Controls				✓	✓
Controls × Decade FE					✓
Mean dep. var.	0.21	0.21	0.21	0.21	0.21
Observations	55,154	55,154	55,154	55,154	55,154

Notes: The unit of analysis is at a 0.5°×0.5° grid-cell. **Observations:** The dataset is a balanced panel at a 10 year frequency for the period 1710-1810 for 6,662 grid cells. The full dataset contains 11 × 6,662 = 73,282 observations. The omitted year is the year prior to the treatment, therefore **N = 73,282 - 6,662 = 66,620**. **Controls:** Distance to the coast (log), elevation, presence of an active mine, terrain ruggedness, and crop suitability. **Standard errors:** Clustered at the level of the closest port. ***p < .01, **p < .05, * p < .1

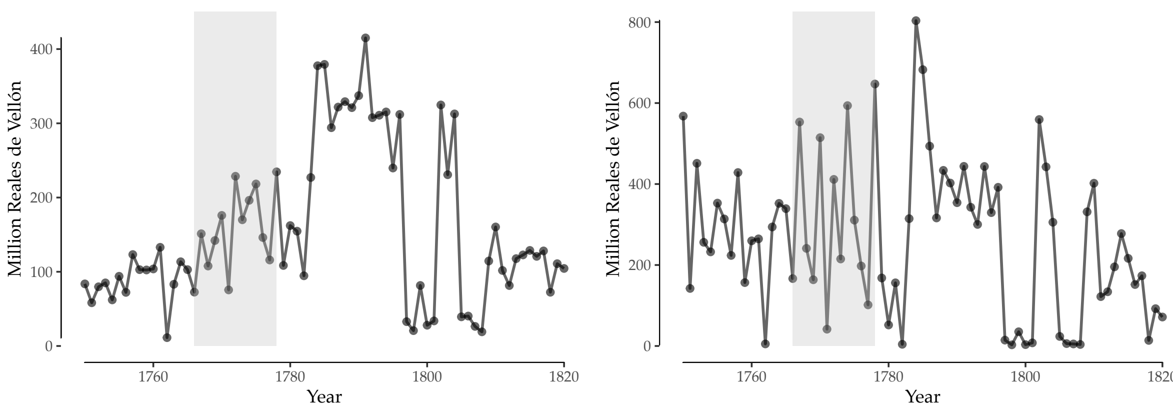

Figure 2: The left figure the value of non-bullion exports from Spain to American ports from 1750-1820. The right panel denotes bullion exports to Spain for a 1750-1820. The vertical lines denote the beginning and end of the main part of the liberalization. The large drop in 1797 is due to the British blockade of Cadiz as part of the Anglo-Spanish War 1796-1808. The lower level after 1807 was due to the Peninsular War as well as the Spanish American wars of independence. Data for 1780 is missing in the original data source. Source: Cuenca-Esteban (2008).

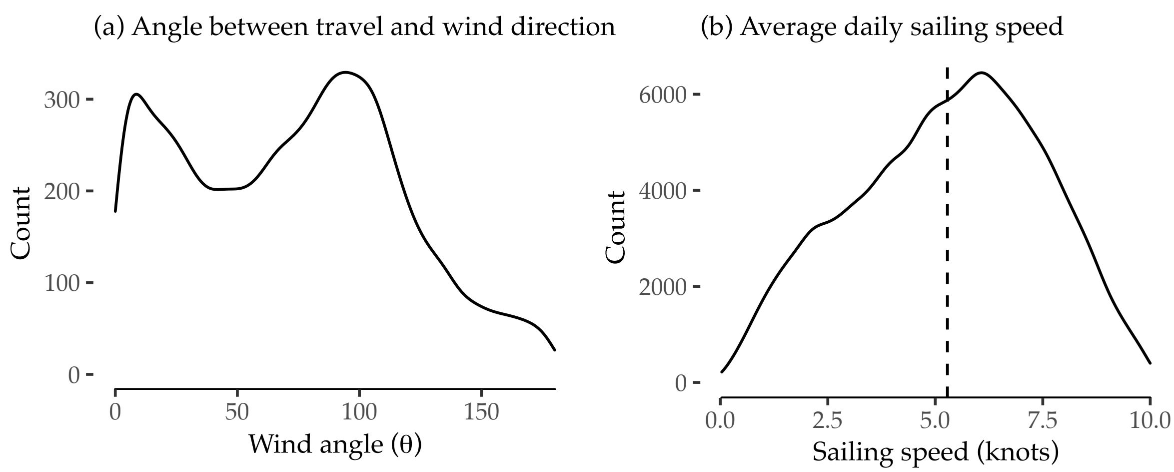

Figure 4: Panel (2) shows the deviation of the sailing direction and wind direction for the logbook entries. Panel (b) displays the average daily speed imputed from the logbook entries.

