Market Integration and Urban Europe, 1100-1800 A.D.*

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December 11, 2024
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Abstract

Understanding the drivers of European development in the pre-industrial era (1100-1800) is a long-standing question in the social sciences. In this paper, we argue that falling trade frictions can provide a unified explanation for several stylized facts of European pre-industrial development: a shift of the center of economic gravity to Northern Europe, which started already in the 12th century, increasing inequality in the city-size distribution, and the falling importance of a fertile hinterland for urban success. To conceptualize this process, we develop a novel quantitative spatial economic model with two sectors of production and endogenous hinterlands. We then use the model to structurally estimate the trade friction parameters in each period. Our results show that trade frictions were overall falling over time, and most importantly, that the differential timing of the reduction between sectors is crucial to explain the stylized facts.

Keywords: Quantitative Spatial Economics, Economic Geography, Urbanization, Agglomeration, European Economic History, Little Divergence.

JEL Codes: N73, O11, O18, R11.

*We want to thank Pol Antràs, Lorenzo Caliendo, Kerem Coşar, Klaus Desmet, Dave Donaldson, James Fenske, Dávid Nagy, Daniel Sturm, Jan Luiten van Zanden, and seminar participants at Bologna, Brown, Hebrew University, and the SED meeting in Cartagena for insightful comments.

1 Introduction

Economists have long acknowledged the interplay among market integration, the spatial distribution of the population, and long-run economic development. In the context of preindustrial Europe, the importance of market integration for European development has been a recurring theme in the economic history literature over the past decades [Epstein, 2000; Findlay and O'Rourke, 2007; Malanima, 2009a]. As cities emerged in the Middle Ages as the main trading hubs of an increasingly interconnected network, market integration and urban development have been considered interrelated phenomena, paving the way to the Industrial Revolution in Northwestern Europe [Lopez, 1976; de Vries, 1984; Findlay and O'Rourke, 2007; de Zwart and van Zanden, 2018].

Despite the attention received in the academic debate, our understanding of these phenomena remains limited for two main reasons. Firstly, in the absence of historical data on trade flows, the most compelling empirical evidence on the evolution of market integration in Europe comes from historical price series [Chilosi, Murphy, Studer, and Tunçer, 2013; Federico, Schulze, and Volckart, 2021]. However, these price series frequently cover limited geographic areas, time periods, and goods. Partly for this reason, there is little agreement among economic historians on either the extent or the timing of market integration in preindustrial Europe, and sector-specific patterns remain unexplored. Secondly, data limitations have also prevented a quantitative analysis of the impact of market integration on the evolution of the European urban network before the Industrial Revolution.

In this paper, we study the relationship between market integration and the evolution of the European urban network from 1100 to 1800 A.D. through the lens of a novel quantitative model. First, we leverage systematic data on the urban population of European cities [Buringh, 2021] to establish three stylized facts in European urban development. Second, we build a quantitative economic geography model with two sectors of production, agricultural and manufacturing, and trade frictions in both sectors. Third, we combine the empirical evidence and the structure of the model to infer information on trade frictions in both sectors over seven centuries.

This approach offers several advantages. First, by relying on systematic data that is consistently available for the entire continent over an extended time frame, it provides a unified perspective on European economic history. Second, it enables us not only to shed light on the evolution of trade frictions in preindustrial Europe, but also to study its impact on the shape of the urban network. While it overcomes many of the limitations of previous research, our approach also entails a greater reliance on theoretical assumptions, and is thus to be viewed as complementary to the existing literature.

In line with the historical evidence, we find a consistent decrease in trade frictions over the study period. Importantly, this reduction occurs at different rates within the manufacturing and agricultural sectors. During the initial phase, from 1100 to 1500, the reduction is more pronounced in manufacturing trade. In a later phase, from 1500 to 1800, it becomes more pronounced in agricultural trade. This pattern of differential reduction across sectors allows the model to replicate the stylized facts of European urban development from 1000 to 1800. Besides providing new insights into the evolution of market integration in preindustrial Europe, these findings support the idea that increasing market integration may offer a unified explanation for the development of the European urban network from the Middle Ages to the onset of the Industrial Revolution.

To conduct our empirical analysis, we rely on a balanced panel of 461 European cities based on the urban population data compiled by Bairoch, Batou, and Chèvre [1988], and recently updated by Buringh [2021]. These cities represent the major urban centers in Europe, accounting for approximately two-thirds of the urban population. Population figures are available at 100-year intervals until 1500 and at 50-year intervals from 1500 to 1800.

We use this data to establish three stylized facts of the evolution of the European urban network from 1100 to 1800, concerning (i) the spatial distribution of urban population (ii) the city-size distribution, and (iii) the correlation between city size and agricultural suitability. First, the share of the urban population living in Northern Europe consistently increased throughout the entire study period. It is important to stress that this shift of population to the North started already in the Middle Ages. Second, after an initial compression, the city-size distribution became increasingly unequal, with the population share of the 10% largest cities rapidly rising after 1500. Third, the correlation between agricultural suitability and city size remained positive until 1300, and consistently declined thereafter, ultimately reaching zero by 1800. In other words, at the onset of the Industrial Revolution in Europe, fertile hinterlands were not a predictor for urban success anymore.

To evaluate the potential role of trade frictions, we quantify the model using data on the actual European geography and on urban population from 1100 to 1800 A.D. To overcome the lack of systematic data on trade flows, wages, and prices for pre-industrial Europe, we develop a novel empirical methodology that aims at pinning down the latent change in trade frictions by (structurally) estimating the latent parameters off the moments of the city size distribution, century by century.

Our quantitative analysis suggests that the process of a reduction in trade-frictions indeed has the potential to provide a simple, but powerful, unified explanation for the seemingly unrelated facts of pre-industrial urban development. Importantly, we find that a specific timing of the reductions in trade frictions in the agricultural and in the manufacturing sector is crucial to obtain this result. When trade frictions in the agricultural sector are large, so that consumption demand for agricultural goods is met with local production, the cost of expanding the rural hinterland restrain agglomeration forces in manufacturing. Under these circumstances, reducing trade costs for manufacturing goods favors cities located in the centre of the urban network. From 1100 to 1500 A.D., this mechanism helps explain the shift of economic activities from the large centers in Southern Spain and Northern Italy to medium-sized cities in the urban belt and central Europe, as well as the a resulting compression of the city size distribution. Moreover, since in this phase urban centers mostly rely on local production of agricultural goods, more fertile settlements grow more.

For the same reason, falling frictions in the agricultural sector are a force towards agglomeration, allowing cities to unleash economies of scale in the manufacturing sector, while importing agricultural goods from other cities. From 1500 to 1800 A.D., this effect explains the increasing inequality in the distribution of city size, with the emergence of few larger cities, as well as the vanishing correlation between agricultural suitability and city size.

All in all, these findings provide a novel explanation for the main facts of European pre-industrial urban development in terms of the shift to the North, the non-monotonic changes in inequality in the city distribution, and on the correlation between agricultural suitability and city growth over the period from 1100 to 1800 A.D. They also provide a sharper characterization to the historical narratives on the importance of market integration for the rise of urban Europe.

Contribution to the literature With our work we aim to bring together three main literatures. First, our paper contributes to the literature on long-term macroeconomics [Galor, 2005; Galor and Weil, 2000], and in particular to the stream of papers that acknowledge the importance of trade and/or space as a determinant of long-term development[1] [see e.g. Michalopoulos and Papaioannou, 2018, for a recent review]. While these approaches are typically in reduced form and often a-spatial, in our theory we consider the spatial dimension explicitly, and we show that it is crucial to provide a unified explanation of some key facts of long-run (urban) growth.

Thus, from a methodological point of view, our paper is more closely related to the literature on quantitative economic models [Redding and Rossi-Hansberg, 2017, provide an excellent overview]. A number of papers in this literature take a dynamic approach to study issues of growth in a spatial perspective, either with contemporaneous data [Desmet and Rossi-Hansberg, 2014; Desmet, Nagy, and Rossi-Hansberg, 2018], or with data from the XIX century [Nagy, 2020; Allen and Donaldson, 2018; Eckert and Peters, 2018]. Our paper is the first to apply a quantitative spatial model to the context of pre-Industrial Europe, in a time period spanning over seven centuries. Thus, one of our contribution is to show that this class of models can be fruitfully put to use to tackle questions of long-run growth in pre-Industrial economies. Our analysis is most closely related to Nagy [2020], who develops a dynamic model of city formation to study the U.S. urbanization in the XIXth century. In his model, agricultural goods are produced in rural locations and shipped to one manufacturing location. In contrast, manufacturing goods can also be traded across manufacturing locations. We extend Nagy's model to allow for trade in agricultural goods *across* cities[2], although, importantly, we take the city network as fixed. Our paper is also related to Fajgelbaum and Redding [2018] [3], who investigate the link between falling trade frictions and structural change in Argentina from 1869 to 1914. In this paper, Argentina is an open-economy, where manufacturing prices are determined on world markets. In contrast, in our model Europe is a closed-economy, such that all prices are determined in general equilibrium.

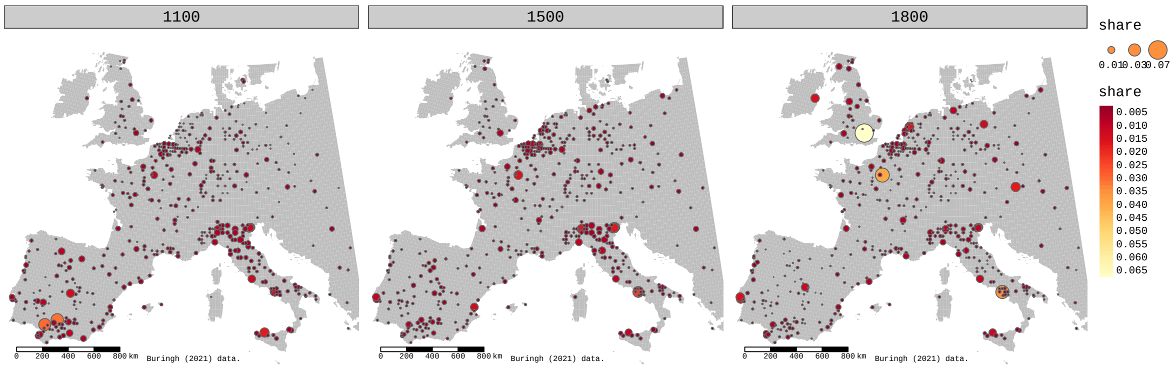
Finally, our paper is related to several studies on European economic history that have analyzed urbanization [de Vries, 1984] and trade [Findlay and O'Rourke, 2007] from an historical perspective. Historians, as well as economists, have also devoted much effort to explaining the little divergence, i.e. the shift of the centre of economic activity towards the North of Europe prior to the Industrial Revolution. While many arguments have been put forward, ranging from institutional [e.g. North and Weingast, 1989; De Long and Shleifer, 1993], demographic [van Zanden, 2009; Fochesato, 2018; Jedwab, Johnson, and Koyama, 2019], and cultural [Jacob, 1997; Mokyr, 2002] factors to the importance of the Atlantic trade [e.g. Barbour, 1963; Davis, 1973; Allen, 2003; Acemoglu, Johnson, and Robinson, 2005], these studies typically rely on historical narratives or reduced-form regressions.

[1] Main contributions that show the importance of trade for long-run development are, inter alia, Galor and Mountford [2006, 2008]; Michalopoulos, Naghavi, and Prarolo [2018]. The importance of space in the context of comparative development has been empirically illustrated, inter alia, by Ashraf and Michalopoulos [2015]; Andersen, Dalgaard, and Selaya [2016a]; Galor and Özak [2016]; Mayshar, Moav, and Neeman [2017]

[2] In their Appendix 5, Allen and Arkolakis [2014] add a second traded sector to their baseline one-sector model, and characterize the properties of the equilibrium under the assumption of no spillovers in productivity or amenities.

[3] See also [Coşar and Fajgelbaum, 2016].

Figure 1: Illustration of baseline sample of cities of Europe, 1300 AD



Notes: The Figure depicts the location and size of the c. 500 cities included in the balanced sample that account for the biggest cities by year 1600 and for which data available from 1100.

2 Historical Evidence and the Facts of Urban Development

In this Section, we document three stylized facts of pre-industrial European (urban) development. We discuss their temporal patterns and the evidence with reference to the historical literature. Several aspects of these facts are novel. First, the so-called "Little Divergence" – the relocation of economic activity to the North of the continent – is usually thought to have started around the time of the discovery of the Americas and the onset of the Atlantic trade. Figure 2 suggests that this was a continuous process that started already at least in the 12th century. Second, the growth of an excessive right tail in the city-size distribution only starts from around 1600. Entirely novel but somewhat intuitive is the third fact depctied in Figure 6, showing that having a fertile hinterland became less important for urban success over time. By 1800, the correlation between city size and agricultural suitability has entirely vanished.

2.1 Data

Our analysis is based on the most recent information on the evolution of urban population in pre-industrial Europe. Early measurement of urban population by [de Vries, 1984] were restricted to big cities, with a population above 10.000 inhabitants, and focused on the post 1500 time period only. The database by [Bairoch et al., 1988] extended the analysis to smaller cities and, subsequently expanded and corrected by [Bosker, Buringh, and van Zanden, 2013] and others, has been hitherto exploited as baseline measure of local development in empirical investigations of pre-industrial growth. We build on the historical database by Buringh [2021] that, largely relying on the earlier estimates, provides an updated and improved measurement of the population in European cities[4]. As baseline we pick a sample of all cities that were above 5.000 inhabitants as of year 1600 according to Buringh [2021]. The resulting dataset comprises the 471 largest cities that, on average, account for over two thirds of the total

[4]One of the innovations of this dataset is that it is much more complete and has by far less missing observations as for example the highly unbalanced data by Bairoch et al. [1988], meaning that for most of the c. 2.000 cities we observe a complete time series. Also many estimates were corrected/updated based on historical documents. Furthermore, the years 1550 and 1650 were added.

urban population in Europe in any period [5]. This balanced sample is used also later for the quantitative-spatial analysis and the structural estimations [6]. The broad patterns and stylized facts described in this section are confirmed also with alternative samples and data sources and consistently emerge also when including information on the smaller cities (with the relevant caveat that data for smaller cities are more scattered and subject to interpolations and that these cities enter the unbalanced sample mostly in the last centuries, see Appendix). As an illustration, Figure 1 shows a map of urban population in year 1300 for the cities included in the baseline balanced sample.

2.2 Spatial distribution of Economic Activity: A shift to the North from 1100.

A first main fact refers to the process of relocation of economic activity, measured by urban population, across the continent. It has been described by a large body of historical narratives, although mostly informally and for scattered areas. Historians describe a revival of economic activity over the period 900 to 1300 as pan-European phenomenon, characterized by significant increases in population, urbanization levels and even real income across the sub-continent [see e.g. van Zanden, 2009]. Narratives describe a comparative decline of the Mediterranean basin as compared to the rise of the Atlantic and Northern areas of the continent. There is also a literature that tries to pinpoint when exactly the Norht overtook the South [see e.g. Malanima, 2013]. A shift of development towards the North is clearly apparent in the centuries prior to the industrial revolution and early accounts pointed to the seventeenth century as onset of this relocation process, sometimes labeled "little divergence", that has also been interpreted as a precondition for the industrial revolution. This process has been largely described as a byproduct of the rise of the Atlantic trade that starts after the discovery of America but gains momentum in the seventeenth century (e.g. [Davis, 1973; Acemoglu et al., 2005]). It is also discussed in the context of the emergence of modern countries and the military revolution in the seventeenth century (particularly e.g. the 1648 with the Peace of Westfalia),and in association to growth enhancing institutional improvements (see e.g. [North and Weingast, 1989; De Long and Shleifer, 1993]).

Several observers have nonetheless noticed that there are reasons to locate the shift of the bulk of European economic activities outside the Mediterranean basin earlier in time, prior to the discovery of the Americas, e.g. [Pamuk, 2007; Fochesato, 2018]). In support of this perspective, following e.g. Allen [2001], recent evidence on real wages and income per capita for selected areas, document that the Center-North and North-West of Europe in fact witnessed an almost continuous growth from the Black Death until 1800 while others, particularly in the South, grew less or even stagnated [see Fouquet and Broadberry, 2015, for a summary] [or Humphries and Weisdorf, 2019; Rota and Weisdorf, 2020, for more recent

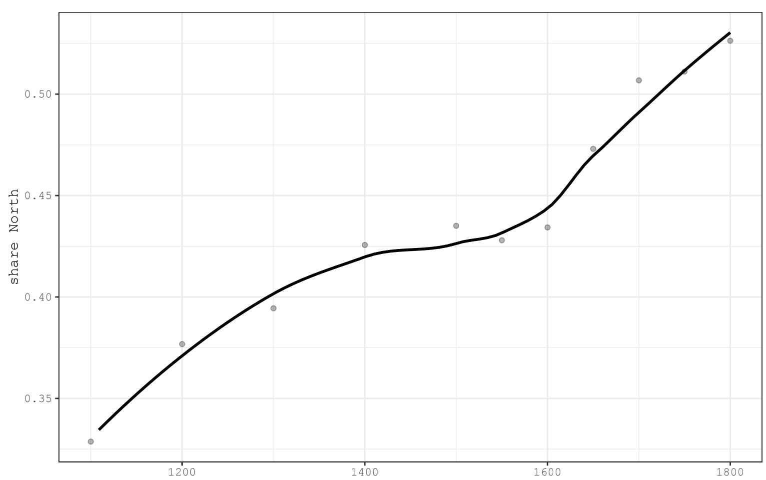
[5]This procedure seems reasonable and ensures that all major cities from the beginning to the end of our study period are selected. The process of city foundation in Europe was practically complete in the late middle ages after the colonization of the East [Bartlett, 1993]. The urban network as we know it today was set roughly in the twelfth century [Stoob, 1979] and we thus do not run into problems of cities appearing only in later centuries (as the Bairoch data often erroneously suggest).

