Disease and Demographic Development: The Legacy of the Black Death*

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Abstract

This paper provides an empirical investigation of the mechanisms underlying the demographic transition using disaggregate data from the German lands. The hypothesis is that disease shocks such as the outbreak of the Black Death led changed the Malthusian equilibrium by increasing population density and eventually provided the ground for the demographic transition. The analysis uses geographic variation in the exposure to medieval plague shocks and documents that areas with greater exposure exhibited more severe plague outbreaks, greater population density in their aftermath, and an earlier onset of the demographic transition. The results are consistent with the predictions of the unified growth literature and provide novel insights into the largely unexplored empirical determinants of the historical transition from stagnation to growth

JEL-classification: O10, J10

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1 Introduction

One of the key questions in economics refers to the reasons for development differences across countries and regions. In view of the non-monotonic dynamics of long-run development, as maintained by unified growth theories, the answer to this question is closely related to the reasons for differences in the timing of the take-off in economic and demographic development. The timing of the demographic transition plays a central role in this context since it is widely viewed as a prerequisite of economic development. In particular, the deliberate reduction in fertility allowed for intensified child rearing, increased human capital investment, and ultimately a sustained increase in incomes per capita as consequence of continuing productivity improvements (Galor and Weil, 2000, Galor, 2005ab). While there is widespread agreement about the role of the demographic transition for the economic take-off and ample evidence regarding the mechanics of these transitions, there is little empirical evidence regarding the determinants of the demographic transition and its timing.

This paper contributes to the literature by investigating the empirical relevance of the central, but so far largely untested, building block of the mechanisms underlying the canonical unified growth model, the transition from a Malthusian population regime to a Post-Malthusian regime with increasing population density and living standards, and ultimately a transition to a Modern Growth regime. The empirical approach is based on the insight that mortality shocks might have triggered adjustment mechanisms that led to shifts in the Malthusian equilibrium with the consequence of higher population density (Voigtländer and Voth, 2013a), which ultimately provided the ground for the transition from (Post-)Malthusian stagnation to a modern growth regime (Galor and Weil, 2000).

The empirical strategy used in the present paper is based on novel evidence that outbreaks of the Black Death in Europe during the Middle Ages did not occur randomly from reservoirs in Europe, but alway occurred following similar patterns. In particular, the evidence shows that the Black Death was repeatedly reintroduced into Europe following favorable climate conditions in Asia (Schmid et al., 2015). The entry ports of these reintroductions were maritime harbors, from where plague reintroductions spread concentrically and with an intensity that decreased in distance to the entry ports. This suggests that cities that were closer to these harbors were affected more by outbreaks of the plague. Under the assumption that outbreaks of the Black Death were random and climate-driven, the travel distance to maritime harbors that were the entry ports for plague reintroductions in Europe serves as measure of the exposure to plague outbreaks. By accounting for access to trade routes, distinguishing between the access to the main medieval traderoutes, access to the hanseatic trade network, and trade networks during the 19th century, the analysis isolates the role of plague

shocks. In particular, the fact that not all maritime harbors were plague entry ports but all were access hubs to trade allows us to disentangle the role of health shocks and access to trade. To rule out spurious results, the analysis controls for an extensive set of additional variables that potentially affect the demographic transition.

The empirical results support the hypothesis that the demographic transition occurred earlier in cities and regions that were more exposed to the Black Death and experienced more frequent and severe mortality shocks. The results are robust to controlling for and other characteristics, including access to medieval and modern trade routes, that have been found to be relevant predictors of the demographic transition.

The paper contributes to the literature in several ways. The results provide empirical support for some of the central predictions of unified growth theory, according to which the demographic transition, which was the prerequisite for long-run development, was fostered by reduced Malthusian population pressure and an increase in the demand for skills (Galor and Weil, 2000, Galor, 2011). Despite the important negative short-run consequences of disease shocks (see, e.g., Chakraborty et al., 2010, Bhattacharya and Chakraborty, 2016) and the set-backs in long-run development caused by repeated epidemic shocks (Lagerlöf, 2003) the evidence shown here suggests that frequent exposure to diseases might indeed have induced transitions to Malthusian steady states with higher per-capita income as response to major population shocks and as consequence of behavioral responses that foster development in the long-run. The findings thereby provide empirical support to the mechanisms proposed by Voigtländer and Voth (2013a), who suggest that exogenous disease shocks like the outbreak of the Black Death might have triggered a transition to a new Malthusian equilibrium with higher wages and population density, with important consequences for long-run development. In fact, plague-related population shocks might have ultimately triggered fertility reduction by fostering female employment and delaying marriage and childbirth (Voigtländer and Voth, 2013b, see also Clark, 2008). Using spatial variation in the plague-related mortality at the city level, Jebwab et al. (2016) explore the impact of the Black Death on city growth and find evidence for recovery of the population, but with heterogeneity regarding geographic endowments of cities. The empirical analysis in this paper provides evidence that corroborates this view by showing that plague outbreaks might in fact have led to an earlier demographic transition once controlling for heterogeneity in other factors.[1]

[1]Higher disease exposure also exerts greater evolutionary pressure, with important implications for long-run development, see, e.g., Galor and Moav (2002). However, the lack of immune resistance to plague and the short period since the medieval outbreaks makes the evolutionary channel appear less relevant in the present context.