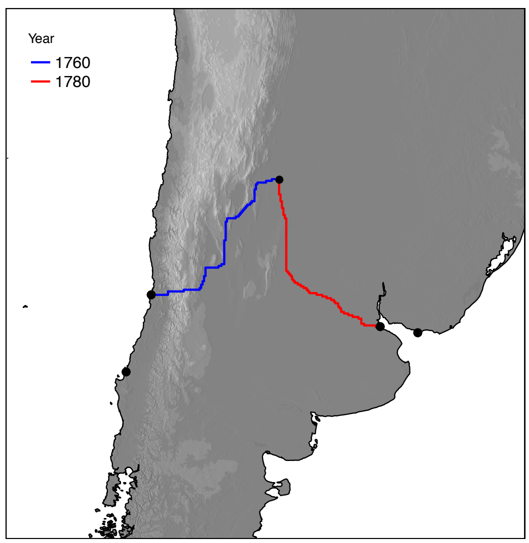

Figure 5: The figure shows the time minimizing route from a location in current day Argentina in 1760 (blue) and 1810 (red).

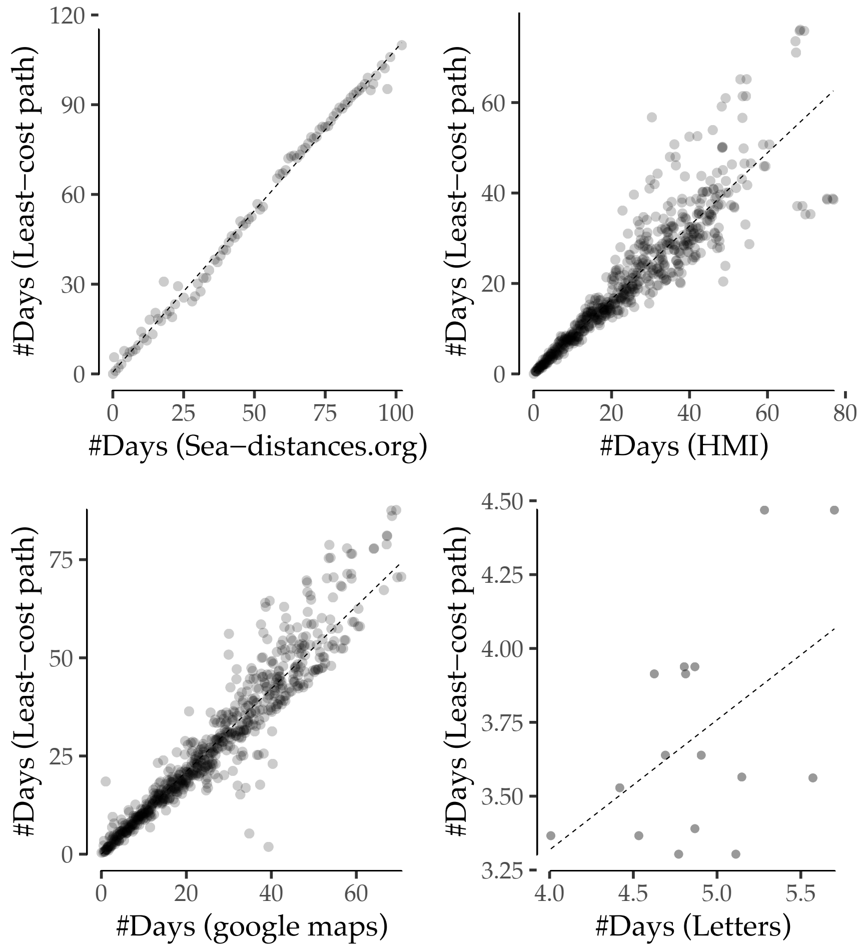

Figure 6: The figures show the results from the main validation exercises. The top-left figure shows the relationship between sailing times produced by the least-cost path on the constructed cost-surface and sailing times from sea-distances.org for voyages between Cadiz and 21 ports in Spanish America. The travel times are set to 4 knots which is the average speed attained over the cost-surface. The top-right figure shows the relationship between bilateral shipping times between large cities generated by the least-cost path on the constructed cost-surface and the Human Mobility Index developed in Özak (2010, 2018). The bottom-left figure shows the relationship between bilateral shipping times between major cities generated by the least-cost path on the constructed cost-surface and google maps.