[6]For a few city-year pairs we have missing observations. For these we apply linear interpolation to make the data balanced, which is a necessary condition to be used in the structural estimation of our model. We also take into account the "Malanima critique" and remove the agro-towns in Sicily from the sample Malanima [1998]. They were essentially not urban but only hosted a large number of farmers. This does not change any of our results, however.

evidence]. Pushing this perspective further back in time, a body of historical narratives has described the revival of urban trading centers associated to the so-called medieval commercial revolution as early as the eleventh and twelfth century [see e.g. Lopez, 1976; Abu-Lughod, 1989; Epstein, 2009]. These narratives describe the increasing population even prior to the Black Death in many small to medium size urban settlements in the urban belt, stretching from Northern Italy to Switzerland, Germany, Holland, and the South of England.

The process of spatial relocation of urban population and the timing of the onset of the shift towards Central and Northern Europe was, however, so far not systematically documented. The recent data on urban population discussed above allows us to track this at the intensive margin in a large scale balanced sample that accounts for a substantial share of total urban population. Figure 2 plots the share of urban population residing in cities in the North of the subcontinent. The data display a clear pattern of relocation of economic activity in terms of urban population that can be clearly detected as early as 1100 and that is roughly monotonic until 1800. The data show, more specifically, an acceleration in the relocation to the North after 1600 after a period of roughly stable share of population from 1400 to 1600 AD that, as discussed above, initially suggested the onset of a relocation after 1500. The data also display, however, an equally sharp shift to the North already from 1200 to 1400 that appears to temporary loose momentum around the turn of the millennium (this temporary slow down is even more visible in other databases and sample as depicted in the Appendix).

Figure 2: Share of urban population in Northern Europe, 1100-1800 AD

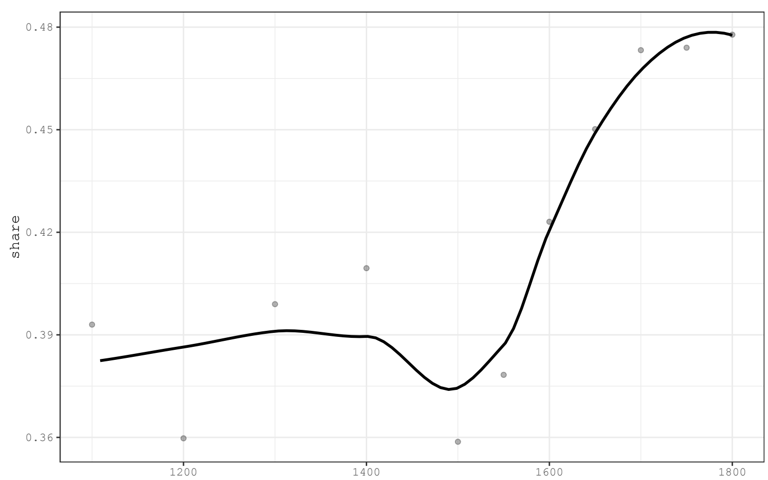


Notes: Share of Urban population in the North of Europe. As baseline, and without loss of generality, locations are classified in the South and in the North depending on whether they are above and below 47 degrees latitude that is, roughly speaking, above and below the Alps (see also Figure XX in the Appendix). The main pattern is confirmed for different data sources and samples (see Appendix).

2.3 Changing concentration of Economic Activity: The Distribution of City Size

The increase in urban population across the centuries and the associated spatial relocation depicted in Figure 2, was also associated to substantial changes in the city size distribution. Historians have described at length two patterns that, as discussed below, are also clearly visible in the most recent data. A first well studied phenomenon to the disproportionate growth in population of a subset of large cities from the seventeenth century onwards. In many cases this process is related to the process of state formation and the increasing role of capital cities, e.g. the sharp rise of e.g. Madrid and the associated decline of the former capital Toledo, and that has also been documented in empirical analysis [see e.g. Cervellati, Lazzaroni, Prarolo, and Vanin, 2019]. In most cases, however, the phenomenon is clearly related to the growth of cities that got increasingly engaged in trade and manufacturing production. The rise of urban, trading and manufacturing, "giants" after 1600 led to a sharp increase in the concentration of the population. This stretch in the city distribution has been already well documented, mostly relying on/comparing rank-size distributions (exploiting the Bairoch data and subsequent updates) [see e.g. Malanima, 2010; Dittmar, 2020]. In line with this, Figure 3 depicts the share of urban population in the biggest cities (those in the top 10 percent of the distribution in each century).

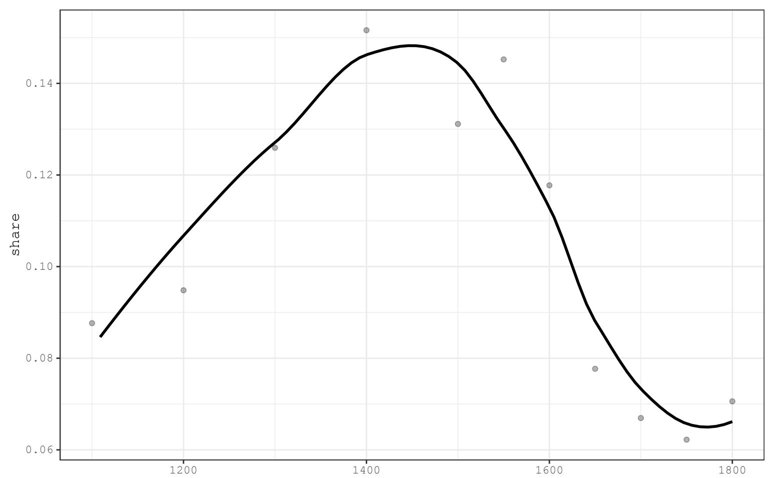
Figure 3: Share of Urban Population in Bigger Cities, 1100-1800 A.D.



Notes: Share of Urban population in the top 10 percent of the city distribution. The Figure depicts the roughly stable share of urban population located in the 47 biggest cities of our balanced sample (where the top 10 biggest cities roughly host around 35 percent of urban population until 1600) followed by a sharp increase from 1600 (with the top 10 percent biggest cities hosting almost 50 percent of the urban population by 1800).

A second phenomenon that has been extensively discussed by historians is the increasing importance of the network of small to medium scale cities in the context of the medieval commercial revolution that gain momentum around 1200 and peaked in terms of importance around 1400 and 1500 that represent the heyday of the importance of small and medium trading cities in continental Europe [see e.g. Epstein, 2001]. The recent data discussed above improve, in particular, in terms of reliable historical data for medium size cities that has so far limited the ability to evaluate their role and importance in the overall rank size distribution. In line with narratives on the increasing role of small to medium size cities in the first half of the millennium, Figure 4 depicts the sharp increase in the share of urban population hosted in the cities at the bottom of the distribution in our sample from 1100 to 1500 followed by an equally sharp reversal. To interpret the data correctly notice that while these are the smallest cities in our baseline sample, they belong to a sub-sample of the 471 biggest cities (out of more than 2.000 urban centers hosting more than 5.000 inhabitants by the year 1800). These are, in fact, cities with intermediate size, that hosted urban centers and markets from year 1100 onwards.

Figure 4: Share of Urban Population in Smaller Cities, 1100-1800 A.D.



Notes: Share of Urban population in the bottom 25 percent of the city distribution in the baseline sample in each period. These are the smaller cities in the baseline sample and the intermediate size cities in the full sample. The Figure depicts the hump-shape evolution of the share of urban population located in small cities. The data display a sharp increase from 1200 until 1500 with a sharp reversal and reduction particularly from 1600.

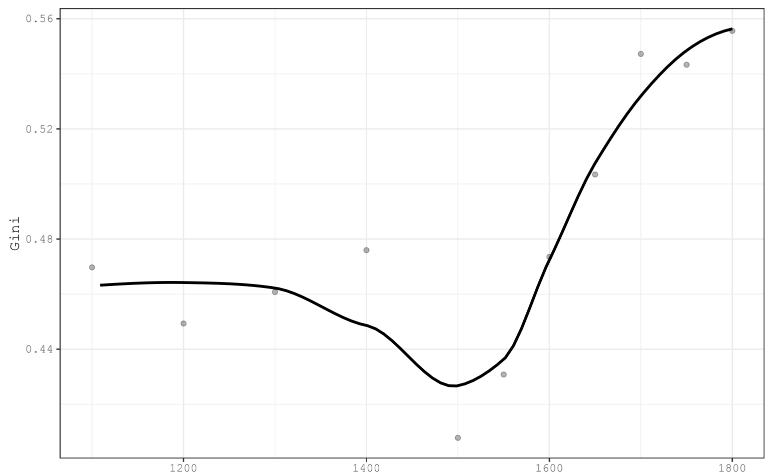
Taken together the patterns depicted in Figures 3 and 4 suggest a non-monotonic process of relocation of economic activity characterized by an initial spread of urban population across many locations with small and intermediate size and a roughly stable share of population in the biggest cities until around 1600. This process sharply reverses after 1600 with the population being increasingly located in few bigger cities. Figure 5 summarizes and complements this discussion by depicting the evolution of a measure of inequality in the distribution of urban population across locations in terms of the Gini Index.

2.4 The Role of Agricultural Suitability for City Size

The size of urban settlements depends on local geographic features and amenities and, in particular, on agricultural suitability particularly in comparatively autarkic environments. Urban historians argue, in particular, that in the absence of substantive trade flows of agricultural and subsistence foodstuff, the size of a city should be essentially determined by the agricultural suitability of its immediate hinterlands [see e.g. Davis, 1955; Bairoch, 1988; Malanima, 2009b]. For the middle ages the relevant agricultural hinterland should be around 30-50km, because transportation of agricultural goods becomes prohibitively costly over larger distances due to the fact that transport animals have to be fed from the goods they are transporting [see e.g. Clark and Haswell, 1964]. Lack of systematic data on trade frictions, costs and actual flows of goods prevent, however, a direct test of the role of local trade in shaping the relationship between local agricultural suitability and city size.

Figure 6 depicts the evolution of the cross-sectional correlation between urban population

Figure 5: Inquality in the Distrbution of Population: Gini Index, 1100-1800 A.D.

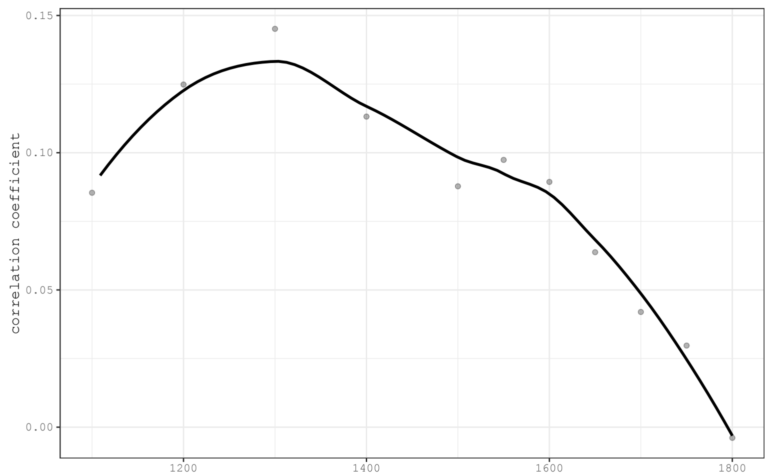


Notes: The Figure depicts the evolution of inequality in terms of Gini Index that "it is more sensitive to changes in the middle of income distribution and less sensitive to changes at the top and the bottom of income distribution" [Atkinson, 1970]. The data display a slight reduction in inequality, associated to a spread of economic activity across locations, with a minimum around 1500 followed by a sharp increase from 1600.

and local (i.e. same cell) agricultural suitability.[7] Interestingly, the correlation nearly doubles from 1100 to 1300. This means that, in this time period, cities that experienced the largest population increases were located in cells with comparatively high agricultural suitability. Notice that this period coincides with the so called medieval commercial revolution that mostly involved trade of valuable manufacturing goods, and, from the patterns discussed above, a dispersion of population also in smaller and intermediate size cities and a shift of economic activity towards the north. From 1300 onwards the correlation stabilizes and display a sharp decline from 1600 reaching zero in 1800 (and even turning negative in the unreported period 1850 when the largest cities are actually those located in cells with a relatively lower suitability index). The data documents that, particularly from 1500, urban growth increasingly took place in locations that were relatively less suitable for agriculture. The evidence of a reduction in the saliency of first nature geography and local agricultural suitability aligns with the results of Henderson, Squires, Storeygard, and Weil [2018], obtained by looking at satellite light data at night on a global level for the post WWII time period.

[7] In the model, the relevant variable will be agricultural suitability in the whole rural hinterland; however, due to spatial correlation in suitability, whether we compute it at the cell-level or averaging over buffers around cities has little impact on the patterns depicted in Figure 6.

Figure 6: Correlation between Agricultural Suitability and City Size, 1100-1800 A.D.



Notes: The Figure depicts the evolution of the cross-sectional correlation between local agricultural suitability and urban population. We estimate the correlation of urban population in every 0.25 degree cell with its land suitability (which is the predicted value of the propensity of a given parcel of land to be under cultivation based on four measures of climate and soil according to Ramankutty, Foley, Norman, and McSweeney [2002]. The data display an initial increase suggesting from 1100 to 1300 suggesting that a relative relocation of the population to cities characterized by a higher agricultural suitability. The patterns reverses from 1400 with a sharp reduction of the correlation from 1600. By 1800 there is not significant correlation between agricultural suitability and the size of cities.

3 Model

This section presents a theoretical model of trade and development for pre-industrial Europe. Our point of departure is the quantitative economic geography model of Allen and Arkolakis [2014]. As in this work and the ensuing literature, our model includes a realistic geography, with an arbitrary number of locations that may differ in terms of productivity and other characteristics, and that are positioned in space according to a distance matrix that also depends on the underlying geography [Redding and Rossi-Hansberg, 2017]. Secondly, as in the branch of this literature that focuses on growth processes due to dynamic agglomeration spillovers, our model includes a process of technological change that is linked to the size of the local population [Nagy, 2020; Allen and Donaldson, 2018; Eckert and Peters, 2018]. Third, as in Eckert and Peters [2018], Peters [2021], Nagy [2015], Nagy [2020], our model includes two sectors of production: manufacturing and agriculture. With respect to these studies, it is important to note that we allow the size of trade frictions to differ between the two sectors. Finally, as in Nagy [2015], Nagy [2020] we introduce a distinction between urban and rural locations related, first, to the production sector operating in that location: the manufacturing sector operates in cities, whereas the agricultural sector operates in the countryside; second, to the role of cities as trading hubs: agricultural products need to be shipped to an urban market to be traded with other cities. Beside the nature of the location and the size of trade frictions, another crucial difference between agricultural and manufacturing lies in the sign of the economies of scale: while agricultural labor is subject to decreasing returns (a congestion externality), manufacturing labor is subject to external economies of scale (an agglomeration externality). Population is freely mobile across locations and sectors, and its equilibrium distribution will be a function of the underlying geography (i.e., the exogenous characteristics of each location), of the balance between agglomeration and congestion spillovers, as well as of the size of trade frictions.

3.1 Geography and endowments

The geography consists of a finite set of rural locations $\mathcal{X}$, and a subset $\mathcal{Y} \in \mathcal{X}$ of urban locations, which also host a city. The urban network, i.e. the number and the location of the cities in $\mathcal{Y}$, is taken as given. These two types of locations correspond to two different sectors. Cities produce a manufacturing (or urban) good, whereas rural locations produce an agricultural (or rural) good. As in Nagy [2020], cities are trading places, i.e. goods can only be exchanged in cities, and farmers commute to one urban market to sell agricultural goods and purchase manufacturing goods [this is consistent with historical evidence on pre-industrial Europe, see e.g. van der Woude, Hayami, and de Vries, 1990; Hohenberg and Lees, 1995; Jones, 1975, and many others].

Locations in the model are heterogeneous. Rural locations in $\mathcal{X}$ may differ in terms of *i.* their agricultural productivity ; *ii.* the amount of land available for agricultural production; *iii.* their geographic position, as described by a matrix of bilateral travel distances. All these fundamentals are taken to be time-invariant.[8] Furthermore, urban locations in $\mathcal{Y}$ may also differ in terms of manufacturing productivity, which in turn is allowed to evolve over time.

Agents are *ex ante* identical. All of them are endowed with one unit of labor that is supplied inelastically to the market. In equilibrium, they are employed in the urban sector (workers) or in the rural sector (farmers). Farmers own an equal share of land at their rural location. Thus, urban income equals the urban wage rate, whereas rural income equals farm revenues per capita. Labor is freely mobile across sectors and across locations.[9] The total urban population in the economy is an exogenous constant $\bar{L}^M$.

3.2 Production

The agricultural good is produced in rural locations using labor l^A and land h under conditions of constant returns to scale. Its production technology in $x_r \in \mathcal{X}$ is given by:

$$y^A_{r,t} = \phi^A_r (l^A_{r,t})^\beta (h_r)^{1-\beta}, \quad 0 < \beta < 1 \tag{1}$$

where ϕ^A_r is agricultural productivity [10], l^A_r is the rural population, and h_r is land area. Because land is available in fixed supply, the production of agricultural goods is subject to

[8] In the empirical application, grid cells will differ in land area because because in coastal areas parts of the cell are covered by water.

[9] While migration frictions were certainly important in pre-Industrial Europe, mobility has been much higher than previously thought - maybe even similar to the degree of mobility observed in 20th century contexts [see e.g. Moch, 2003; Lucassen and Lucassen, 2009]. This is also substantiated by the literature on the importance of mobile artisans and craftsmen between cities and polities [Jones, 2003; Mokyr, 2016; de la Croix, Docquier, Fabre, and Stelter, 2020; Serafinelli and Tabellini, 2022]. Throught history, there are many snapshots providing anecdotal evidence for very high degrees of mobility. For example, around the year 1600 roughly a third of the population of Amsterdam were foreigners [Israel, 1995] Especially migration from rural areas into cities was always a characteristic element of pre-industrial society [e.g. de Vries, 1984; Schäfer, 2013, and many others]. Lastly it has to be noted that the period length for our model is one century in the beginning and later on 50 years. Even with very low yearly migration rates it would theoretically be possible to move around a large number of people within such a broad time horizon.

[10] There is, of course, a literature that studies the general importance of increases in agricultural productivity for sustained economic growth [see e.g. Jones, 1968; Schultz, 1968; Overton, 1996; Desmet and Parente, 2012, and many others]. Increases in agricultural productivity were sharp in the Middle Ages - slightly before the

decreasing marginal returns to labor, which acts as a congestion force in the economy.