Our findings also complement evidence that fertility reductions were linked to increased education (Becker et al., 2010, 2013), consistent with the unified growth perspective of a close link between the fertility transition, education and economic development. The empirical findings also complement evidence of higher education attainment in predominantly Protestant areas (Becker and Woessmann, 2008, 2009, 2010), while Protestantism was mainly adopted in regions where the return to education was comparably high, related to, e.g., access to major trade routes of the time, which affected the demographic dynamics above and beyond the distance to entry ports of reintroduced plague outbreaks (Cervellati and Sunde, 2016). The results are also consistent with a role of greater life expectancy for long-run development (Cervellati and Sunde, 2013, 2015), because plague outbreaks represent infrequent epidemics that unfold their consequences through population dynamics at the macro level rather than through individual incentives for education attainment. Finally, the use of disaggregate data complements recent evidence for the role of policies, such as the introduction of public health systems, for longevity and development (**?**Strittmater and Sunde, 2013)

The remainder of the paper is structured as follows. Section 2 describes the background of the resurgent outbreaks of the Black Death in Europe and the resulting hypothesis. Section 3 describes the data and the empirical strategy. Section 4 presents the main results. Section 5 provides a discussion of the findings.

2 Background and Main Hypothesis

2.1 The Plague in Medieval Europe: Some Background

The outbreak of the Black Death in Europe in 1347 marks one of the largest pandemics in human history. This experience has influenced the social and cultural thinking, unlike any other epidemic disease (and even unlike the earlier outbreak of the "Justinian Plague" in 541), and it is present even in today's consciousness regarding public health (see, e.g., Cantor, 2002, Slack, 2012).

The Black Death, the bubonic and pneumonic plague, is a zoonotic disease that is caused by the bacterium *Yersinia pestis*. The disease primarily affects mammals, with more than 200 mammalian species reported to be naturally infected with the pathogen, but rodents are the most important hosts, see Perry and Fetherston (1997). Three different variants of *yersinia pestis* have been shown to be responsible for the three major outbreaks of the plague in history, the Justinian plague in 541, the medieval Black Death that began in 1347, and the outbreak in China in 1890. All these outbreaks originated in Asia. Transmission of the disease can occur through direct contact or ingestion, but

transmission is mostly through fleas, in particular the oriental rat flea (*Xenopsylla cheopis*), which acquire the pathogen from mammals, in particular rodents, through blood meals. The virulence of *yersinia pestis* is temperature-dependent and increases due to the temperature difference between the flea and infected mammals. Upon infection with *Yersinia pestis*, the fleas develop a blockage of their esophagus, which leads to repeated attempts to feed. The blockages causes blood sucked from the mammal host to be mixed with *Yersinia pestis* bacilli in the flea's esophagus and ultimately to be re-injected to the host by regurgitation. Within the mammal host, most *Yersinia pestis* cells are initially destroyed by the immune system. However, already after three to five hours at high temperatures in the mammal (with body temperatures at and above 37^oC, which is about 15^oC higher than in the flea's body), *yersinia pestis* develops resistance to the phagocytes (i.e., the bacterium cannot be detected by the immune system anymore) and leads to an infection in the entire body (sepsis). Usually, the pathogen first spreads to lymph nodes, where it multiplies (causing the swelling known as bubonic plague), but depending on the infected organs, this can also lead to pneumonic plague (which is highly infectious from human to human).

Until recently, it has been assumed that the bacterium stayed and reproduced in rodent reservoirs in wildlife or urban environments after the introduction of *Yersinia pestis* in Europe in 1347. From these reservoirs, repeated outbreaks were thought to have led to waves of plague in Europe, until the disappearance of the plague during the 19th Century (see, e.g., Davis, 1986, Keeling and Gilligan, 2000). The dynamics of outbreaks have in fact been shown to depend on the relative abundance of host populations and vector populations (Reijniers et al., 2012). The dynamics themselves have also been shown to heavily depend on climatic conditions, which might have favored a synchronization of host and vector populations, and thereby an increased risk of an outbreak, as documented by evidence from Asia (Stenseth et al., 2006, Kausrud et al., 2007, Samia et al., 2011).