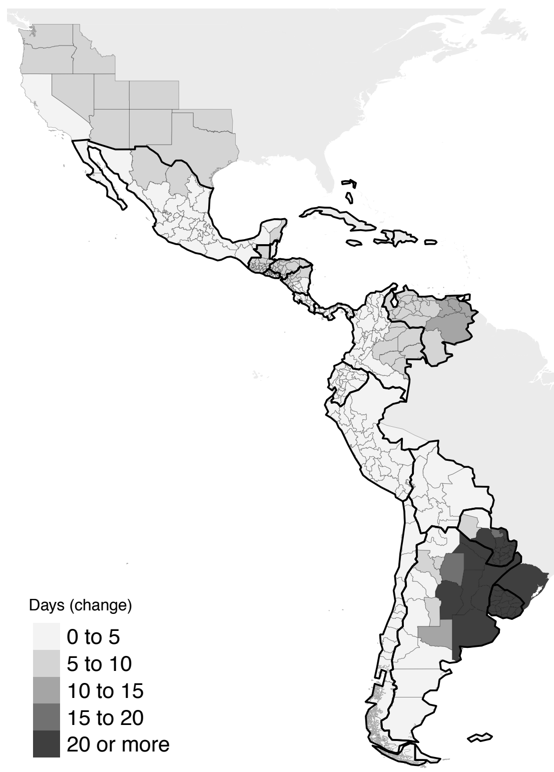

Figure 7: The figure shows the difference between shipping times in 1760 and 1810 by aggregated to the province-level. Darker colors indicate larger reductions in shipping times. Full lines denote modern country borders.

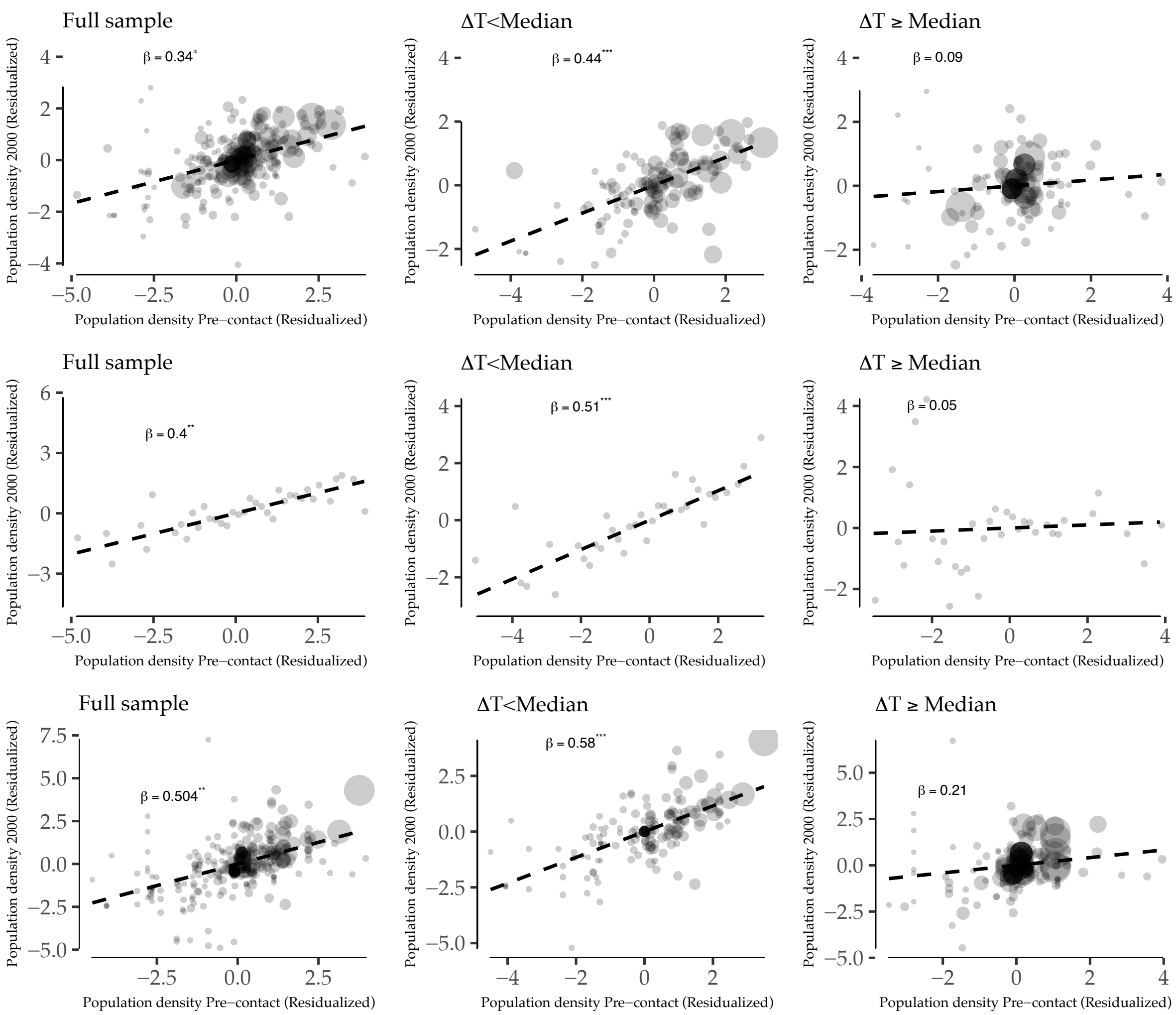

Figure 8: The figure shows the relationship between pre-contact population density and the population density in year 2000 at the level of the province. The left figure shows the relationship for the full sample. The middle figure shows the relationship for provinces with below median change in the distance to Europe between 1760 and 1810. The right figure shows the relationship for the sample above median reduction in shipping time to Europe between 1760 and 1810. Pre-colonial population density is the number of people per square kilometre pre-contact. The dependent variable is the log of people per square km in 2000. The full sample contains 337 observations. **Geographical controls:** Altitude, ruggedness, rainfall, and inverse distance to the coast (see Maloney and Valencia (2016) for details). **Standard errors** are clustered at the country-level.