In contrast, manufacturing production is subject to external economies of scale [Duranton and Puga, 2004; Rosenthal and Strange, 2004; Allen and Arkolakis, 2014]. Its production technology in city $y_i \in \mathcal{Y}$ is given by:

$$Y_i^M = \phi_i^M L_i^M, \tag{2}$$

where L_i^M denotes the amount of labor employed in the manufacturing sector and ϕ_i^M denotes city y_i's manufacturing productivity, which in turn is the product of an exogenous component, $\tilde{\phi}_i^M$, and an endogenous components that depends on the size of the urban labor force:

$$\phi_i^M = \tilde{\phi}_{i,t}^M (L_i^M)^{\gamma_1} \tag{3}$$

Here $\tilde{\phi}_i^M$ captures the exogenous characteristics of a location related to its suitability for manufacturing production, while γ_1 parametrizes the strength of agglomeration spillovers in the economy. Because firms are competitive and take ϕ_i^M as given, the city-gate price of the manufacturing good equals its marginal production cost:

$$p_i^M = \frac{w_i}{\phi_i^M}. \tag{4}$$

3.3 Trade linkages and trade frictions

Two distinct forms of trade coexist in the model: rural-urban trade and intercity trade. Rural-urban trade occurs because economic exchanges can only take place in cities. Farmers travel to an optimally chosen urban market to sell their agricultural products. This implies that the equilibrium of the model will feature market areas (or rural hinterlands) surrounding each city in $\mathcal{Y}$. For the moment, let $\Omega_i \subset \mathcal{X}$ the market area around city y_i, for $y_i \in \mathcal{Y}$, and defer to Section XXX a discussion of how they are endogenously formed in general equilibrium. The modeling of intercity trade follows the standard Armington formulation (Armington, 1959; Anderson and Van Wincoop, 2003): each city supplies a unique variety of the manufacturing good and the agricultural good, and consumers wish to consume all varieties[11]

Shipping goods from one location to another incurs a trade cost that takes the iceberg form, i.e., a fraction of the cargo is set aside to pay for transport. More precisely, it takes D_{ri} units of the rural good to ship one unit from a rural location $x_r \in \mathcal{X}$ to a city $y_i \in \mathcal{Y}$. Similarly, it takes T_{ij}^M and T_{ij}^A units of, respectively, manufacturing good and agricultural good, to ship one unit from city y_i to city y_j. Given no arbitrage conditions, delivery prices from city y_j to city y_i are given by: $p_{ij}^M = T_{ij}^M p_j^M$ and $p_{ij}^A = T_{ij}^A p_j^A$, for manufacturing and agricultural goods respectively.

initial period of our study - [the so-called medieval agricultural revolution, see e.g. White, 1962; Malanima, 2009a; Andersen, Jensen, and Skovsgaard, 2016b] but remained modest up until the 1700's [except for England and the Netherlands Overton, 1996; Allen, 2000]. Albeit the discovery of the Americas did alter the agricultural *potential* of Europe [Crosby, 1972; Galor and Özak, 2016], historical evidence suggests that high caloric crops - most importantly the potato - were not adopted on a large scale up until the 18th century [e.g. Pounds, 1979; Braudel, 1988]. For all of the above reasons we do abstract from increases in agricultural productivity in order to show that a large part of the three documented facts can be explained in the absence of such an increase. The usage of different measures/assumptions on agricultural productivity does not alter our conclusions in any significant way (results available upon request).

[11] Note that the agricultural goods are homogeneous within each rural hinterland, and acquire their identity, in the consumer's eyes, at the trading location, rather than at the production location.

Finally, trade costs are parametrized as a power function of distance. Let d_{rs} denote the distance between cells $x_r, x_s \in \mathcal{X}$ recall also that $i, j \in \mathcal{Y} \subset \mathcal{X}$). Thus, we have:

$$D_{r,i} = (1 + d_{ri})^{\delta}, \quad T_{ij}^{M} = (1 + d_{ij})^{\tau^M}, \text{ and } T_{ij}^{A} = (1 + d_{ij})^{\tau^A}, \tag{5}$$

The parameters τ^M and τ^A are the main object of interest in our quantitative application (Section XXX). In particular, we will use our panel data on urban population to obtain structural estimates of τ^M and τ^A at fifty or one-hundred year intervals from year 1100 to year 1800.

3.4 Consumer's problem

Agents order consumption baskets according to a Cobb-Douglas utility function defined over manufacturing and agricultural composite goods $U(C^M, C^A) = (C^M)^{\alpha}(C^A)^{1-\alpha}$, where C^M and C^A are CES bundles of the good varieties imported from all cities:

$$C_i^k = \left(\sum_{y_j \in \mathcal{Y}} \left(c_{ij}^k \right)^{\frac{\sigma^k - 1}{\sigma^k}} \right)^{\frac{\sigma^k}{\sigma^k - 1}}, \quad k = A, M, \quad \text{all } y_i \in \mathcal{Y},$$

Here $1-\alpha$ denotes the share of expenditure devoted to agricultural goods[12], and σ^k, $k = A, M$ denote the elasticities of substitution between varieties in each sector. Together with $1 - \beta$ (the land share in agricultural production), $1 - \alpha$ determines the strength of the congestion force in the economy, as it captures the extent to which decreasing returns in agriculture ultimately affect consumer's welfare.

To ease the exposition and the solution of the model, we assume that all agents, including farmers, consume their goods at the trading place.[13] The main implication of this assumption is that all agents, both farmers and urban workers, who do business in city $y_i \in \mathcal{Y}$ will face the same consumption prices, and as a consequence, if their welfare equalizes in a spatial equilibrium, so will their nominal income. Let v_i denote the nominal income of a representative agent who works or trades in city $y_i \in \mathcal{Y}$. Then we can write the consumer's problem as:

$$\max_{\{c_{ij}^M, c_{ij}^A\}_{y_j \in \mathcal{Y}}} U\big(C_i^M, C_i^A\big) \quad \text{subject to} \quad \sum_{y_j \in \mathcal{Y}} p_{ij}^M c_{ij}^M + \sum_{y_j \in \mathcal{Y}} p_{ij}^A c_{ij}^A \leq v_i,$$

where p_{ij}^M and p_{ij}^A are the prices in y_i of, respectively, the manufacturing and agricultural varieties imported from y_j. Let X_{ij}^k denote the value of city y_i's imports of good $k = M, A$ from city y_j. This consumption structure leads to the familiar gravity equation:

$$X_{ij}^k = \alpha (T_{ij}^k)^{1-\sigma^k} (p_j^k)^{1-\sigma^k} (P_i^k)^{\sigma^k - 1} w_i L_i \quad k = M, A, \tag{6}$$

where P_i^k is the CES price index:

$$P_i^k = \left(\sum_{y_j \in \mathcal{Y}} (T_{ij}^k)^{1-\sigma^k} (p_j^k)^{1-\sigma^k} \right)^{\frac{1}{1-\sigma^k}}, \quad k = M, A \tag{7}$$

[12]According to the historical evidence, expenditure shares did not change decisively in our study period. First, there was just not a lot of choice when it came to manufacturing. It is mostly cloth, candles, oil, soap [e.g. Allen, 2001; Malanima, 2009a]. Second, there is plenty of evidence that the substitution effects took place within goods categories and not across. There was usually a desire to find grain substitutes for bread and also to increase the share of meat [Abel, 1981].

[13]This assumption is also in Nagy [2020].

3.5 Welfare equalization

Because agents are freely mobile across sectors and locations, at a spatial equilibrium welfare must equalize along three margins. First, all farmers within a rural hinterland must receive the same welfare in equilibrium. Second, farmers in a rural hinterland must receive the same welfare as workers in the corresponding urban center. Finally, welfare must equalize for urban workers living in different cities. Let V_{ri}^A denote the indirect utility of a farmer living in rural location $x_r \in \Omega_i$ and shipping his produce to city $y_i \in \Omega_i$, and let V_i^M denote the indirect utility of an urban worker in city y_i. Then welfare equalization requires:

$$V_{ri}^A = V_i^M = V, \quad \text{for all } x_r \in \mathcal{X}, y_i \in \mathcal{Y}. \tag{8}$$

where V is a constant denoting the equilibrium level of welfare in the economy. Before closing this section, note that imposing welfare equalization between the countryside and the city delivers an expression for the city-gate price of the agricultural variety supplied by city y_i, before inter-city trade costs are incurred:

$$p_i^A = \left(\frac{L_i^A}{\Phi_i^A} \right)^{1-\beta} w_i, \tag{9}$$

where $L_i^A = \sum_{x_r \in \Omega_i} l_r^A$ and

$$\Phi_i^A = \sum_{x_r \in \Omega_i} \left[\left(\phi_r^A / D_{r,i} \right)^{\frac{1}{1-\beta}} h_r \right]. \tag{10}$$

Thus L_i^A is the total rural population in Ω_i, and Φ_i^A is the total effective agricultural productivity in the rural hinterland.

3.6 Market clearing

Markets clear when the revenues of sector $k = M, A$ in each city $y_i \in Y$ equals the total expenditure on goods exported from y_i:

$$w_i L_i^k = \sum_{y_j \in \mathcal{Y}} X_{ji}^k, \quad k = A, M. \tag{11}$$

Here we have already used the zero profit condition in the manufacturing sector and the fact that, at the spatial equilibrium, all farmers within a rural hinterland earn the same income, equal to the urban wage.

3.7 Rural hinterlands

The previous discussion keeps the rural hinterlands fixed. We now show how they are determined in equilibrium from the optimal trading choices of farmers. The indirect utility of a farmer living in x_r and trades with y_i can be written as:

$$V_{r,i}^A = \frac{\hat{p}_i^A}{D_{r,i}} \frac{y_r^A}{l_r^A}, \quad \text{where } \hat{p}_i^A = \frac{p_i^A}{(P_i^M)^\alpha (P_i^A)^{1-\alpha}}. \tag{12}$$

This equation shows that farmer's welfare depends on i via two components: first, the "real" agricultural price, $\hat{p}_i^A$; second, travel distance to all cities. Hence farmers balance the unit revenues, in real terms, they can obtain for their products on a given market, with the cost of traveling to that market. To find his optimal urban market, a farmer in $x_r \in \mathcal{X}$ then solves:

$$\max_{y_i \in \mathcal{Y}} V_{r,i}^A \tag{13}$$

One difficulty with this expression is that it involves a maximization problem over $|Y|$ alternatives for each rural location in $\mathcal{X}$, making difficult to compute the equilibrium market areas jointly with the equilibrium price indices. However, given the properties of (12) and the fact that $\mathcal{Y}$ only contains finitely many cities, the farmer's trading choice in (13) can be reformulated in a simpler way. To see this, note that the market area around city $y_i \in \mathcal{Y}$ can be expressed as:

$$\begin{aligned}\Omega_i &= \{x \in \mathcal{X} : V^A(x, y_i) \geq V^A(x, y_j), \text{ all } y_j \in \mathcal{Y}, y_j \neq y_i\} \\ &= \{x \in \mathcal{X} : dist(x, y_i) - \frac{1}{\delta}\log \hat{p}_i^A \leq dist(x, y_j) - \frac{1}{\delta}\log \hat{p}_j^A, \text{ all } y_j \in \mathcal{Y}, y_j \neq y_i\},\end{aligned} \tag{14}$$

where in the second line we have taken logs and used the parametrization for shipping costs D. The formulation in (14) coincides with a geometric construct known in computational geometry as a Voronoi diagram with additive weights (see Okabe et al., 2008 for an extensive review on the subject), where the weights are defined as:

$$\lambda_i = \frac{1}{\delta}\log \hat{p}_i^A$$

More precisely, given a vector of weights λ, a Voronoi tessellation is a partition of space into mutually-exclusive market areas $\{\Omega_i\}_{y_i \in \mathcal{Y}}$ such that each Ω_i is defined from (14). The key observation to make here is that in order to construct a tessellation we only need to know the $|\mathcal{Y}|$-dimensional vector of weights and the bilateral distance matrix, which is given exogenously. Thus the problem of computing the optimal trading choices of farmers effectively reduces to the much simpler problem of computing the $|\mathcal{Y}|$ Voronoi (endogenous) weights. This leads us to develop a novel solution procedure, that we explain in Section XXX. To conclude, note that equation (14) makes clear that each rural hinterland Ω_i is a function of the full vector of weights $\lambda = \{\lambda_1, ..., \lambda_{|\mathcal{Y}|}\}$. To highlight this relationship, we henceforth write $\Omega_i(\lambda)$. This implies that the effective agricultural productivity of city y_i's hinterland, Φ_i^A as defined in (10), is also a function of the weight vector λ. Therefore, in what follows we also write $\Phi_i^A(\lambda)$.

3.8 Equilibrium

Definition 1. *A competitive equilibrium in this economy is a set of price vectors:* $\{P^A, P^M, p^A, p^M, w\}$, *population distribution across regions and sectors* $\{L, L^A, L^M\}$, *and a common welfare level* V, *such that:*

1. *the price indices are given by (7);*

2. *welfare equalizes across cities and within rural hinterlands (8);*

3. *the markets for manufacturing and agricultural goods clear, (11) ;*

4. *local labor markets clear* $L_i^A + L_i^M = L_i$*, and the aggregate urban population constraint holds:* $\sum_{y_i \in \mathcal{Y}} L_i^M = \bar{L}^M$*;*

5. *the endogenous Voronoi weights are given in* **??***;*

and where, furthermore: bilateral trade expenditures are given by (6), factory prices are given by (4) and (9), and manufacturing TFP is given by (3).

After some algebra, the above conditions can be expressed a system of $6 \times |\mathcal{Y}| + 1$ equations in terms of the same number of unknowns: the $|\mathcal{Y}|$-dimensional vectors: w, P^M, P^A, L^M, L^A, L, plus the welfare scalar V. In particular, we have:

- the market clearing condition for the manufacturing good:

$$w_i^{\sigma^M} (L_i^M)^{1-(\sigma^M-1)\gamma_1} = \alpha \sum_{y_j \in \mathcal{Y}} (T_{j,i}^M)^{1-\sigma^M} (P_j^M)^{\sigma^M-1} (\hat{\phi}_i^M)^{\sigma^M-1} w_j L_j. \tag{15}$$

- the expression for the manufacturing price index:

$$(P_i^M)^{1-\sigma^M} = \sum_{y_j \in \mathcal{Y}} (T_{ij}^M)^{1-\sigma^M} (\hat{\phi}_j^M)^{\sigma^M-1} w_j^{1-\sigma^M} (L_j^M)^{(\sigma^M-1)\gamma_1}. \tag{16}$$

- the market clearing condition for the agricultural good:

$$w_i^{\sigma^A} (L_i^A)^{1+(\sigma^A-1)(1-\beta)} = (1-\alpha) \sum_{y_j \in \mathcal{Y}} (T_{j,i}^A)^{1-\sigma^A} (P_j^A)^{\sigma^A-1} B_i^{(\sigma^A-1)(1-\beta)} w_j L_j. \tag{17}$$

- the expression for the agricultural price index:

$$(P_i^A)^{1-\sigma^A} = \sum_{y_j \in \mathcal{Y}} (T_{ij}^A)^{1-\sigma^A} B_j^{(\sigma^A-1)(1-\beta)} w_j^{1-\sigma^A} (L_j^A)^{-(\sigma^A-1)(1-\beta)}. \tag{18}$$

- welfare equalization across cities:

$$w_i = V (P_i^M)^{\alpha} (P_i^A)^{1-\alpha}. \tag{19}$$

- the local population constraint:

$$L_i = L_i^M + L_i^A. \tag{20}$$

- the expression for the endogenous weights

These equilibrium conditions must hold for all $y_i \in \mathcal{Y}$. Finally, we have the aggregate population constraint:

$$\sum_{y_i \in \mathcal{Y}} L_i = \bar{L}, \tag{21}$$

where $\bar{L}$ is an exogenous positive constant.

3.9 Technological progress

While our baseline quantitative exercise is based on the hypothesis of constant manufacturing productivity over time, we also explore the role of technological progress. To this end, we will assume that manufacturing productivity in a location i evolves according to the following dynamic process :

$$\tilde{\phi}^M_{i,t+1} = \tilde{\phi}^M_{i,t} + \gamma^2 (L^M_{i,t})^{\gamma^3} (\tilde{\phi}^M_{i,t})^{1-\gamma^4}. \tag{22}$$

This is the semi-endogenous growth specification proposed in Jones [1995] and adopted in recent studies on spatial growth [Peters, 2022; Burchardi, Chaney, Hassan, Tarquinio, and Terry, 2020]. It states that the productivity level in the next period is the sum of the current level plus an innovation term. In turn, the innovation term is allowed to depend on the size of the urban population and on the current productivity level. In our context, this specification is useful because it flexibly incorporates two distinct economic forces. First, for $\gamma^3 > 0$, there is a push toward *divergence*, because more productive cities will tend to host larger populations in equilibrium, and therefore, other things equal, to grow faster. Dynamic economies of scale in the urban sector are consistent with the idea that urban interactions increase the scope for the exchange of ideas and innovation activities. Second, for $\gamma^4 > 0$, there is a push toward *convergence*, because the current productivity level is negatively correlated, other things equal, with the growth rate. This is consistent with the idea, for instance, that there are decreasing returns to innovation activities. Finally, conditional on $gamma^3$ and $gamma^4$, parameter γ^2 helps control the size of the innovation relative to the current productivity level (for $\gamma^2 = 0$ the specification clearly embeds the constant productivity case). We refer the reader to Jones [1995] for an insightful discussion of equation (22).

3.10 Numerical solution

In Appendix A we show that the equilibrium of the model has scale-invariance properties. As in Allen, Arkolakis and Li (2016), this suggests solving the model in two steps. First, we find a rescaled solution of the model ignoring the role of the welfare scalar. Then, we can rescale the solution so that urban population in the model sums up to value observed in the Bairoch data. The details of the numerical procedure are given in section B.

4 Empirical strategy

This section describes our approach to connecting the theoretical model with the empirical evidence from pre-industrial Europe. We will develop a methodology to infer the value of the trade cost parameters, which may vary over time, from the structure of the model together with the available historical data on the European urban population. This will allow us to answer quantitative questions on the role of trade frictions for the evolution of the European urban network and to conduct some historical counterfactuals.