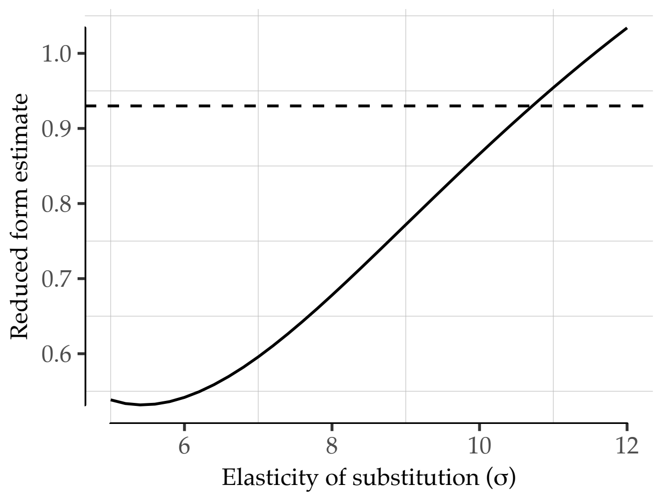

Figure 9: The figure displays the model-implied impact of the reform for different values of σ. The reduced form estimate is given by the horizontal line.

Appendix

A Model Derivation

This section shows the main steps of the derivation of the model, the equilibrium conditions, and the estimation of the parameters.

Preferences. The consumers problem is standard and I outline the main steps in this section. The utility function is defined over a traded good that is specific to every location (the Armington assumption) and a non-traded good (food). These preferences take the Cobb-Douglas form and are defined as follows,

$$U_i = \frac{C_i^{\mu} F_i^{1-\mu}}{\mu^{\mu}(1-\mu)^{1-\mu}}, \tag{A.1}$$

where $C_i = \left(\sum_{j\in N} c_{ji}^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}}$. Since Y_i is the total income in region i, p_{ji} is the price of the j-good in location i, and r_i is the price of land, the demand for land is given by $F_i = (1-\mu)Y_i \,/\, r_i$ and the demand for the traded composite good is given by $C_i = \mu Y_i \,/\, P_i$. To find the demand function for each location-specific good the I solve the following problem (where time subscripts are supressed for legibility),

$$\max_{\{c_{ji}\}_{j=1}^{R}} \left(\sum_{j\in R} c_{ji}^{\frac{\sigma-1}{\sigma}}\right)^{\frac{\sigma}{\sigma-1}} \text{ s.t. } \sum_{j\in R} c_{ji} p_{ji} \leq E_i, \tag{A.2}$$

where E_i is the aggregate expenditure in region i. As a result, by $c_{ji} = p_{ji} Y_i P_i^{\sigma-1}$ where $P_i = \left(\sum_{j\in N} p_{ji}^{1-\sigma}\right)^{\frac{1}{1-\sigma}}$ and denotes the price index for the traded good. Finally, inserting the demand functions into the utility function gives the indirect utility function for an individual in location i,

$$V_i = \frac{w_i}{P_i^{\mu} r_i^{1-\mu}}. \tag{A.3}$$

Production. Production takes place under perfect competition and as a result the price for traded and non-traded goods is equal to its marginal cost. Since a worker in i can produce A_i units of a good and the wage is w_i, the price of the good in location i is given by $p_i = w_i \,/\, A_i$. Since there are iceberg transportation costs, the price faced by an individual in location i is given by $p_{ji} = \tau_{ij} \,/\, w_j A_j$. A_j are either exogenous externalities that are not internalized by the production entities in each location or an endogenous function of the population size. The productivity of location j is given by $A_{it} = \bar{A}_i L_{it}^{\alpha_1} L_{it-1}^{\alpha_2}$. Finally, the use of land in production is constant returns to scale and a function of the availability of arable land H_i which is an exogenous feature of each location. As a result, $F_i = H_i$. The market for land is perfectly competetive. Since the market for land is competetive and supply exogenous, the price for land is pinned down by the demand function for F_i is given by $r_i = \frac{(1-\mu)Y_i}{H_i}$.

Trade. Assuming market clearing such that $c_{ji} = q_{ji}$, the value of trade from location j to location i is given by $X_{ji} = q_{ji} p_{ji} = p_{ji}^{1-\sigma} \mu Y_i P_i^{\sigma-1} = \left(\tau_{ji} \frac{w_j}{A_j}\right)^{1-\sigma} \mu Y_i P_i^{\sigma-1}$. Using the expression for the local productivity A_i and that $\mu Y_i = w_i L_i$ in equilibrium gives the expression in the derivations that follow.