Concretely, we will proceed in steps. First, we set up a spatial grid in order to discretize the European continent (the set X in the model). Second, we use the Fast Marching Method to compute the matrix of bilateral distances between each pair of grid cells (the matrix $\{dist_{rs}\}$ in the model). Third, we calibrate some of the model parameters externally, based on previous work in economics and economic history. Fourth, we compute a vector of manufacturing productivities ($\{\phi^M_i\}^n_{i=1}$ in the model) in order to match the urban distribution in 1300, used as a base year. This step also requires us to pick a pair of initial values for the trade frictions parameters, τ^M and τ^A; to this end, we ensure that the model is also consistent with historical price information for year 1300. Finally, with the vector of manufacturing productivities in hand, we estimate the trade frictions parameters in all other time periods using moments of the urban distribution as empirical targets. The next paragraphs describe each of these steps in detail.

4.1 Step 1: spatial grid

The geographic bounding box for our study is demarcated by 57 degrees latitude to the North and 22 degrees longitude to the East. We discretize this area into roughly 7000 grid cells of 25×25 km using an equal area projection. Our empirical analysis is then carried out at the grid cell level. The choice of the cell size is based on a trade off: on the one hand, a low number of cells eases the numerical solution of the model; on the other hand, if cells are too large, they will often end up including more than one urban center. Large cells also tend to create some instability in the computation of rural hinterlands, as one rural cell switching market will cause too large a swing in the market price. We strike a balance between these different factors. In a few cases where we still observe multiple cities in a single cell, we add up their urban population and treat them as a single urban center.

4.2 Step 2: transport costs

We compute bilateral travel distances between each pair of grid cells taking into account the geographic attributes of the European continent. In particular, Masschaele [1993] provides estimates of transport costs for Medieval England and concludes that the ratio of land transport to river transport to sea transport was in the order of 8:4:1. We use this evidence to assign a transit cost to each grid cell. Once the transit costs are known, we can use the Fast Marching Method (FMM) to compute the least cost path between each pair of cells [Allen and Arkolakis, 2014; Nagy, 2021]. The final distance corresponds to the sum of the transit costs incurred along the least cost path.

Motivated by the figures in Masschaele [1993], we set the transit cost equal to one if a grid cell lies in the sea and equal to four if it contains a navigable river. [14] For land cells, we also take into account the ruggedness of the terrain, based on a ruggedness index that runs from one to one hundred. If a land cell has the minimum value of ruggedness observed in the data (e.g. the coastal region in the Netherlands), we assign a transit cost equal to eight; then, we incorporate a penalty according to the following formula:

$$t(x) = 8 \times (1 + 0.2 \times \text{rugged}(x))$$

This is important to ensure that mountainous regions are meaningful geographical barriers. For instance, with this specification traveling from Milan to Zürich is seven times as costly as traveling from Milan to Venice. Note that this methodology implicitly normalizes the smallest bilateral distance between two grid cells to one, and ensures that the iceberg trade costs in equations (5) are weakly greater than one.

Figure 15a, in the Appendix, shows the map of transit costs that we use as an input in the procedure, whereas Figures 15b and 15c, as an illustration, show the computed travel distances from London and Milan, respectively, to all other grid cells in Europe.

[14] We use data on navigable rivers and elevation from the Natural Earth database.

In our baseline exercise, we use the same matrix of bilateral distances for intercity trade in both sectors. This provides a useful benchmark and it ensures that the trade cost parameters, τ^M and τ^A, are comparable in magnitude. As far as rural-urban trade is concerned, we also adopt the same matrix with the exception that sea transport is assumed to be prohibitively costly. This is to ensure that rural hinterlands do not jump over the sea.

4.3 Step 3: calibration

We set the value of the model parameters α, β, σ^M, σ^A, and γ_1 based either on the previous economics literature or on the available historical evidence. Table 1 summarizes the values of the calibrated parameters.

Table 1: External calibration

parameter		value	source
α	expenditure share on manufacturing goods	0.3	Allen [2001]
β	labor share in agricultural production	0.7	Grigg [1980, 1992]
σ^M, σ^A	elasticity of substitution among consumption varieties	4	Monte, Redding, and Rossi-Hansberg [2018]
γ_1	agglomeration spillovers in manufacturing production	0.02	Combes and Gobillon [2015]

4.4 Step 4: initialization

The goal of this step is compute a vector of manufacturing productivities $\{\phi_i^M\}$ and a pair of trade cost parameters τ^M, τ^A to use as base-year values for the subsequent analysis. To see the problem that arises, note that for a given value of τ^M, τ^A, and given data on agricultural productivity, we can in general invert the model and find the vector of manufacturing productivities that rationalizes the urban population data as an equilibrium of the model. This suggests that, in order to identify τ^M and τ^A in a base year, we need to target additional moments unrelated to the distribution of urban population.

Thus, in the initialization step, we also target the coefficient of variation in manufacturing and agricultural prices in year 1300. Price variation is informative of the extent of spatial frictions in the economy, and for this reason it is often use as a measure of market integration. In our context, intuitively, the price moments will pin down the parameters τ^M and τ^A, whereas the urban population is used to back out the vector $\{\phi_i^M\}$ (although in reality all parameters are computed jointly).

The choice of 1300 as the initial year represents a compromise between the advantages of going further back in time and the availability of price information for per-Industrial Europe. As far as agricultural prices are concerned, Federico et al. [2021] have collected a time series for the price of wheat from the mid-fourteenth to the twentieth century for almost 600 European markets. Wheat prices are convenient because they are relatively well documented and easy to harmonize. Their Figure 1 suggests that the coefficient of variation of agricultural prices was around 0.4 in 1300 and this is the value with use in the initialization. Information on manufacturing prices is sparser. The best available evidence comes from Allen [2001], who collected time series data for a number of relatively comparable manufactures, such as soap and candles. By looking at the time series for the price of candles in a subset of European cities, we conjecture that a plausible value for the coefficient of variation in 1300 is 0.22.

4.5 Step 5: estimation

Once we have backed out the vector of manufacturing productivities that rationalizes the data in 1300, we can turn to the main exercise of this paper. Our goal is to exploit the urban population data, in combination with the structure of the model, to infer the evolution of trade frictions in Europe before the Industrial Revolution. This analysis will also reveal how far changes in trade frictions can go in explaining the long-term evolution of the European urban network.

More precisely, we search for the values of parameters τ^M and τ^A which minimize the distance between the model solution and the macro-facts of urban development presented in Section 2: the share of urban population in the North, the share of population in the top 10 percent of cities, and the correlation between urban size and agricultural productivity.

Formally, let $\tau = \{\tau^M, \tau^A\}$, and let $\tau \mapsto \hat{L}^M(\tau)$ denote the map between the parameter vector and the equilibrium vector of urban population in the model. Finally let $L^M \mapsto m_i(L^M)$ for $i = 1, 2, 3$ denote our target moments given an urban population vector L^M. Our estimated τ is computed in order to minimize the loss function:

$$\sqrt{\sum_{i=1}^{3} \Big(m_i(\hat{L}^M(\tau)) - m_i(L^M) \Big)^2}$$

5 Quantitative Analysis

5.1 Baseline: changes in trade frictions, no technical change

We start our quantitative analysis from a baseline scenario where the vector of manufacturing productivities is held constant at the initialized value in 1300. This version of the model is fully static: there are no linkages between one period and the next. Starting from this baseline has a number of advantages: first, it tells us how far a story based *solely* on trade frictions can go in explaining the major empirical features of urban growth in Europe. Second, it allows us to illustrate cleanly, without overlapping forces, the implications of trade frictions in each sector for each of the macro facts. Finally, it represents a plausible historical benchmark given that productivity growth was not a major force in pre-industrial Europe. We report the estimated parameters and the model fit for this scenario.

Estimated trade costs Figure 7 presents the estimated values of τ^M and τ^A. A number of patterns emerge from the figure. First, both parameters exhibit a broadly decreasing pattern. Thus our analysis leads us to conclude that trade frictions were falling during the European pre-industrial period. In relative terms, the reduction was stronger in the manufacturing sector: in 1800, the estimated value of τ^M is $14,7\%$ lower than in 1100, whereas the value of τ^A is $10,6\%$ lower.

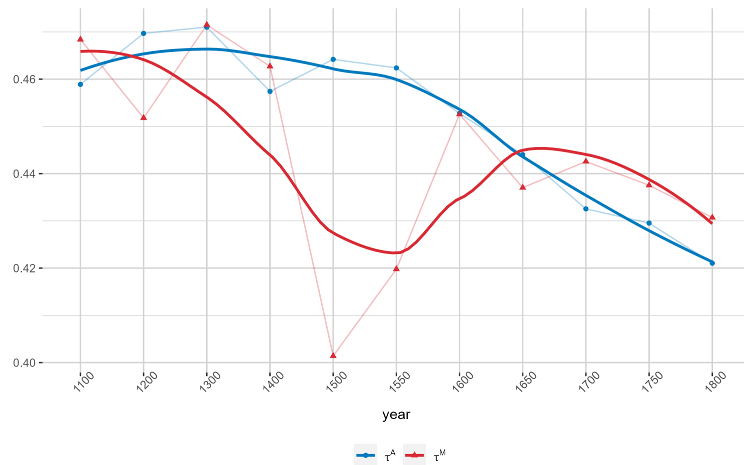
Second, the timing of the reduction is crucially different for the two sectors. Before 1550, the decline in trade costs is steeper for manufacturing goods than agricultural goods. After 1550, the decline is steeper for agricultural goods, whereas the manufacturing sector witnesses a small rebound until 1650 and a mild decline thereafter.

Finally, note that the value of τ^A lies above the value of τ^M throughout the study period. This plausibly suggests that distance mattered relatively more for the shipment of agricultural products than of manufacturing products.

Model fit As a next step, it is important to understand how well the model is able to fit the data. In Figure 8, we report the three target moments in the data and in the model, given the trade costs reported in 7. Thus the blue lines in Figure 8 reproduce the main facts presented in Section 2. As the figure illustrates, falling trade frictions, within the structure of the model, are able to generate, at least qualitatively, the main facts of European target development.

Quantitatively, the model falls short of the data on two dimensions. First, the model is unable to fully match the stretch of the city-size distribution after 1650. Second, and more notably, the model generates an increase in the share of urban population living in Northern Europe of 2.5 percentage points over the entire study period, whereas the increase observed in the data is 18 percentage points. Thus the model only captures sixteen percent of the time variation of this target moment. The reason is that that the model with constant manufacturing productivity enters a dilemma from 1500 onward, concurrently with the emergence of urban giants: on the one hand, reduced trade frictions in the agricultural sector, boosting the relative advantage of the most productive urban sites, help match the share of urban population living in the largest cities; on the other hand, this process goes too much in favor of Southern Europe, because manufacturing productivities are assigned to match the urban distribution in 1300, when Southern Europe is still the most prosperous region of the continent. This discussion suggests that some form of technical change reducing the gap between

Figure 7: Estimates of the trade costs parameters in the baseline exercise without technological progress.



Notes: The figure reports the estimated trade cost parameters for manufacturing goods (red triangles) and agricultural goods (blue dots) in the baseline exercise without technological progress. The thick lines display the corresponding LOESS curves for each of the two parameter series. The values of the estimated parameters are chosen so as to minimize the Euclidean distance between a vector of target moments in the model and in the data. The target moments are: 1. share of urban population in Northern Europe; 2. share of urban population in cities in the top 10 percent of the city-size distribution; 3. cross-sectional correlation between agricultural productivity and urban population.

the North and the South may resolve the dilemma and improve the model fit. We will explore this idea below, but before we do that, we carry out some counterfactual exercises to further clarify the role of trade frictions for our results.

5.2 Counterfactual exercises

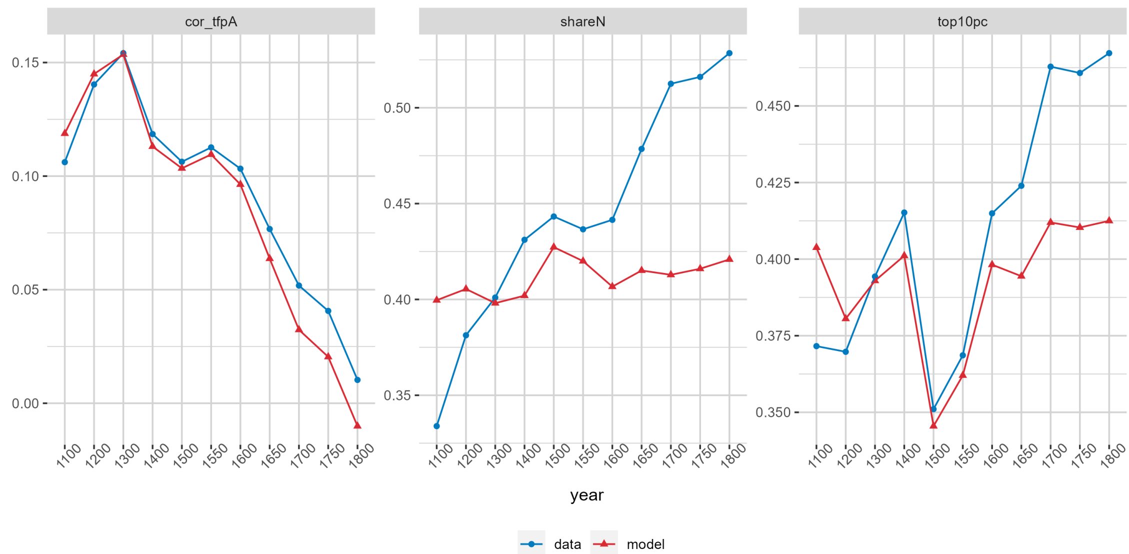
How do changes in trade costs help explain the macro facts of European pre-industrial development? One way to answer this question is to run some counterfactual exercises, where the role of each parameter (τ^M and τ^A) is studied in isolation. This is done in the next subsection. One take-away from this analysis is that the presence of two traded sectors with opposite economies of scale is crucial to obtain our results.

To corroborate this conclusion, we next check whether other economic forces can explain the main facts of European pre-industrial development equally well as, or better than, reductions in trade frictions. Here, we are interested in long-term economic forces that may be at work throughout the period, rather than specific historical episodes. In particular, in section 5.2.2, we start exploring the role of technical change. Our analysis reveals that technological progress *alone* cannot provide a unified explanation for the main facts.

5.2.1 Reducing trade costs in one sector at a time

Figure 9 displays the target moments for two counterfactual exercises: in the first counterfactual (blue line), τ^M freezes at its 1300 value for the remainder of the study period, whereas τ^A evolves as in Figure 7. In the second counterfactual (orange line), we perform the opposite exercise, with τ^A freezes in 1300 and τ^M evolves as in Figure 7. The dark grey line in the figure reproduces the baseline results in Figure 12.

Figure 8: Model fit for the baseline exercise without technological progress.



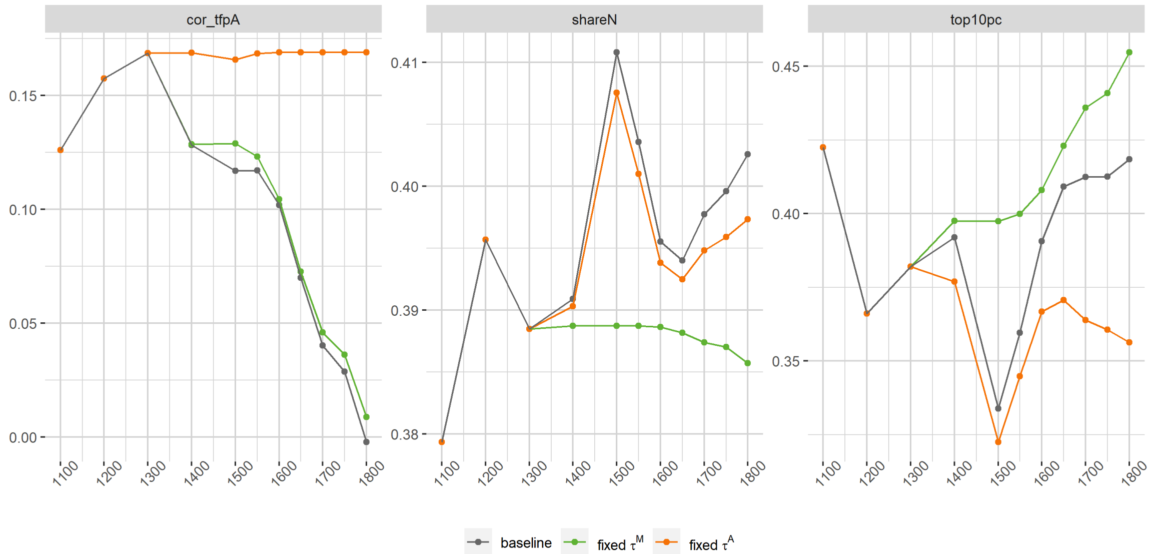
Notes: The figure reports the evolution of the moments used as targets in the estimation of the trade costs parameters, both in the data (blue dots) and in the model (red triangles), at the estimated parameter values, for the baseline exercise without technological progress. The three moments, shown from left to right in the three corresponding panels, are: i) the correlation between urban population and local agricultural suitability; ii) the share of the urban population in Northern Europe; iii) the share of urban population in the top 10 percent of the city-size distribution.

A number of remarks are in order. First, we observe that the secular decline of the correlation between urban population and agricultural productivity after 1300 is entirely accounted for by the reduction in τ^A. When τ^A is kept constant, the correlation remains stable throughout the period. This is intuitive: lower trade costs for agricultural goods reduce the importance of a fertile hinterland, since a large urban population can be sustained with imports from other cities. Second, the increase in the share of urban population living in Northern Europe is entirely accounted for by the reduction in τ^M. When τ^M is kept constant at the 1300 level, the share of the population in Northern Europe stays constant until 1600, and declines thereafter, in concurrence with the fall of τ^A. Finally, τ^M and τ^A have opposite effects on the shape of the city-size distribution. In the constant τ^M counterfactual, the share of urban population living in the top decile cities lies above the baseline and reaches 45 percent in 1800, approximately the same figure that we observe in the data. In contrast, it lies below the baseline, and even declines after 1650, in the constant τ^A counterfactual.