Labor mobility. The utility of an individual moving from region i to region j is given by $V_{ij} = \frac{V_j}{\mu_{ij}} \epsilon_j$ where ϵ_j is an iid draw from a Fréchet-distribution with shape parameter θ and captures individual level heterogeneity in location preferences. An individual chooses to move from i to j if the realized utility of that location is higher, which happens with probability $Pr\left(V_{ij}\epsilon_j \geq V_{ik}\epsilon_k \forall k \neq j \in R\right)$. Since the shock is iid and there is a continuum of agents in each location this corresponds to the share moving, denoted π_{ij}. It follows that the conditional probability of moving is,

$$\pi_{ij}|\epsilon_j = Pr\left(\epsilon_k \leq \frac{V_{ij}\epsilon_j}{V_{ik}}\epsilon_k \forall k \neq j \in R\right) = \prod_{k\neq j} Pr\left(\epsilon_k \leq \frac{V_{ij}\epsilon_j}{V_{ik}}\right). \tag{A.4}$$

As a result, the unconditional distribution is given by,

$$\pi_{ij} = \int_0^\infty f(\epsilon_j) \prod_{k\neq j} Pr\left(\epsilon_k \leq \frac{V_{ij}\epsilon_j}{V_{ik}}\right) d\epsilon_j = \int_0^\infty \theta\epsilon_j^{-1-\theta} \exp\{-\epsilon_j^{-\theta}\} \exp\{-V_{ij}^{-\theta}\epsilon_j^{-\theta} \sum_{k\neq j} V_{ik}^{\theta}\} d\epsilon_j \tag{A.5}$$

$$= \int_0^\infty \theta\epsilon_j^{-1-\theta} \exp\{-\epsilon_j^{-\theta}\Phi_j\} d\epsilon_j = \Phi_j^{-1} = \frac{V_{ij}^{\theta}}{\sum_{k\in R} V_{ik}^{\theta}} = \frac{(V_j \,/\, \mu_{ij})^{\theta}}{\sum_{k\in R}(V_k \,/\, \mu_{ik})^{\theta}}, \tag{A.6}$$

which follows after making the substitution defining $x = \epsilon_j^{-\theta}\Phi_j$. The expected utility (prior to the realization of shocks) for an agent living in location i is given by $E[\max_{j\in R} V_{ij}]$. To derive the expression define ψ_{ij} which gives the utility expected to be derived from location j. It follows that $\psi_{ij}|\epsilon_j = V_{ij}\epsilon_j Pr\left(\epsilon_k \leq \frac{V_{ij}\epsilon_j}{V_{ik}}\epsilon_k \forall k \neq j \in R\right) = V_{ij}\epsilon_j \prod_{k\neq j} Pr\left(\epsilon_k \leq \frac{V_{ij}\epsilon_j}{V_{ik}}\epsilon_k\right)$. As a result, the unconditional expectation is given by,

$$\psi_{ij} = \int_0^\infty f(\epsilon_j) V_{ij}\epsilon_j \prod_{k\neq j} Pr\left(\epsilon_k \leq \frac{V_{ij}\epsilon_j}{V_{ik}}\right) d\epsilon_j. \tag{A.7}$$

Again using the distributional assumptions and rearranging gives

$$\psi_{ij} = \theta V_{ij} \int_0^\infty \epsilon_j^{-\theta} \exp\{-\epsilon_j^{-\theta}\Phi_j\}\epsilon_j. \tag{A.8}$$

Substituting with $x = \epsilon_j^{-\theta}\Phi_j$, it follows that $\psi_{ij} = CV_{ij}\Phi_j^{\frac{1-\theta}{\theta}}$. Then summing over ψ_{ij} gives $\Pi_i = \sum_{k\in R}\psi_{ik} = \left(\sum_{k\in R} V_{ik}^{\theta}\right)^{\frac{1}{\theta}}$. The number of people moving from i to j is the $L_{ijt} = \pi_{ij}L_{it-1} = L_{it-1}V_j^{\theta}\Pi_i^{-\theta}\mu_{ij}^{-\theta}$ which is the gravity equation for migration in the model.

Equilibrium. The equilibrium of the model is characterized by the following six equations.

1. $w_iL_i = \sum_{k\in N} X_{ik}$. The expenditure on goods produed in i equals the revenue in each location, which in turn equals the cost of labor when there are zero profits (goods market clearing).
2. $w_iL_i = \sum_{k\in N} X_{ki}$. Income from trade equals total expenditure on goods (balanced trade in each location).
3. $Y_i = \frac{w_iL_i}{\mu}$. Total income in each location equals income derived from land and labor (labor and land market clearing condition).
4. $\sum_{k\in N} L_i = \bar{L}$. The total population size of the economy is fixed.
5. $L_i = \sum_{k\in N} L_{ji}$. The total population equals the number arriving at the location.
6. $L_{it-1} = \sum_{k\in N} L_{ijt}$. The total population equals the number exiting that location.

Since trade is balanced and trade costs are quasi-symmetric, it follows that the origin and destination terms in the gravity equation are proportional (Allen and Arkolakis, 2014). Therefore $w_i^{1-\sigma}A_i^{\sigma-1} \propto w_iL_iP_i^{\sigma-1}$. Using the indirect utility, it follows that $P_i^{\sigma-1} = w_i^{\sigma-1}V_i^{\frac{1-\sigma}{\mu}}H_i^{\frac{(1-\mu)(\sigma-1)}{\mu}}L_i^{\frac{(\mu-1)(\sigma-1)}{\mu}}$. Inserting this gives the following expression for the nominal wage,

$$w_i = A_i^{\tilde{\sigma}} L_i^{\tilde{\sigma}\left(\frac{1}{1-\sigma}+\frac{1-\mu}{\mu}\right)} V_i^{\frac{\tilde{\sigma}}{\mu}} H_i^{\frac{(\mu-1)\tilde{\sigma}}{\mu}}. \tag{A.9}$$

Using the goods market clearing condition, it follows that

$$w_i L_i = \sum_{j \in R} \tau_{ij}^{1-\sigma} w_i^{1-\sigma} A_i^{\sigma-1} L_j w_j P_j^{\sigma-1} \tag{A.10}$$

$$A_i^{\tilde{\sigma}\sigma+1-\sigma} L_i^{1+\tilde{\sigma}\sigma\left(\frac{1}{1-\sigma}+\frac{1-\mu}{\mu}\right)} V_i^{\frac{\tilde{\sigma}\sigma}{\mu}} H_i^{\frac{(\mu-1)\tilde{\sigma}\sigma}{\mu}} = \sum_{j \in R} \tau_{ij}^{1-\sigma} A_j^{\tilde{\sigma}\sigma} L_j^{1+\tilde{\sigma}\sigma\left(\frac{1}{1-\sigma}+\frac{1-\mu}{\mu}\right)} V_j^{\frac{\tilde{\sigma}\sigma}{\mu}+\frac{1-\sigma}{\mu}} H_j^{\frac{\mu-1}{\mu}(\tilde{\sigma}\sigma-\sigma+1)} \tag{A.11}$$

Using the functional form of the agglomeration spillovers then results in the following equations for the equilibrium of the model,

$$L_i^{\tilde{\sigma}\left(1-\sigma\frac{\mu-1}{\mu}-\alpha_1(\sigma-1)\right)} V_i^{\frac{\tilde{\sigma}\sigma}{\mu}} = \bar{A}_i^{\tilde{\sigma}(\sigma-1)} H_i^{\frac{(1-\mu)\tilde{\sigma}\sigma}{\mu}} L_{it-1}^{\alpha_2\tilde{\sigma}(\sigma-1)} \sum_{j \in R} \tau_{ij}^{1-\sigma} \bar{A}_j^{\tilde{\sigma}\sigma} L_j^{\tilde{\sigma}\left(1+\alpha_1\sigma+\sigma\frac{1-\mu}{\mu}\right)} V_j^{\frac{\tilde{\sigma}(1-\sigma)}{\mu}} H_j^{\frac{\tilde{\sigma}(\mu-1)(1-\sigma)}{\mu}} L_{jt-1}^{\sigma\tilde{\sigma}\alpha_2} \tag{A.12}$$

$$\Pi_i^{\theta} = \sum_{j \in R} \mu_{ij}^{-\theta} V_j^{\theta} \tag{A.13}$$

$$L_i V_i^{-\theta} = \sum_{j \in R} \mu_{ij}^{-\theta} \Pi_j^{-\theta} L_{jt-1} \tag{A.14}$$

Existence and uniqueness. The set of model parameters that guarantee uniqueness and existence of the equilibrium can be derived using the results in Allen and Donaldson (2018) and Allen, Arkolakis and Li (2020). There are $3 \times R$ endogenous variables that need to be solved for. Ordering the endogenous variables as L, V, and Π gives the following matrices of coefficients,

$$\mathbf{B} = \begin{bmatrix} \tilde{\sigma}(1-\sigma\frac{\mu-1}{\mu}-\alpha_1(\sigma-1)) & \frac{\tilde{\sigma}\sigma}{\mu} & 0 \\ 0 & 0 & \theta \\ 1 & -\theta & 0 \end{bmatrix}, \tag{A.15}$$

$$\mathbf{\Gamma} = \begin{bmatrix} \tilde{\sigma}(1+\alpha_1\sigma+\sigma\frac{1-\mu}{\mu}) & \frac{\tilde{\sigma}(1-\sigma)}{\mu} & 0 \\ 0 & \theta & 0 \\ 0 & 0 & -\theta \end{bmatrix}, \tag{A.16}$$