5.2.2 Technological progress as an alternative explanation

Can technological progress provide a competing explanation, as opposed to reductions in trade frictions, to explain the macro facts of European pre-industrial development? To answer this question, we solve a version of the model with constant trade frictions after year 1300 and time-varying productivity levels in the urban sector. We use the semi-endogenous growth equation (22) to update productivity levels over time. While it would be unfeasible to run a counterfactual for each growth process considered in the economic literature, we believe that equation (22) is insightful because it allows us to explore the role of two opposing economic

Figure 9: Counterfactual scenarios: trade costs fall in only one sector



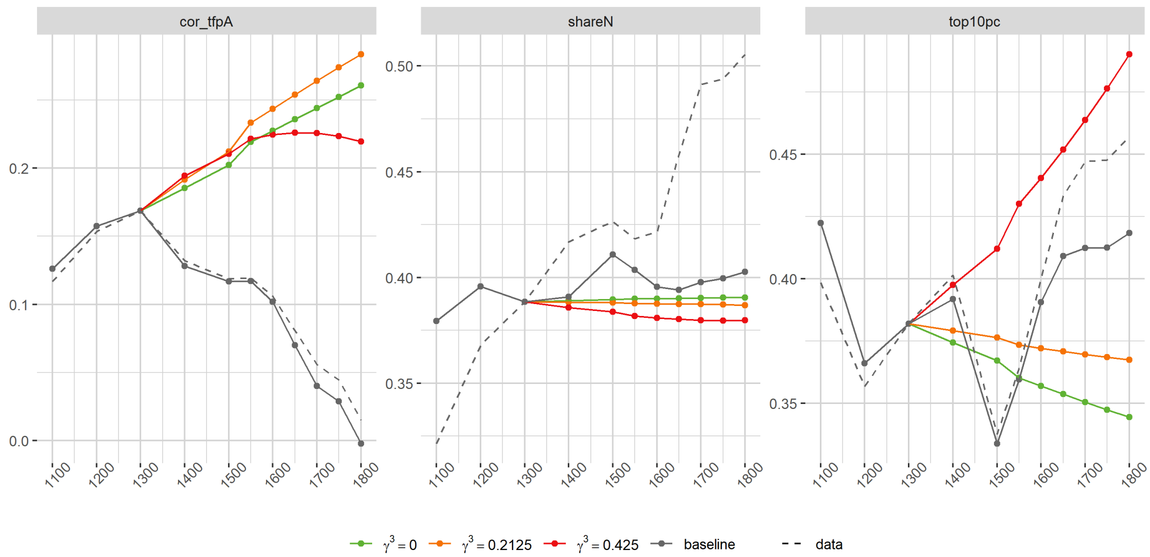
Notes: The figure reports the moments used as targets in the estimation procedure in the baseline exercise and in two counterfactual scenarios. The three moments, shown from left to right in the three corresponding panels, are: i) the correlation between urban population and local agricultural suitability; ii) the share of the urban population in Northern Europe; iii) the share of urban population in the top 10 percent of the city-size distribution. In each panel, the dark gray line reproduces the baseline results from Figure 8; the green line displays the evolution of the target moment in a scenario where τ^M is held constant from 1300 A.D. onward, while τ^A evolves as in Figure 7; the orange line displays the evolution of the target moment in a scenario where τ^A is held constant from 1300 A.D. onward, while τ^M evolves as in Figure 7.

forces: one toward divergence (as parameterized by γ^3) and one toward convergence (as parametrized by γ^4).

In Figure 10 we display the results for $\gamma^2 = 0.02$ and $\gamma^4 = 1$ and for different values γ^3, ranging from zero to 0.425. Anticipating the results of the next section, these values of γ^2 and γ^4 will turn out to be our preferred values when τ^M and τ^A are estimated in a setting with technological progress (the corresponding value for γ^3 will be 0.425). The figure also reproduces the baseline results (solid gray line) and the data moments (dashed gray line).

The general message from the figure is that none of these models can rationalize the main facts of European urban development. There are two main reasons why these models fail. First, none of them can generate, *at the same time*, a shift of the urban population from Southern to Northern Europe and from small to large cities. As an example, consider the case with $\gamma^3 = 0$, such that only the convergence force remains active, that is, less productive locations grow faster: while the population share of Northern Europe is mildly increasing (though underperforming our baseline results), the population share of the top decile cities declines in this scenario. Next, consider the case $\gamma^3 = 0.425$: here divergence forces become predominant and large cities increase their relative advantage over time, even overshooting the pattern observed in the data; in turn, though, the population share of Northern Europe tends to fall. A second deficiency of these models is that all of them generate a rising correlation between urban size and agricultural productivity throughout the study period (with the exception of the case γ^3, which display a small hump towards the end). In contrast, as we discussed above, falling trade frictions in the agricultural sector generate a declining correlation that closely matches the data.

Figure 10: Counterfactual scenario: technical change with constant trade frictions



Notes: The figure reports the evolution of the macro-facts used as target moments in the GMM procedure in a counterfactual scenario where: i) manufacturing technology evolves over time according to Equation (22) in Section 3; ii) trade costs are held constant from 1300 A.D. onwards. The three data moments, shown from left to right in the three corresponding panels, are: i) the share of the urban population in Northern Europe, ii) the share of urban population in the top 10 percent of the city-size distribution, iii) the correlation between urban population and local agricultural suitability

5.3 Extension: technological progress

We now explore if technological progress can, in conjunction with falling trade frictions, improve the quantitative performance of the model as compared to the baseline. Ideally, to answer this question, one would like to estimate the parameters γ^2, γ^3, and γ^4 of equation (22) jointly with the trade cost parameters τ^A and τ^M. In practice, this is computationally burdensome, as it requires us to solve for the entire time path of the model (eleven time periods) for each trial value of the (five-dimensional) parameter vector. Instead, in order to offer an illustrative exercise, we run a coarse grid search using Burchardi et al. [2020]'s analysis as a reference.

In that paper, the authors estimate a value of 0.85 for γ^3 under the restrictions $\gamma^3 = \gamma^4$ and $\gamma^2 = 1$. In our grid search, we relax these restrictions; in particular, $\gamma^2 = 1$ would generate counterfactually high growth rates for pre-industrial Europe. This strategy allows us to tie our hands to an external benchmark, while at the same time adjusting the parametrization to account for the different empirical context. It is also clear that it provides a lower bound to the model performance in this setting.

The grid comprises all combinations of values

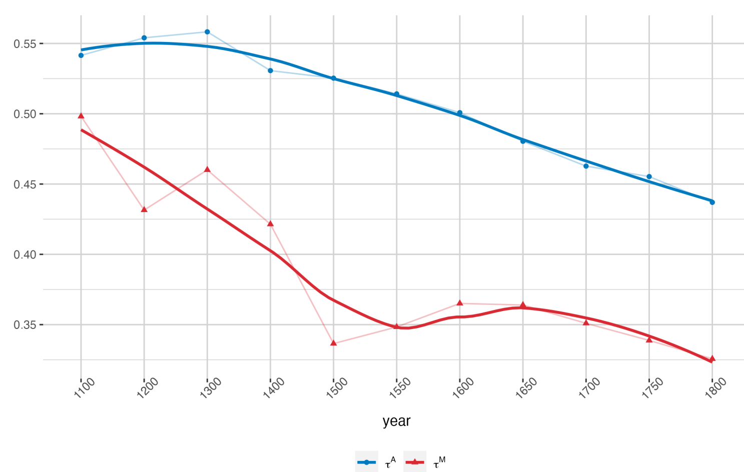
$$\gamma^2 \in \{0.002, 0.004, 0.008, 0.01\}, \gamma^3 \in \{0, 0.2125, 0.425, 0.85\}, \text{ and } \gamma^4 \in \{0.85, 1\}.$$

For each grid point, we repeat the estimation of the trade cost parameters (see Step 5 in Section 4.5) except that now, after year 1300, we update the vector of manufacturing productivities according to equation (22) (when the time interval is fifty years, we use $\gamma^2/2$). We then select the triplet of parameters that minimizes the distance between the model and the data along two dimensions: the population share of Northern Europe in year 1750, and a mean growth rate (across cities and time periods) of three percent per century from 1300 onward. As for the baseline, we report the estimated trade costs as well as the model fit.

Estimated trade costs The evolution of trade costs with technological progress, displayed in Figure 11, paints a very similar picture to the one we observe in the baseline. If anything, the fall in trade frictions, as well as its different timing in the two sectors, are now more clearly visible.

Model fit As we discussed in Section 5.1, our baseline exercise missed part of the stretching out of the urban distribution after 1650, and it only accounted for sixteen percent of the shift to Northern Europe throughout the study period. Introducing technological progress markedly improves the performance of the model along both dimensions: first, the population share of the the top ten percent cities is closely matched until 1800; second, the share of urban population living in Northern Europe increases by seven percentage points from 1100 to 1800, more than twice the increase prompted by the baseline, so that the model now captures forty percent of the secular increase observed in the data.

Figure 11: Estimates of the trade costs parameters in the exercise with technological progress.

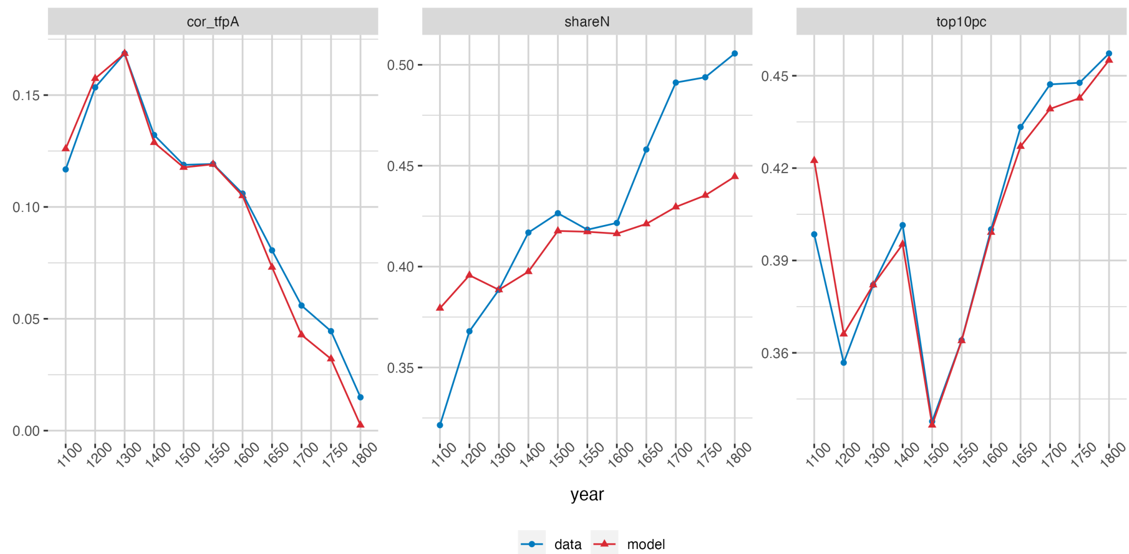


Notes: The figure reports the estimated trade cost parameters for manufacturing goods (red triangles) and agricultural goods (blue dots), when the vector of manufacturing productivities evolves according to equation (22). The thick lines display the corresponding LOESS curves for each of the two parameter series. The values of the estimated parameters are chosen so as to minimize the Euclidean distance between a vector of target moments in the model and in the data. The target moments are: 1. share of urban population in Northern Europe; 2. share of urban population in cities in the top 10 percent of the city-size distribution; 3. cross-sectional correlation between agricultural productivity and urban population.

5.4 Untargeted moments

To close this section, we illustrate that the model performs well when evaluated against untargeted moments. First, and most importantly, we use novel time series data on the

Figure 12: Model fit for the exercise with technological progress



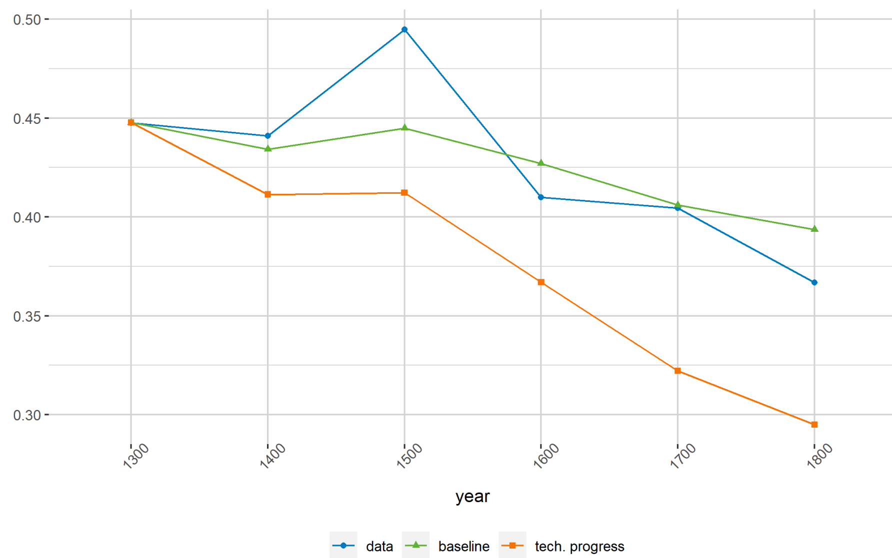
Notes: The figure reports the evolution of the moments used as targets in the estimation of the trade costs parameters, both in the data (blue dots) and in the model (red triangles), at the estimated parameter values, when the vector of manufacturing productivities evolves according to equation (22). The three moments, shown from left to right in the three corresponding panels, are: i) the correlation between urban population and local agricultural suitability; ii) the share of the urban population in Northern Europe; iii) the share of urban population in the top 10 percent of the city-size distribution.

evolution of agricultural prices across several hundred markets from Federico et al. [2021]. We then use moments from the urban data that we did not use to estimate the model.

Agricultural prices To create a measure for the level of dispersion of agricultural prices, we take the raw data from Federico et al. [2021] and compute the coefficient of variation for each century. Since this is a scale free measure of dispersion, we can compare it to the coefficient of variation of the spatio-temporal series of agricultural prices from our model. Figure 13 illustrates that the model performs well when benchmarked against these external data. Both the overall trend of a falling degree of dispersion and the temporary increase in dispersion between 1400 and 1600 are being matched. Note that this pattern of a temporary uptick in 1500 is completely untargeted, lending credence to the interpretation that this movement in the population distribution is indeed related to trade frictions.

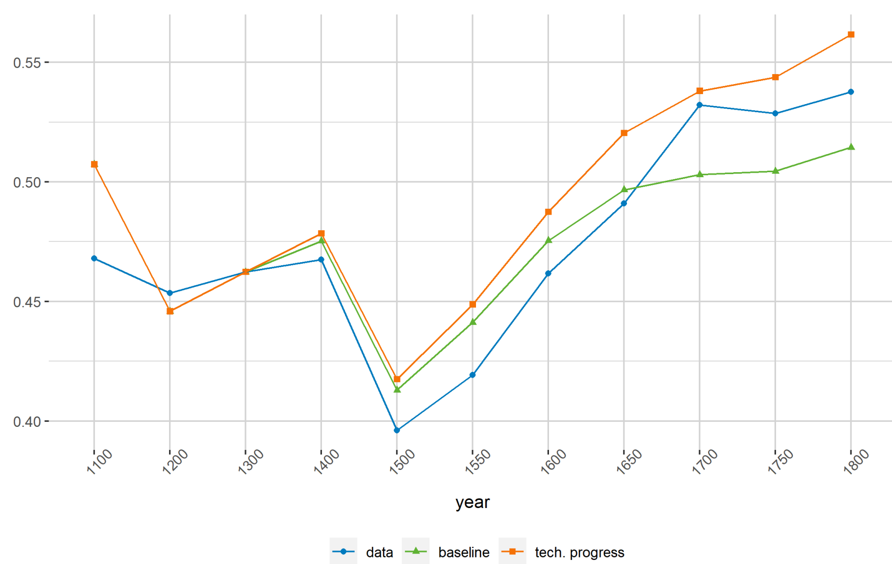
City-size distribution To evaluate how the the results of the model perform against other moments from the Buringh [2021] data, we compute the Gini index of the city-size distribution. Figure 14 shows that the Gini index resulting from the estimated distribution of city sizes for both the model with and without technological progress line up well with the data. There is an initial decrease of the "degree of inequality" in city size followed by a sharp increase after 1500.

Figure 13: Coefficient of variation of agricultural prices



Notes: The figure reports the evolution of the coefficient of variation of agricultural prices from year 1100 to 1800 in the data (blue line), in the baseline model (green line) with the estimated trade frictions from Figure 7 and constant productivity, and in the model with technological progress (orange line) with the estimated trade frictions from Figure (11 and manufacturing productivity evolving according to equation (22). The data series is based on Federico et al. [2021]'s dataset.

Figure 14: Gini index of the city-size distribution



Notes: The figure reports the evolution of the Gini index of the city-size distribution from year 1100 to 1800 in the data (blue line), in the baseline model (green line) with the estimated trade frictions from Figure 7 and constant productivity, and in the model with technological progress (orange line) with the estimated trade frictions from Figure (11 and manufacturing productivity evolving according to equation (22).

6 Concluding Remarks

The peculiar evolution of the spatial distribution of economic activity in historical Europe, with a shift of population towards the North of the continent and the emergence of large manufacturing cities, has been often regarded as a pre-condition for the Industrial revolution and the rise of Europe. Furthermore, given the large spatial persistence of economic activities, understanding the drivers of the location of historical urban population and city sizes is key also to understand the working of modern economies. Scholars debate, since decades, multiple hypothesis ranging from the role of shocks, market integration to the development of formal institutions. Lack of data still poses, and will most likely always pose, a serious challenge to the understanding of the historical facts. As a result, existing arguments are often developed on intuitive, a-spatial grounds, and evidence is at most based on reduced form regressions of city growth that offer a limited scope for exploring mechanisms. The analysis in this paper revisits the long-lasting question of the drivers of the evolution of urban Europe. Specifically, we build on the recent literature on quantitative-spatial analysis with disaggregated, geo-referenced data as a tool to advance the understanding of both the theoretical and quantitative implications of historical structural transformations and shocks.