It follows that the inverse of $\mathbf{B}$ is given by,

$$\mathbf{B}^{-1} = \frac{1}{\theta^2 b_{11} + \frac{\tilde{\sigma}\sigma\theta}{\mu}} \begin{bmatrix} \theta^2 & 0 & \frac{\tilde{\sigma}\sigma\theta}{\mu} \\ \theta & 0 & -\theta b_{11} \\ 0 & \theta b_{11} + \frac{\tilde{\sigma}\sigma}{\mu} & 0 \end{bmatrix}, \tag{A.17}$$

where $b_{11} = \tilde{\sigma}(1-\sigma\frac{\mu-1}{\mu}-\alpha_1(\sigma-1))$. As a result,

$$\mathbf{\Gamma B}^{-1} = \frac{1}{b_{11}\theta^2 + \frac{\tilde{\sigma}\sigma\theta}{\mu}} \begin{bmatrix} \theta^2\Gamma_{11} + \frac{\theta\tilde{\sigma}(1-\sigma)}{\mu} & 0 & \Gamma_{11} - \frac{\theta b_{11}(1-\sigma)}{1-\mu} \\ \theta^2 & 0 & -\theta^2 b_{11} \\ 0 & -\theta^2 b_{11} - \frac{\tilde{\sigma}\sigma\theta}{\mu} & 0 \end{bmatrix}. \tag{A.18}$$

As noted in Allen and Donaldson (2018), the spectral norm of the abosulte value of the above matrix is equivalent to the spectral norm of the smaller matrix,

$$\mathbf{A}^p = \left|\frac{1}{\theta^2 b_{11} + \frac{\tilde{\sigma}\sigma\theta}{\mu}}\right| \begin{bmatrix} \left|\theta^2\Gamma_{11} + \frac{\theta\tilde{\sigma}(1-\sigma)}{\mu}\right| & \left|\Gamma_{11} - \frac{\theta b_{11}(1-\sigma)}{1-\mu}\right| \\ \left|\theta^2\right| & \left|-\theta^2 b_{11}\right| \end{bmatrix}. \tag{A.19}$$

Next, consider the long run steady state of the model. There will still be migration in the model in the steady state, but bilateral flows will cancel out leaving the relative size of all locations fixed. The long-run steady state is characterized by $L_{it} = L_{it-1}$ for all i. Using this condition gives the following system of equations for the steady state of the model.

$$L_i^{\tilde{\sigma}\left(1-\sigma\frac{\mu-1}{\mu}-(\alpha_1+\alpha_2)(\sigma-1)\right)} V_i^{\frac{\tilde{\sigma}\sigma}{\mu}} = \bar{A}_i^{\tilde{\sigma}(\sigma-1)} H_i^{\frac{(1-\mu)\tilde{\sigma}\sigma}{\mu}} \sum_{j\in R} \tau_{ij}^{1-\sigma} \bar{A}_j^{\tilde{\sigma}\sigma} L_j^{\tilde{\sigma}(1+(\alpha_1+\alpha_2)\sigma+\sigma\frac{1-\mu}{\mu})} V_j^{\frac{\tilde{\sigma}(1-\sigma)}{\mu}} H_j^{\frac{\tilde{\sigma}(\mu-1)(1-\sigma)}{\mu}} \tag{A.20}$$

$$\Pi_i^{\theta} = \sum_{j\in R} \mu_{ij}^{-\theta} V_j^{\theta} \tag{A.21}$$

$$L_i V_i^{-\theta} = \sum_{j\in R} \mu_{ij}^{-\theta} \Pi_j^{-\theta} L_{jt} \tag{A.22}$$

As the equations pinning down the steady state are the same as for the equilibrium except for the parameters, the existence and uniqueness follows directly from the above condition where α_1 is replaced by $\alpha_1 + \alpha_2$.

Reduced form relationships. The deterministic component of indirect utility is given by $V_i = w_i P_i^{-\mu} r_i^{\mu-1}$ where again $r_i = (1-\mu) w_i L_i \,/\, H_i$ and assuming quasi-symmetric trade costs $w_i^{1-\sigma} A_i^{\sigma-1} \propto w_i L_i P_i^{\sigma-1}$. As a result, $V_i^{-\sigma} = w_i^{-\mu\sigma} P_i^{\mu\sigma} L_i^{\sigma(1-\mu)} H_i^{\sigma(1-\mu)}$ and $w_i^{-\sigma\mu} \propto A_i^{\mu(1-\sigma)} L_i^{\mu} P_i^{\mu(\sigma-1)}$. Inserting the latter expression into the former gives and using the specification for the agglomeration economies gives,

$$L_i^{\mu+\sigma(1-\mu)+\frac{\sigma}{\theta}+\alpha_1\mu(1-\sigma)} = \kappa \Lambda_{it}^{-\sigma} \bar{A}_i^{\mu(\sigma-1)} L_{it-1}^{\alpha_2\mu(\sigma-1)} P_{it}^{\mu(1-2\sigma)} H_i^{\sigma(1-\mu)}. \tag{A.23}$$