We have offered a first attempt to systematically measure the main facts of the changes that urban Europe underwent from the middle ages until the eve of the Industrial Revolution. We have conceptualized, in particular, the predicted implications of the historical changes in market integration for the evolution of the distribution of urban population across the main urban settlements. The analysis has been motivated also by extensive narratives of economic historians that portray increasing intercity trade and market integration of valuable manufacturing goods already during the middle ages. This is subsequently followed by increasing trade also for bulkier agricultural subsistence goods, e.g. grains. We build a model that allows to study the role of trade frictions in pre-industrial economies that, as for developing countries still today, heavily rely on (local) agricultural production for subsistence. Specifically, our quantitative model builds on state-of-the-art economic geography models, but extends the scope of the analysis to multiple production sectors, agriculture and manufacturing, featuring different degrees of congestion and agglomeration externalities. We propose a methodology to solve the equilibrium of the model with the endogenous characterization of the borders of the agricultural hinterlands around cities. The theoretical analysis allows to derive general equilibrium predictions on the implications of reducing trade-frictions in the different sectors.

The task of assessing the empirical impact of trade frictions on a pan-European perspective was hitherto not possible due to non-existing data on prices, wages, and, most importantly, trade flows (with the exception of a few scattered cities in selected periods). To overcome the severe data limitations on trade frictions and trade-flows, we perform a structural estimation of the latent trade frictions off the moments of the urban distribution in 11 periods from 1100 to 1800 A.D. They roughly cover the period from the later middle ages to the onset of the Industrial Revolution in many parts of Europe. Our estimates exhibit a differential decrease in trade frictions that is consistent with existing historical narratives: the estimated latent trade-frictions first decline in manufacturing from around 1200 and then more visibly also in agriculture from c. 1600, when Europe entered a so-called "age of crisis".

We initialize the model to match the initial city distribution and apply the estimated changes in trade frictions to simulate the evolution of population growth across the 500 cities of the urban network from year 1200 to 1800. The analysis delivers several insights. First, increasing market integration in manufacturing and in agriculture have very different effects on the spatial location of economic activity across the network of urban settlements. Starting from comparatively autarchic agricultural hinterlands, the increasing trade in manufacturing leads to a dispersion of economic activity across many intermediate size cities and induces a relocation of population towards the center of the city network, that is the urban belt. This process also induces a comparative decline of the Mediterranean basin even prior the Black Death. Second, lower trade frictions in agricultural goods around 1600 helps unfolding agglomeration externalities in the manufacturing sector and facilitate the rise of bigger urban centers, specialized in manufacturing production. Finally, the combination of these effects with the peculiar geography of Europe implies a progressive shift of urban population to the North and the rise of manufacturing cities particularly in the locations that benefit, most importantly due to geography, from the possibility to import subsistence foodstuff (e.g. locations in Britain or the Low Countries). The increasing trade of agricultural goods can explain the increasing concentration of economic activities in few bigger cities in the last centuries prior to the Industrial Revolution and the associated vanishing importance of having a fertile hinterland for urban success.

A set of counterfactual analysis shows the technological progress alone cannot explain the main facts but that the joint consideration of the reductions in trade frictions and technological progress can offer a powerful, but so far neglected, explanation of the main facts of the development of pre-industrial Europe. As a result, the estimated changes in trade frictions when applied to the actual European geography, together with some technological progress, can explain a non-negligible part of three key macro-facts of the European economy. Further counterfactual analysis shows that the shift observed relocation of economic activity is largely imputed to the specific geography of Europe with its long coastlines, dense network of navigable rivers and the North Sea. The results therefore allow to provide an illustration of the key importance that trade and geography might have played for Europe on its pathway to the onset of modern economic growth.

The analysis also allows to study the performance of the model for un-targeted data moments and, interestingly, it allows to derive the predicted paths of urban growth for all areas and each of the cities in the sample. This allows to point out some interesting avenues for further research. Not surprisingly, the model tends to over-estimate city growth in areas and locations that suffered from declines related to shocks (e.g. cities affected by pandemic or plundering) or that belonged to polities or civilizations facing decline (e.g. the decline of Muslim Spain or the fading out of Venice after loosing its colonies) The model also systematically underestimates the growth of capital cities and, more generally, of cities that gain economic importance in the process of the emergence of modern states. In contrast, the model does a surprisingly good job in predicting the growth of cities that, according to narratives, owe their fortunes to manufacturing and trade. While we have abstracted from the consideration of polity borders and political frictions, the data suggest that a substantial part of urban growth is likely related to the evolution of the political landscape (which is not considered in the model). Incorporating the evolution of political borders and frictions into quantitative spatial analysis appears a key, although far from trivial, avenue for future research.

References

Abel, W. (1981): *Stufen der Ernährung: Eine historische Skizze*, Göttingen: Vandenhoeck & Ruprecht.

Abu-Lughod, J. L. (1989): *Before European Hegemony: The World System A.D. 1250-1350*, Oxford University Press.

Acemoglu, D., S. Johnson, and J. Robinson (2005): "The Rise of Europe: Atlantic Trade, Institutional Change, and Economic Growth," *American Economic Review*, 95, 546–579.

Allen, R. C. (2000): "Economic Structure and Agricultural Productivity in Europe, 1300–1800," *European Review of Economic History*, 4, 1–25.

——— (2001): "The Great Divergence in European Wages and Prices from the Middle Ages to the First World War," *Explorations in Economic History*, 38, 411–447.

——— (2003): "Progress and Poverty in Early Modern Europe," *The Economic History Review*, 56, 403–443.

Allen, T. and C. Arkolakis (2014): "Trade and the Topography of the Spatial Economy," *The Quarterly Journal of Economics*, 129, 1085–1140.

Allen, T. and D. Donaldson (2018): "The Geography of Path Dependence," *mimeo*, 48.

Andersen, T. B., C.-J. Dalgaard, and P. Selaya (2016a): "Climate and the Emergence of Global Income Differences," *The Review of Economic Studies*, 83, 1334–1363.

Andersen, T. B., P. S. Jensen, and C. V. Skovsgaard (2016b): "The Heavy Plow and the Agricultural Revolution in Medieval Europe," *Journal of Development Economics*, 118, 133–149.

Ashraf, Q. and S. Michalopoulos (2015): "Climatic Fluctuations and the Diffusion of Agriculture," *The Review of Economics and Statistics*, 97, 589–609.

Atkinson, A. B. (1970): "On the Measurement of Inequality," *Journal of Economic Theory*, 2, 244–263.

Bairoch, P. (1988): *Cities and Economic Development*, University of Chicago Press.

Bairoch, P., J. Batou, and P. Chèvre (1988): *La Population des villes européennes de 800 à 1850*, Geneve: Droz.

Barbour, V. (1963): *Capitalism in Amsterdam in the 17th Century*, University of Michigan Press.

Bartlett, R. (1993): *The Making of Europe: Conquest, Colonization and Cultural Change 950 - 1350*, Allen Lane.

Bosker, M., E. Buringh, and J. L. van Zanden (2013): "From Baghdad to London: Unraveling Urban Development in Europe, the Middle East, and North Africa, 800–1800," *The Review of Economics and Statistics*, 95, 1418–1437.

Braudel, F. (1988): *The Identity of France, Volume 2: People and Production*, Collins.

Burchardi, K. B., T. Chaney, T. A. Hassan, L. Tarquinio, and S. J. Terry (2020): "Immigration, Innovation, and Growth," Working Paper 27075, National Bureau of Economic Research.

Buringh, E. (2021): "The Population of European Cities from 700 to 2000: Social and Economic History," *Research Data Journal for the Humanities and Social Sciences*, -1, 1–18.

Cervellati, M., S. Lazzaroni, G. Prarolo, and P. Vanin (2019): "Political Geography and Pre-Industrial Development: A Theory and Evidence for Europe 1000-1850," *CEPR Discussion Paper.*

Chilosi, D., T. E. Murphy, R. Studer, and A. C. Tunçer (2013): "Europe's many integrations: Geography and grain markets, 1620–1913," *Explorations in Economic History*, 50, 46–68.

Clark, C. and M. Haswell (1964): *The Economics of Subsistence Agriculture*, London: Macmillan.

Combes, P.-P. and L. Gobillon (2015): "Chapter 5 - The Empirics of Agglomeration Economies," in *Handbook of Regional and Urban Economics*, ed. by G. Duranton, J. V. Henderson, and W. C. Strange, Elsevier, vol. 5 of *Handbook of Regional and Urban Economics*, 247–348.

Coşar, A. K. and P. D. Fajgelbaum (2016): "Internal Geography, International Trade, and Regional Specialization," *American Economic Journal: Microeconomics*, 8, 24–56.

Crosby, A. W. (1972): *The Columbian Exchange: Biological and Cultural Consequences of 1492*, Greenwood Publishing Company.

Davis, K. (1955): "The Origin and Growth of Urbanization in the World," *American Journal of Sociology*, 60, 429–437.

Davis, R. (1973): *The Rise of the Atlantic Economies*, Ithaca, NY: Cornell University Press, 1st edition ed.

de la Croix, D., F. Docquier, A. Fabre, and R. Stelter (2020): "The Academic Market and the Rise of Universities in Medieval and Early Modern Europe (1000-1800)," Tech. Rep. 14509, C.E.P.R. Discussion Papers.

De Long, J. B. and A. Shleifer (1993): "Princes and Merchants: European City Growth before the Industrial Revolution," *The Journal of Law and Economics*, 36, 671–702.

de Vries, J. (1984): *European Urbanization, 1500-1800*, London: Routledge.

de Zwart, P. and J. L. van Zanden (2018): *The Origins of Globalization: World Trade in the Making of the Global Economy, 1500–1800*, Cambridge University Press.

Desmet, K., D. K. Nagy, and E. Rossi-Hansberg (2018): "The Geography of Development," *Journal of Political Economy*, 126, 903–983.

Desmet, K. and S. L. Parente (2012): "The Evolution of Markets and the Revolution of Industry: A Unified Theory of Growth," *Journal of Economic Growth*, 17, 205–234.

Desmet, K. and E. Rossi-Hansberg (2014): "Spatial Development," *The American Economic Review*, 104, 1211–1243.

Dittmar, J. (2020): "Cities, Markets, and Growth: The Emergence of Zipf 's Law," *mimeo.*

Duranton, G. and D. Puga (2004): "Micro-Foundations of Urban Agglomeration Economies," in *Handbook of Regional and Urban Economics*, Elsevier, vol. 4, 2063–2117.

Eckert, F. and M. Peters (2018): "Spatial Structural Change$_*$," 61.

Epstein, S. A. (2009): *An Economic and Social History of Later Medieval Europe, 1000-1500*, Cambridge University Press.

Epstein, S. R. (2000): *Freedom and Growth: The Rise of States and Markets in Europe, 1300-1750*, London: Routledge.

Epstein, S. R., ed. (2001): *Town and Country in Europe, 1300-1800*, Cambridge UK ;;New York: Cambridge University Press.

Fajgelbaum, P. D. and S. J. Redding (2018): "Trade, Structural Transformation and Development: Evidence from Argentina 1869-1914," *mimeo.*

Federico, G., M.-S. Schulze, and O. Volckart (2021): "European Goods Market Integration in the Very Long Run: From the Black Death to the First World War," *The Journal of Economic History*, 81, 276–308.

Findlay, R. and K. H. O'Rourke (2007): *Power and Plenty: Trade, War, and the World Economy in the Second Millennium*, Princeton, N.J.: Princeton University Press.

Fochesato, M. (2018): "Origins of Europe's North-South Divide: Population Changes, Real Wages and the 'Little Divergence' in Early Modern Europe," *Explorations in Economic History*, 70, 91–131.

Fouquet, R. and S. Broadberry (2015): "Seven Centuries of European Economic Growth and Decline," *Journal of Economic Perspectives*, 29, 227–244.

Galor, O. (2005): "From Stagnation to Growth: Unified Growth Theory," in *Handbook of Economic Growth*, ed. by P. Aghion and S. Durlauf, Elsevier, vol. 1, Part A, chap. 04, 171–293, first ed.

Galor, O. and A. Mountford (2006): "Trade and the Great Divergence: The Family Connection," *American Economic Review*, 96, 299–303.

——— (2008): "Trading Population for Productivity: Theory and Evidence," *The Review of Economic Studies*, 75, 1143–1179.

Galor, O. and Ö. Özak (2016): "The Agricultural Origins of Time Preference," *American Economic Review*, 106, 3064–3103, https://ozak.github.io/Caloric-Suitability-Index/.

Galor, O. and D. N. Weil (2000): "Population, Technology, and Growth: From Malthusian Stagnation to the Demographic Transition and Beyond," *American Economic Review*, 90, 806–828.

Grigg, D. (1992): *The Transformation of Agriculture in the West*, Oxford, UK ; Cambridge, USA: Blackwell Pub, first edition edition ed.

Grigg, D. B. (1980): *Population Growth and Agrarian Change: An Historical Perspective*, Cambridge Eng. ; New York: Cambridge University Press.

Henderson, V., T. Squires, A. Storeygard, and D. Weil (2018): "The Global Distribution of Economic Activity: Nature, History, and the Role of Trade," *The Quarterly Journal of Economics*, 133, 357–406.

Hohenberg, P. M. and L. H. Lees (1995): *The Making of Urban Europe, 1000-1994*, Harvard University Press.

Humphries, J. and J. Weisdorf (2019): "Unreal Wages? Real Income and Economic Growth in England, 1260–1850," *The Economic Journal*, 129, 2867–2887.

Israel, J. (1995): *The Dutch Republic: Its Rise, Greatness, and Fall 1477-1806*, Oxford History of Early Modern Europe, Oxford, New York: Oxford University Press.

Jacob, M. C. (1997): *Scientific Culture and the Making of the Industrial West*, New York: Oxford University Press, subsequent edition ed.

Jedwab, R., N. D. Johnson, and M. Koyama (2019): "Bones, Bacteria and Break Points: The Heterogeneous Spatial Effects of the Black Death and Long-Run Growth," .

Jones, C. I. (1995): "R&D-Based Models of Economic Growth," *Journal of Political Economy*, 103, 759–784.

Jones, E. (2003): *The European Miracle: Environments, Economies and Geopolitics in the History of Europe and Asia*, Cambridge, UK ; New York, NY: Cambridge University Press, 3rd edition ed.

Jones, E. L. (1968): "Agricultural Origins of Industry," *Past & Present*, 58–71.

Jones, W. N. P. a. E. L. (1975): *European Peasants and Their Markets. Essays in Agrarian Economic History*, Princeton University Press.

Lopez, R. S. (1976): *The Commercial Revolution of the Middle Ages, 950-1350*, Cambridge University Press.

Lucassen, J. and L. Lucassen (2009): "The Mobility Transition Revisited, 1500–1900: What the Case of Europe Can Offer to Global History," *Journal of Global History*, 4, 347–377.

Malanima, P. (1998): "Italian Cities 1300-1800. A Quantitative Approach," *Rivista di storia economica*, 91–126.

——— (2009a): *Pre-Modern European Economy: One Thousand Years (10th-19th Centuries)*, Boston, NETHERLANDS: BRILL.

——— (2009b): *Pre-Modern European Economy: One Thousand Years (10th-19th Centuries)*, Boston, NETHERLANDS: BRILL.

——— (2010): "Urbanisation," in *Volume 1: 1700-1870*, ed. by S. Broadberry and K. H. O'Rourke, Cambridge University Press, The Cambridge Economic History of Modern Europe, 235–263.

——— (2013): "When Did England Overtake Italy? Medieval and Early Modern Divergence in Prices and Wages," *European Review of Economic History*, 17, 45–70.

Masschaele, J. (1993): "Transport Costs in Medieval England," *The Economic History Review*, 46, 266–279.

Mayshar, J., O. Moav, and Z. Neeman (2017): "Geography, Transparency, and Institutions," *American Political Science Review*, 1–15.

Michalopoulos, S., A. Naghavi, and G. Prarolo (2018): "Trade and Geography in the Spread of Islam," *The Economic Journal*, 128, 3210–3241.

Michalopoulos, S. and E. Papaioannou (2018): "Spatial Patterns of Development: A Meso Approach," *Annual Review of Economics*, 10, 383–410.

Moch, L. P. (2003): *Moving Europeans: Migration in Western Europe since 1650*, Interdisciplinary Studies in History, Bloomington: Indiana University Press, 2nd ed ed.

Mokyr, J. (2002): *The Gifts of Athena: Historical Origins of the Knowledge Economy*, Princeton, NJ: Princeton University Press.

——— (2016): *A Culture of Growth: The Origins of the Modern Economy*, Princeton University Press.

Monte, F., S. J. Redding, and E. Rossi-Hansberg (2018): "Commuting, Migration, and Local Employment Elasticities," *American Economic Review*, 108, 3855–3890.

Nagy, D. K. (2015): "Border Effects and Urban Structure," *mimeo*.

——— (2020): "Hinterlands, City Formation and Growth: Evidence from the U.S. Westward Expansion," *mimeograph*.

——— (2021): "Quantitative Economic Geography Meets History: Questions, Answers and Challenges," *Regional Science and Urban Economics*, 103675.

North, D. and B. Weingast (1989): "Constitutions and Commitment: The Evolution of Institutions Governing Public Choice in Seventeenth-Century England," *The Journal of Economic History*, 49, 803–832.

Overton, M. (1996): *Agricultural Revolution in England: The Transformation of the Agrarian Economy 1500-1850*, Cambridge ; New York: Cambridge University Press.

Pamuk, Ş. (2007): "The Black Death and the Origins of the 'Great Divergence' across Europe, 1300–1600," *European Review of Economic History*, 11, 289–317.

Peters, M. (2021): "Market Size and Spatial Growth - Evidence from Germany's Post-War Population Expulsions," Tech. Rep. 29329, National Bureau of Economic Research, Inc.

——— (2022): "Market Size and Spatial Growth—Evidence From Germany's Post-War Population Expulsions," *Econometrica*, 90, 2357–2396.

Pounds, N. J. G. (1979): *An Historical Geography of Europe, 1500-1840*, Cambridge University Press.

Ramankutty, N., J. A. Foley, J. Norman, and K. McSweeney (2002): "The Global Distribution of Cultivable Lands: Current Patterns and Sensitivity to Possible Climate Change," *Global Ecology and Biogeography*, 11, 377–392.

Redding, S. and E. Rossi-Hansberg (2017): "Quantitative Spatial Economics," *Annual Review of Economics*, 9, 21–58.

Rosenthal, S. S. and W. C. Strange (2004): "Evidence on the Nature and Sources of Agglomeration Economies," in *Handbook of Regional and Urban Economics*, Elsevier, vol. 4, 2119–2171.

Rota, M. and J. Weisdorf (2020): "Italy and the Little Divergence in Wages and Prices: New Data, New Results," *The Journal of Economic History*, 80, 931–960.

Schäfer, R. (2013): "Rural–Urban Migrations, Medieval Era," in *The Encyclopedia of Global Human Migration*, American Cancer Society.

Schultz, T. W. (1968): *Economic Growth and Agriculture*, McGraw-Hill.

Serafinelli, M. and G. Tabellini (2022): "Creativity over Time and Space," *Journal of Economic Growth*, 27, 1–43.

Stoob, H. (1979): "Die Hochmittelalterliche Städtebildung Im Okzident," in *Die Stadt. Gestalt Und Wandel Bis Zum Industriellen Zeitalter*, 131–156.

van der Woude, A., A. Hayami, and J. de Vries, eds. (1990): *Urbanization in History: A Process of Dynamic Interactions*, Oxford: Oxford University Press.

van Zanden, J. L. (2009): *The Long Road to the Industrial Revolution: The European Economy in a Global Perspective, 1000-1800*, BRILL.

White, L. J. (1962): *Medieval Technology and Social Change*, Oxford University Press.

Appendix

A Scale invariance

We show that the system of equations (15)-(21) has scale-invariance properties. That is, the rescaled variables $\tilde{L}_i^M \equiv L_i^M/c$, $\tilde{L}_i^A \equiv L_i^A/c$, and $\tilde{L}_i \equiv L_i/c$, for $c \neq 0$, are the solutions to a system equivalent to (15)-(21), after a suitable rescaling of the price indexes and the welfare scalar.

To see this, note that (15) can be rewritten as:

$$w_i^{\sigma^M}(\tilde{L}_i^M)^{1-(\sigma^M-1)\gamma_1} = \alpha \sum_{y_i \in \mathcal{Y}} (\tau_{s,i}^M)^{1-\sigma^M} c^{(\sigma^M-1)\gamma_1} (P_i^M)^{\sigma^M-1} (\hat{\phi}_i^M)^{\sigma^M-1} w_i \tilde{L}_i.$$

Second, define $\tilde{P}_i^M \equiv c^{\gamma_1} P_i^M$, so that

$$\left(\tilde{P}_i^M\right)^{1-\sigma_M} = c^{(1-\sigma^M)\gamma_1}(P_i^M)^{1-\sigma^M} = \sum_{y_i \in \mathcal{Y}} (\tau_{s,i}^M)^{1-\sigma^M} (\hat{\phi}_i^M)^{\sigma^M-1} w_i^{1-\sigma^M} (\tilde{L}_i^M)^{(\sigma^M-1)\gamma_1}.$$

It follows that equations (15)-(16) can be rewritten in terms of the rescaled variables $\tilde{L}_i^M, \tilde{L}s$, and $\tilde{P}_i^M$. Following the same steps, it can be shown that equations (17)-(18) can be written in terms of $\tilde{L}_i^A, \tilde{L}s$, and $\tilde{P}_i^A$, where $\tilde{P}_i^A \equiv c^{-(1-\beta)} P_i^A$.

Written in terms of the rescaled prices, the welfare equalization condition (19) becomes:

$$w_i = \frac{V}{c^{\alpha\gamma_1-(1-\alpha)(1-\beta)}} (\tilde{P}_i^M)^{\alpha} (\tilde{P}_i^A)^{1-\alpha}, \quad \forall s \in S$$

Equations (20) and (21) trivially hold after the rescaling. Finally, the farmer's problem in (**??**) is also invariant with respect to multiplicative constants.

B Numerical procedure

We adapt the technique developed in Allen, Arkolakis and Li (2016), and proceed in two steps. First, we find a solution to the system fixing $V = 1$. Then, we adjust V so that the constraint on total manufacturing population holds.

In order to carry out step 1, we further elaborate on the system (15)-(19) to reduce the number of variables we need to solve for in the numerical procedure. First, rearrange (19) into: $P_i^M = V^{-\frac{1}{\alpha}} w_i^{\frac{1}{\alpha}} (P_i^A)^{-\frac{1-\alpha}{\alpha}}$ to substitute out P_i^M in (15); second, we use (16) to substitute out P_i^M in (19). We obtain the following system of three equations:

$$w_i^{\sigma^M}(L_i^M)^{1-(\sigma^M-1)\gamma_1} = \alpha \sum_{y_i \in \mathcal{Y}} (\tau_{i,s}^M)^{1-\sigma^M} (\tilde{\phi}_i^M)^{\sigma^M-1} (P_i^A)^{(1-\sigma^M)\frac{1-\alpha}{\alpha}} w_i^{1+\frac{\sigma^M-1}{\alpha}} L_i, \tag{23}$$

$$w_i^{\sigma^A}(L_i^A)^{1+(\sigma^A-1)(1-\beta)} = (1-\alpha) \sum_{y_i \in \mathcal{Y}} (\tau_{s,i}^A)^{1-\sigma^A} (P_i^A)^{\sigma^A-1} B_i^{(\sigma^A-1)(1-\beta)} w_i L_i, \tag{24}$$

$$w_i^{\frac{1-\sigma^M}{\alpha}} = \sum_{y_i \in \mathcal{Y}} (\tau_{i,s}^M)^{1-\sigma^M} (\tilde{\phi}_i^M)^{\sigma^M-1} (P_i^A)^{(1-\sigma^M)\frac{1-\alpha}{\alpha}} w_i^{1-\sigma^M} (L_i^M)^{(\sigma^M-1)\gamma_1}, \tag{25}$$

where P_i^A is given by (18).

Our convergence procedure nests two loops: in the inner loop, we find the equilibrium values of L^A, L^M and w such that (23),(24),(25) hold for a given value of the Voronoi weights; in the outer loop, we update the value of the Voronoi weights and iterate until convergence. In detail, the steps of the convergence procedure are:

1. guess the optimal choices of farmers;
2. given these choices, compute total agricultural TFP in each rural hinterland, net of shipping costs, B_i;
3. guess initial values for wages, agricultural labor and manufacturing labor in all cities $s \in S$;
4. given these values, compute the P^A using (18);
5. given P^A, and the previous guess, compute the left-hand sides of equations (23), (24), and (25);
6. back out updated values for wages, agricultural labor and manufacturing labor;
7. compute the optimal choices of farmers
8. check the convergence criterion and, if not met, iterate from step 1;

C Proofs

Proof of Proposition 1.

$$\frac{\partial}{\partial Z^M}\left(\frac{\mathrm{d}L^M}{\mathrm{d}\phi^M}\right) = \frac{\alpha}{2}\left(\frac{2\sigma^M - 1}{(\rho^1 - \rho^2 Z^M)^2}\right)\left[1 - \left(\frac{1-\alpha}{\alpha}\right)(1-\beta)\right]$$

□

Proof of Proposition 2. The proof involves some tedious algebra. First, note that the partial derivative of $\mathrm{d}L^M/\mathrm{d}\phi^M$ with respect to Z^M can be studied by focusing on the term $\Psi^M/(1-\alpha Z^M)$. We have:

$$\frac{\partial}{\partial Z^M}\frac{\Psi^M}{1-\alpha Z^M} = \frac{2}{(1-\alpha Z^M)^3}\left[\frac{\alpha}{2}(2\sigma^M - 1) - Z^M\left(\sigma^M - 1 + \alpha(1-\alpha) + \frac{\alpha^2}{2} - \frac{\alpha(1-\alpha)\sigma^A}{1+(\sigma^A)(1-\beta)}\right)\right]$$

Write in term in square brackets as: $A - Z^M B$, where:

$$A = \frac{\alpha}{2}(2\sigma^M - 1), \quad B = \sigma^M - 1 + \alpha(1-\alpha) + \frac{\alpha^2}{2} - \frac{\alpha(1-\alpha)\sigma^A}{1+(\sigma^A)(1-\beta)}.$$

The derivative with respect to Z^M is hump-shaped if and only if $B > 0$ and $A/B < 1$. Otherwise, it is positive for all values of Z^M. This completes the first part of the proof. Suppose now that $\sigma^M = \sigma^A = \sigma$. The expression for B can be rearranged so that:

$$B = \frac{\alpha^2}{2} + \frac{\sigma - 1}{1-(\sigma-1)(1-\beta)}\Big((1-\beta)\sigma + (1-\alpha(1-\alpha)\beta\Big),$$

which is always positive. We next need to show that $A/B < 1$, or $B - A > 0$, for σ sufficiently high. Using the original expression for B, we have:

$$B - A = (1-\alpha)\left[\sigma\left(1 - \frac{\alpha}{1+(\sigma-1)(1-\beta)}\right) + \alpha\right] + \frac{\alpha}{2} - 1 + \frac{\alpha^2}{2}$$

Note that this expression is positive if the term in square brackets is greater that one half. But since:

$$1 - \frac{\alpha}{1+(\sigma-1)(1-\beta)} > 1 - \alpha,$$

the term in square brackets will be greater than one. Therefore $\mathrm{d}L^M/\mathrm{d}\phi^M$ will be increasing in Z^M for $0 < Z^M < A/B < 1$, and decreasing otherwise. This concludes the proof. □

Proof of Proposition 3. We can focus on the term:

$$\frac{\Psi^A}{(Z^A)^2} = (1-\alpha)^2 - (1-\alpha)(1-\beta) - (\sigma^A-1)(1-\beta) + \frac{1}{(Z^A)^2} + \frac{(\sigma^A-1)(1-\beta)}{(Z^A)^2} + \frac{(1-\alpha)(1-\beta)}{Z^A} - \frac{2(1-\alpha)}{Z^A}.$$

Its derivative with respect to Z^A is given by:

$$\frac{\partial}{\partial Z^A}\frac{\Psi^A}{(Z^A)^2} = -\frac{2}{(Z^A)^3}\left[1 + (\sigma^A-1)(1-\beta) - (1+\beta)\left(\frac{1-\alpha}{2}\right)Z^A\right].$$

Since $\sigma^A > 1$, $alpha < 1$, $\beta < 1$, and $Z^A \geq 1$, the term in brackets is positive, and the derivative is negative. It follows that the derivative of $\mathrm{d}L^A/\mathrm{d}\phi^M$ with respect to Z^A is negative. □

D Trade frictions and the distribution of economic activity: analytical results

While the model presented in the previous sections is suited for quantitative applications, it is too complex to derive analytic results. However, it is desirable to have a formal understanding of the main economic forces acting inside the model and, in particular, of those forces related to changes in the size of trade frictions.

To achieve this goal, we consider a stylized version of the model with two locations and with exogenous rural hinterlands. We then investigate the role of trade frictions in a neighborhood of the symmetric equilibrium, when a minimal amount of heterogeneity is introduced. This amounts to putting the model under the microscope to highlight an economic mechanism in the simplest possible setting [15].

Suppose the two locations are identical in terms of manufacturing and agricultural productivity. In a symmetric equilibrium, each location will host one half of the total population, and a share α will be employed in the manufacturing sector. Trade costs are symmetric and described by one parameter for each sector: T^M, T^A. By choice of units and numeraire, we

[15] Note that this exercise is different from the usual approach in New Economic Geography of characterizing the conditions for the existence of a stable symmetric equilibrium *vis a vis* a full agglomeration equilibrium. Instead, we restrict our attention to the parameter range where there is a unique and stable interior equilibrium, and asks whether trade frictions dampen or amplify productivity differences between locations.

have $w_1 = w_2 = 1$, $p_1^M = p_2^M = 1$, and $p_1^A = p_2^A = 1$. As in Fujita, Krugman, and Venables (2002), it will be convenient to define:

$$Z^M \equiv \frac{1-(T^M)^{1-\sigma^M}}{1+(T^M)^{1-\sigma^M}}, \quad Z^A \equiv \frac{1-(T^A)^{1-\sigma^A}}{1+(T^A)^{1-\sigma^A}};$$

Z^M and Z^A represent indices of trade costs ranging from 0, when trade is free, to $+\infty$, when trade is prohibitively costly. In the following, we will perturb the model with tiny productivity differences between locations, and investigate how Z^M and Z^A influence the reallocation of urban population in a neighborhood of a symmetric equilibrium. In particular, we focus on differences in the productivity of the manufacturing sector, motivated by the fact that, in our quantitative application, the variation of manufacturing productivity dwarfs the variation of agricultural productivity across locations.

Consider a relative increase in location 1's manufacturing productivity such that: $\mathrm{d}\phi_1^M = -\mathrm{d}\phi_2^M$. Around the symmetric equilibrium, any change in an endogenous variable x will take the form: $\mathrm{d}x_1 = -\mathrm{d}x_2$. As a result, we can focus on the equilibrium conditions for one location only, which greatly simplifies the problem.

Now, linearize the equilibrium conditions (15) - (20) around the symmetric equilibrium.

$$\begin{aligned}[1-(\sigma^M-1)\gamma-\alpha Z^M]\mathrm{d}L^M = &\frac{\alpha(\sigma^M-1)}{2}\mathrm{d}\phi^M + \frac{\alpha(\sigma^M-1)}{2}Z^M\frac{\mathrm{d}P^M}{P^M} \\ &- \frac{\alpha(\sigma^M-Z^M)}{2}\mathrm{d}w + \alpha Z^M \mathrm{d}L^A\end{aligned} \tag{26}$$

$$\frac{\mathrm{d}P^M}{P^M} = -Z^M\mathrm{d}\phi^M + Z^M\mathrm{d}w - \frac{2\gamma}{\alpha}\mathrm{d}L^M \tag{27}$$

$$\begin{aligned}[1+(\sigma^A-1)(1-\beta)-(1-\alpha)Z^A]\mathrm{d}L^A = &\frac{(1-\alpha)(\sigma^A-1)}{2}\mathrm{d}\phi^A + \frac{(1-\alpha)(\sigma^A-1)}{2}Z^A\frac{\mathrm{d}P^A}{P^A} \\ &- \frac{(1-\alpha)(\sigma^A-Z^A)}{2}\mathrm{d}w + (1-\alpha)Z^A\mathrm{d}L^M\end{aligned} \tag{28}$$

$$\frac{\mathrm{d}P^A}{P^A} = -Z^A\mathrm{d}\phi^A + Z^A\mathrm{d}w + \frac{2(1-\beta)}{1-\alpha}\mathrm{d}L^A \tag{29}$$

$$\mathrm{d}w = \alpha\frac{\mathrm{d}P^M}{P^M} + (1-\alpha)\frac{\mathrm{d}P^A}{P^A} \tag{30}$$

$$\mathrm{d}L = \mathrm{d}L^M + \mathrm{d}L^A \tag{31}$$

This is a linear system of equations that can be solved for $\mathrm{d}L^M, \mathrm{d}L^A, \mathrm{d}L, \mathrm{d}P^M, \mathrm{d}P^A, \mathrm{d}w$ as a function of $\mathrm{d}\phi^M$ and $\mathrm{d}\phi^A$.

D.1 Reducing trade costs for manufacturing goods

Case 1: $T^A = \infty$. We first explore the consequences of reducing trade costs for manufacturing goods when the agricultural good is not traded. In this case $Z^A = 1$. The sectoral allocation is fixed with $L^M = \alpha L$, and does not react to changes in productivity. After some tedious calculations, we obtain the following partial effect:

$$\frac{\mathrm{d}L^M}{\mathrm{d}\phi^M} = \frac{\alpha}{2}\left(\frac{\sigma^M - 1 + \sigma^M Z^M}{\rho^1 - \rho^2 Z^M}\right),$$

where ρ^1 and ρ^2 are defined from:

$$\rho^1 = 1 - (\sigma^M - 1)\gamma + \sigma^M \left(\frac{1-\alpha}{\alpha}\right)(1-\beta)$$
$$\rho^2 = 1 + \sigma^M\gamma - (\sigma^M - 1)\left(\frac{1-\alpha}{\alpha}\right)(1-\beta)$$

and parametrize the strength of agglomeration and congestion forces in the economy.

Proposition 1. *Suppose that $T^A \to \infty$. Then, lower trade costs for manufacturing goods dampen the impact of productivity differences in manufacturing on the allocation of urban population.*

Case 2: $T^A = 1$. When the agricultural good is freely traded, its price will be equal in both locations. We obtain the following partial effect.

$$\frac{\mathrm{d}L^M}{\mathrm{d}\phi^M} = \frac{\alpha}{2}\frac{\Psi^M}{1-\alpha Z^M - \gamma\Psi^M}$$

where Ψ^M is defined from:

$$\Psi^M = \frac{1}{1-\alpha Z^M}\left[(\sigma^M - 1)\big(1-(Z^M)^2\big) + \alpha Z^M(1-Z^M) + \frac{\alpha(1-\alpha)\sigma^A(Z^M)^2}{1+(\sigma^A-1)(1-\beta)}\right]$$

Proposition 2. *Suppose that $T^A = 1$. Depending on the values of $\alpha, \beta, \sigma^A, \sigma^M$, there are two cases: i. reducing Z^M dampens the impact of productivity differences in the manufacturing sector; ii. reducing Z^M dampens the impact of productivity differences in the manufacturing sector when the initial value of Z^M is low, whereas it amplifies them when the initial value of Z^M is high. In the special case $\sigma^M = \sigma^A = \sigma$, the second case always applies.*

Thus, at least for the parameter values that we use in the quantitative application (i.e., $\sigma^M = \sigma^A$), the impact of trade costs in the manufacturing sector will be bell-shaped when the agricultural good is freely traded.