Taking the natural logarithm of this expression gives the expression in the text. Next, the expression can be used recursively to solve for the current population as a function of the full path of endogenous variables,

$$L_{it} = \kappa_i' + \left(\frac{\alpha_2\mu(\sigma-1)}{\gamma}\right)^T L_{i0} - \frac{\sigma}{\gamma}\sum_{k=0}^{T-1}\left(\frac{\alpha_2\mu(\sigma-1)}{\gamma}\right)^k \Lambda_{it-k} - \frac{\mu(2\sigma-1)}{\gamma}\sum_{k=0}^{T-1}\left(\frac{\alpha_2\mu(\sigma-1)}{\gamma}\right)^k P_{it-k}, \tag{A.24}$$

where $\gamma = \mu + \sigma(1-\mu) + \frac{\sigma}{\theta} + \alpha_1\mu(1-\sigma)$ and κ_i' is a location-specific constant. To analyze the comparative statics underlying the reduced form exercise consider the above equation. It follows that,

$$\frac{\partial L_{it}}{\partial \tau_{iek}} = -\frac{\mu(2\sigma-1)}{\gamma}\left(\frac{\alpha_2\mu(\sigma-1)}{\gamma}\right)^{t-k} P_{ik}^{\frac{\sigma}{1-\sigma}-1} \tau_{iek}^{-\sigma} w_{ek}^{1-\sigma} A_e^{1-\sigma} < 0, \tag{A.25}$$

which shows that a lower trade cost to Europe has a persistent and positive effect on the population size in location i.

B Data sources

B.1 Potential Vegetation

Global potential vegetation data is from the Center for Sustainability and the Global Environment (SAGE). The data is representative of the world's "potential" vegetation, that is vegetation that would most likely exist now in the absence of human activities. The data consists of a global map of natural vegetation at a 5 min resolution classified into 15 vegetation types. These are:

- Tropical evergreen forest/woodland
- Tropical deciduous forest/woodland
- Temperate nroadleaf evergreen forest/woodland
- Temperate needleleaf evergreen forest/woodland
- Temperate deciduous forest/woodland
- Boreal evergreen forest/woodland
- Boreal deciduous forest/woodland
- Evergreen/deciduous mixed forest/woodland
- Savanna
- Grassland/steppe
- Dense shrubland
- Open shrubland
- Tundra
- Desert
- Polar desert/rock/ice

The data is available at https://nelson.wisc.edu/sage/data-and-models/global-potential-vegetation/index.php. Details about the construction of the data can be found in Ramankutty and Foley (1999).

B.2 Agricultural Yield

I use a measure of agricultural potential constructed by Galor and Özak (2015, 2016). The data measure the maximum attainable yield measured in calories that can be achieved for a variety of crops. Agricultural productivity is the maximum potential production capacity in tons per hectare over the seventeen crops

- buckwheat
- barley
- chickpea
- foxtail millet
- groundnut
- maize
- oat
- pearl millet
- wetland rice
- rape
- rye
- sunflower

- soybean
- sweet potato
- sorghum
- wheat
- white potato

B.3 Climate and Temperature

Data on climate and temperature are from the WorldClim global climate database. The data spans (1960-1990) at 5 minute resolution. See https://www.worldclim.org/data/bioclim.html for the data source. The following variables are included in the analysis:

- Annual Mean Temperature
- Mean Diurnal Range (Mean of monthly (max temp - min temp))
- Isothermality
- Temperature Seasonality (standard deviation ×100)
- Max Temperature of Warmest Month
- Min Temperature of Coldest Month
- Temperature Annual Range
- Mean Temperature of Wettest Quarter
- Mean Temperature of Driest Quarter
- Mean Temperature of Warmest Quarter
- Mean Temperature of Coldest Quarter
- Annual Precipitation
- Precipitation of Wettest Month
- Precipitation of Driest Month
- Precipitation Seasonality (Coefficient of Variation)
- Precipitation of Wettest Quarter
- Precipitation of Driest Quarter
- Precipitation of Warmest Quarter
- Precipitation of Coldest Quarter

B.4 Ruggedness, Slope, and Elevation.

The Terrain Ruggedness Index was developed in Elliot, DeGloria and Riley (1999) and follows the the classification:

- 0-80 - level terrain surface.
- 81-116 - nearly level surface.
- 117-161 - slightly rugged surface.
- 162-239 - intermediately rugged surface.
- 240-497 - moderately rugged surface.
- 498-958 - highly rugged surface.
- >959 - extremely rugged surface.

I measure ruggedness by the average standard deviation of elevation. Plains will score low in this measure, while mountains and valleys will score high.

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