D.2 Reducing trade costs for agricultural goods

Case 1: $T^M = \infty$. In this case the partial effect is given by:

$$\frac{\mathrm{d}L^M}{\mathrm{d}\phi^M} = \frac{1-\alpha}{2}\left(\frac{\sigma^A + (\sigma^A - 1)Z^A}{\hat{\rho}^1 - \hat{\rho}^2 Z^A}\right)$$

where $\hat{\rho}^1$ and $\hat{\rho}^2$ are now defined from:

$$\hat{\rho}^1 = 1 - \sigma^A\frac{\alpha}{1-\alpha}\gamma + (\sigma^A - 1)(1-\beta)$$
$$\hat{\rho}^2 = 1 + (\sigma^A - 1)\frac{\alpha}{1-\alpha}\gamma - \sigma^A(1-\beta).$$

Proposition 3. *Suppose that $T^A \to \infty$. Then, lower trade costs for agricultural goods dampen the impact of productivity differences in manufacturing on the allocation of urban population.*

Case 2: $T^M = 1$**.**

$$\frac{\mathrm{d}L^M}{\mathrm{d}\phi^M} = \frac{\alpha}{2} \frac{\sigma^M - 1}{1 - (\sigma^M - 1)\gamma + \frac{\alpha(1-\alpha)(1-\beta)\sigma^A (Z^A)^2}{\Psi^A}},$$

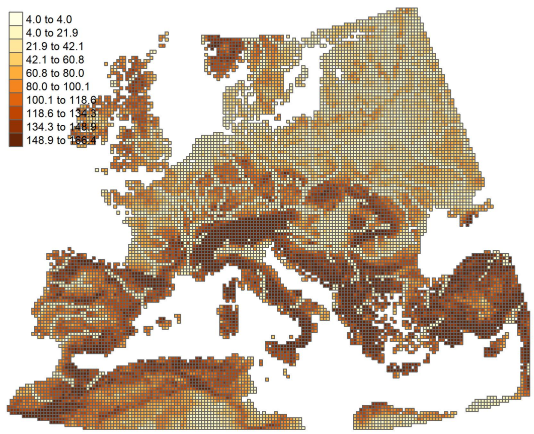
where Ψ^A is defined from:

$$\Psi^A = \Big(1 - (1-\alpha)Z^A\Big)^2 + (1-\beta)\Big((\sigma^A - 1)(1 - (Z^A)^2) + (1-\alpha)Z^A(1 - Z^A)\Big).$$

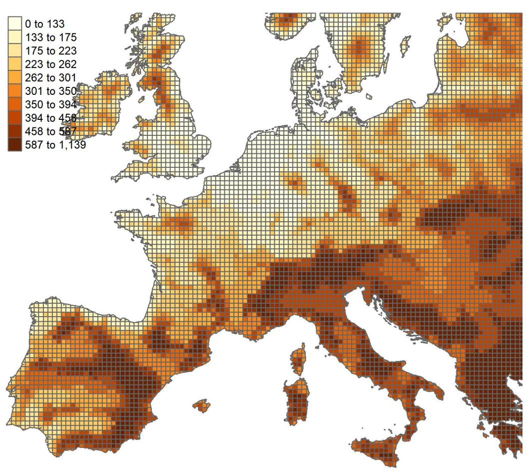
Proposition 4. *Suppose that $T^M = 1$. Then, reducing trade costs for agricultural goods amplifies the impact of productivity differences in the manufacturing sector on the allocation of urban population.*

E Computing bilateral distances

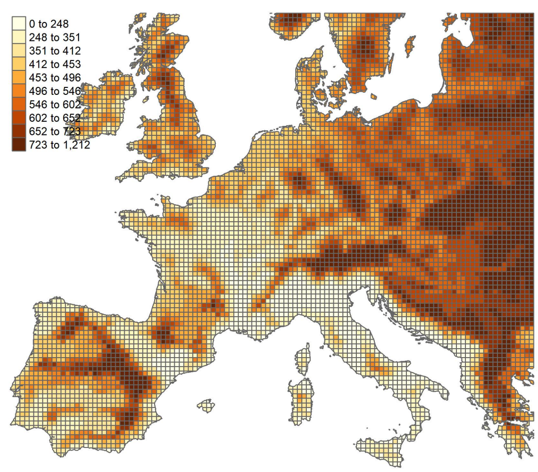
Figure 15: Computing the matrix of effective distances among grid-cells: an illustration



(a) Transit costs (excluding sea cells)



(b) Effective distances to London



(c) Effective distances to Milan

F Data

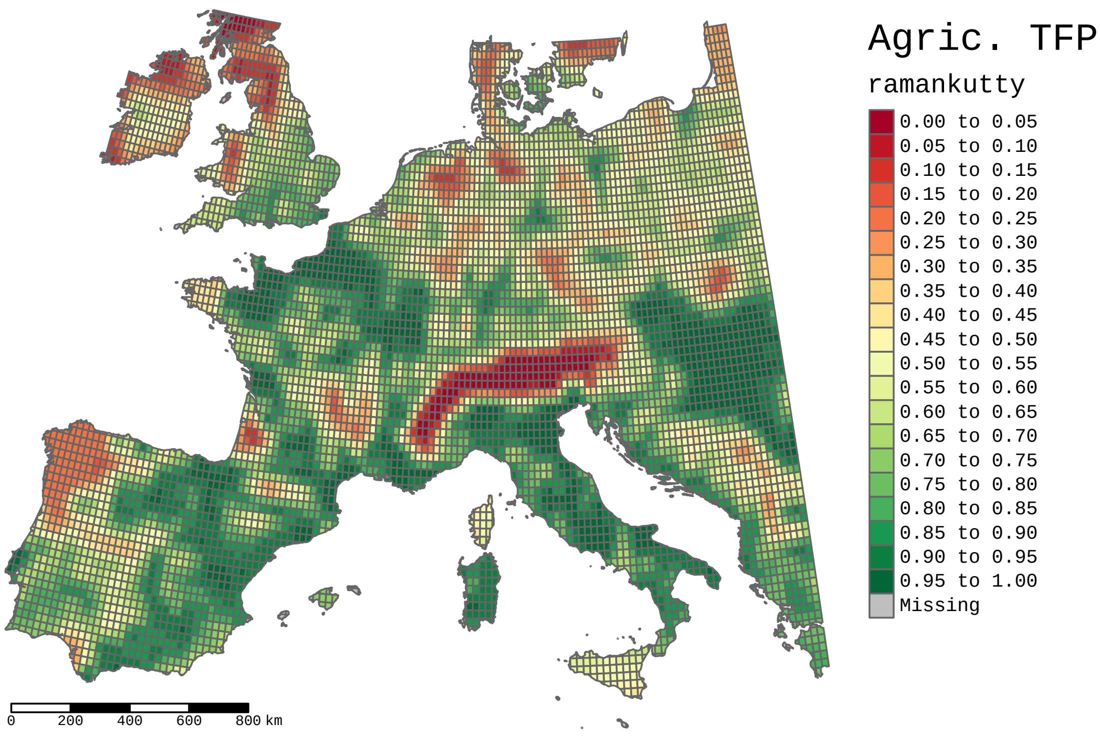


Figure 16: Agricultural productivity in each gridcell.

G Estimation

G.1 Initialization

H Computation

I Results

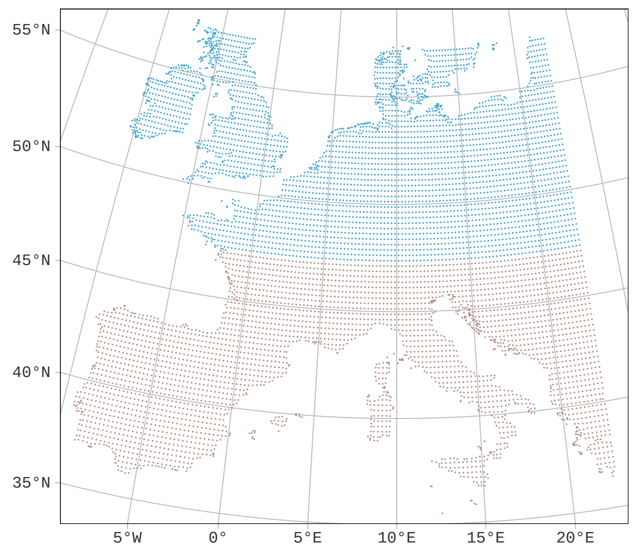


Figure 17: Illustration of the chosen bounding box on top of graticules. We define "Northern Europe" as every cell that is above 47 degrees of latitude, i.e. roughly speaking everything above the Alps.

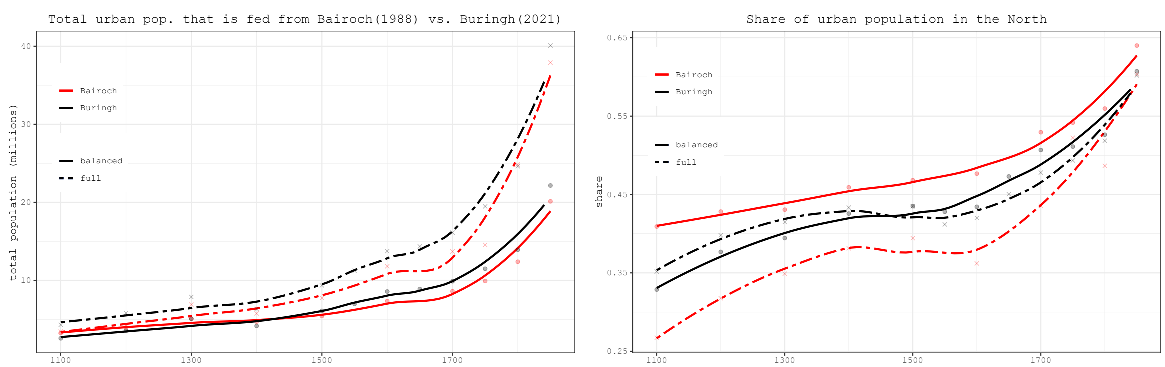


Figure 18: Plots to show robustness across datasets and full vs. balanced samples.

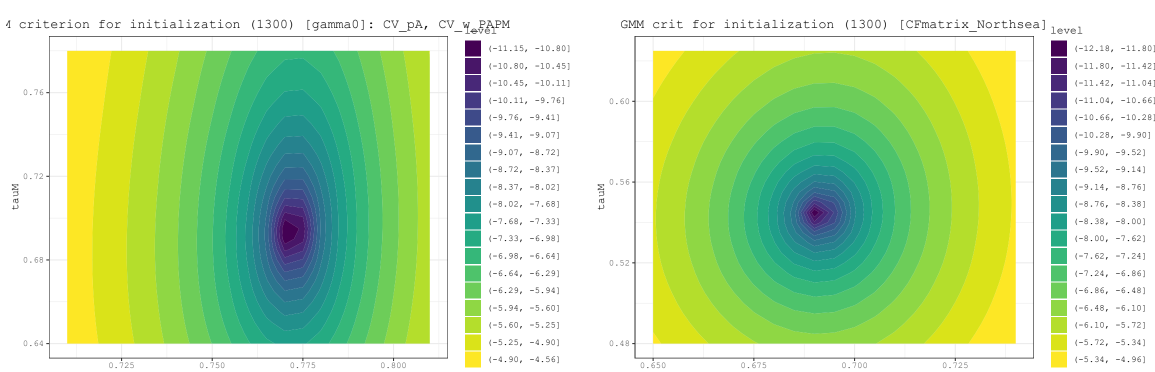


Figure 19: Initialization given both trade cost matrices have unique global minima.

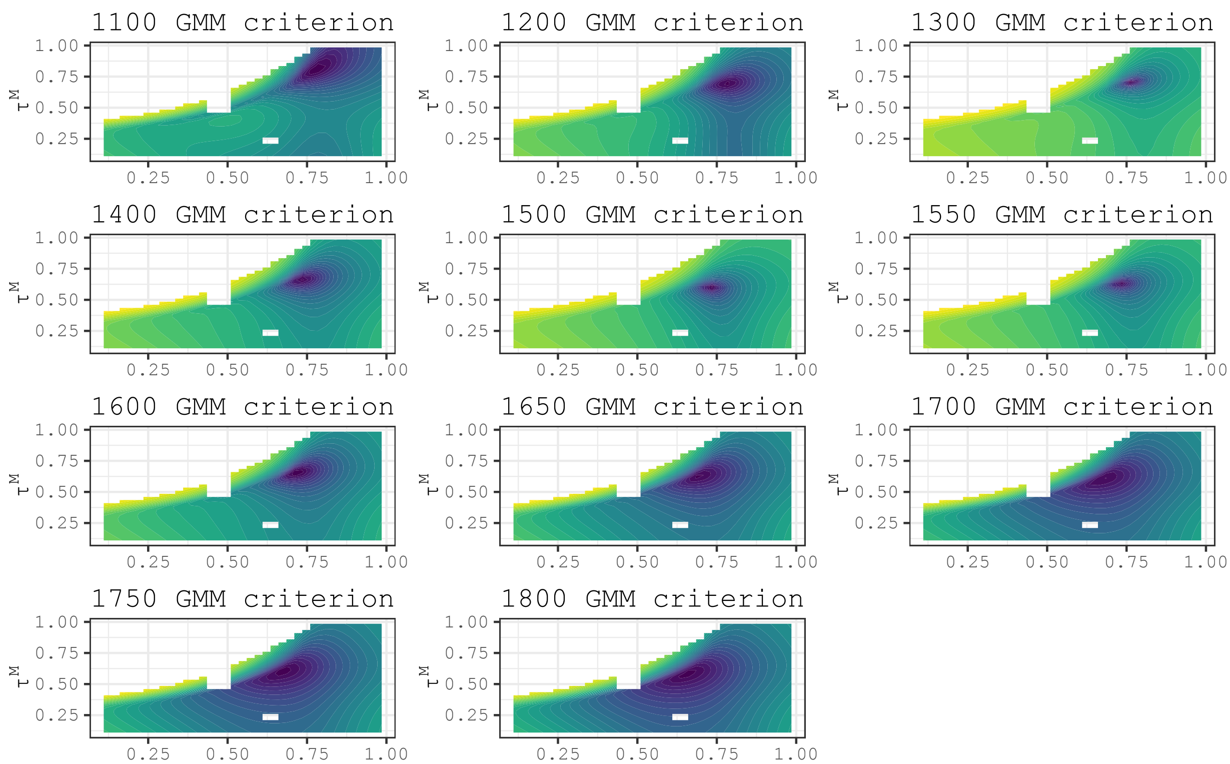


Figure 20: GMM criterion in each century for the baseline exercise without technical change. Our procedure delivers a unique global minimum in each century

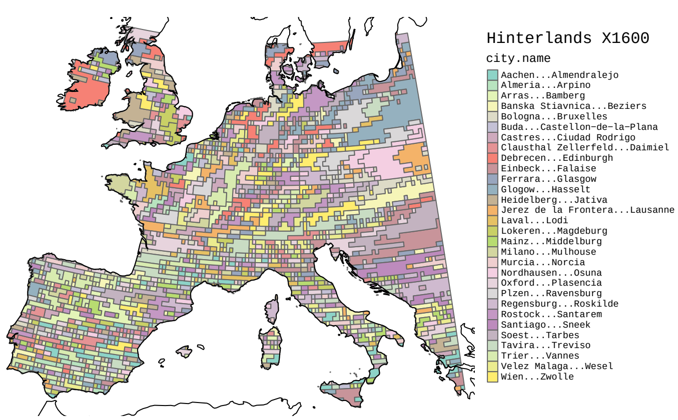


Figure 21: Illustration of the implied rural hinterlands for one century. All farmers in one grid choose their trading city optimally.

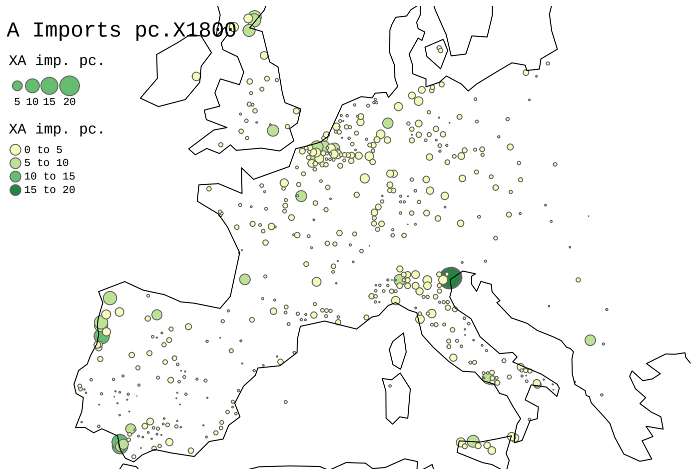


Figure 22: Illustrating depth of the model: imports of agricultural goods per capita in 1800 (unscaled value).

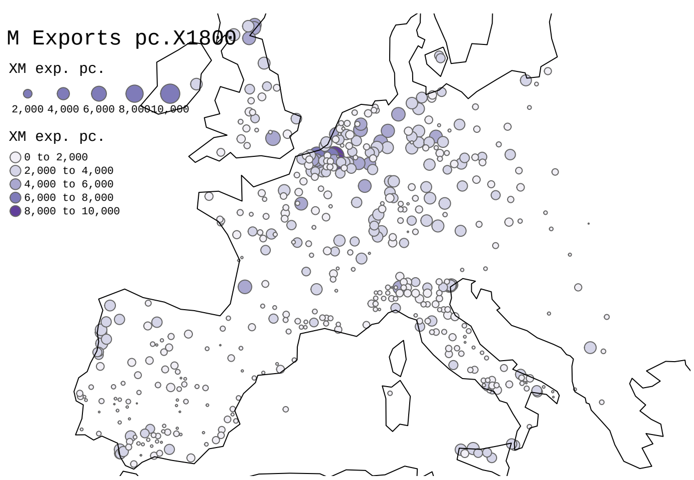


Figure 23: Illustrating depth of the model: exports of manufacturing goods per capita in 1800 (unscaled value).

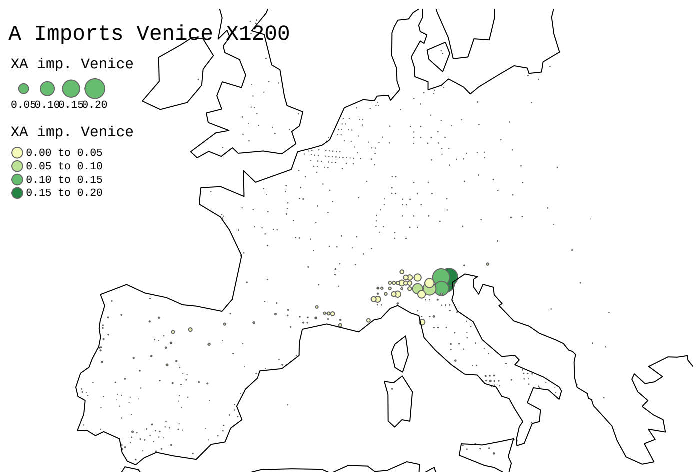


Figure 24: Analyzing single cities: agricultural imports of Venice in 1200 as an example.