Recent evidence by Schmid et al. (2015) suggests, however, that rather than persisting in hidden reservoirs in Europe, *Yersinia pestis* was repeatedly reintroduced from Asia following particular climatic conditions that favored the outbreak and spread of the pathogen. In particular, climate fluctuations suitable for plague outbreaks in Europe do not seem to have been related to actual outbreaks. Instead, plague outbreaks in Europe can be traced back to outbreaks in the vicinity or to maritime imports from other cities. Ultimately, outbreaks at the beginning of the chain of maritime transmissions can be isolated as outbreaks for which there was no earlier plague outbreak (within a time span of two years) within a 500km radius on land, or 1000km radius for harbors. These outbreaks were therefore not the result of a transmission from other European cities, but instead point to repeated reintroductions of the plague from outbreaks in Central Asia. The respective entry

ports were all located at trade points connecting Europe with trading routes to Asia. Building on earlier evidence by (Stenseth et al., 2006, and Samia et al., 2011), Schmid et al. (2015) then show that all outbreaks can be related to suitable climatological conditions in Asia for an outbreak more than ten years earlier. In essence, climate-related fluctuations led to initial outbreaks in Asia that then spread along trade routes, resulting in repeated reintroductions of the plague in Europe with a delay of up to 15 years. Figure 1 provides a map of the entry ports and the dates of the respective plague outbreaks.

Figure 1: Plague Reintroductions in Europe

Notes: Plague outbreaks of maritime harbors that are not related to nearby land-based or maritime outbreaks, replicated from Figure 1 in Schmid et al. (2015). Black circles indicate important ports of medieval Europe. Grey circles indicate entry ports for plague reintroductions. Sizes of grey circles reflect the total number of plague outbreaks for the given city, the years next to the cities indicate plague outbreaks that have not been preceded by a plague outbreak on land within a 500 km radius and on harbors within a 1000 km radius for two years prior to the outbreak. Lines indicate maritime and land-based trading routes, respectively. The darker areas indicate locations of modern wildlife plague foci.

2.2 Empirical Hypothesis and Strategy

The reintroduction of the plague as consequence of climatic conditions in Asia implies that the Black Death repeatedly spread across Europe using the same entry ports and overland trade routes, instead of spontaneous outbreaks within Europe. Hence, geographic location to a large extent determined the exposure to plague outbreaks, which spread concentrically from the entry ports, see Schmid et al. (2015). Cities and regions closer to the entry ports faced a higher risk of being hit by an outbreak. Due to this opaque and irregular pattern, outbreaks of the plague were taken as random events, possibly caused by metaphysical or other forces (Cantor, 2002). There was no systematic migration related to the infrequent outbreaks of the plague that would indicate that individuals

avoided the entry ports and the related trade routes. Moreover, recent work by suggests that the spread of the Black Death in Sweden in 1350 is well approximated by travel distances on the medieval road network.[2] Taken together, this suggests that, ceteris paribus, the mortality shocks caused by outbreaks of the plague were more frequent and intense in locations closer to the entry ports.

In the centuries that followed the great outbreak of the Black Death in 1347, plague and other deadly epidemics ravaged throughout the continent and caused millions of casualties. According to Keyser (1941), these deaths were compensated by higher birth rates that compensated the population loss in the aftermath of the outbreak. This implies that medieval Europe can be described as being governed by a Malthusian population regime. Voigtländer and Voth (2013a) show that population shocks like plague epidemics imply large shocks to income per capita, and in the medium run lead to increased urbanization, birth and death rates, and ultimately to a transition from one Malthusian regime to a another Malthusian regime with higher real income per capita. The loss of lives caused by an epidemic outbreak also led to a scarcity of labor and increased land-labor ratios, favoring more land-intensive production in terms of animal husbandry as compared to the relatively labor-intensive plow agriculture producing crops. According to Voigtländer and Voth (2013b), this and the comparative advantage of women in pastoral farming increased the incentives for female employment, leading to higher marriage ages and lower fertility in the aggregate. Lower fertility, in turn, implied lower opportunity costs for undergoing the demographic transition, from quantity to quality investments in children, which is the basis for the economic takeoff (Galor, 2011). Taken together, this gives rise to the hypothesis that the mechanisms related to these population shocks, such as labor shortage, increased female employment, and the consequential change in fertility behavior were more prevalent and powerful in these locations.

The hypothesis that follows from this discussion is that repeated exposure to the plague might have accelerated the demographic development. By spreading from city to city, the outbreak of the plague might have had a major impact on many cities. Importantly, however, this impact was likely to be heterogeneous, depending on the location of the city which determined the exposure to the occasional reintroduction of the plague from Asia. Hence, cities and regions that were more exposed to reintroduced outbreaks faced more frequent and pronounced population shocks and, ceteris paribus, a faster demographic development along the lines outlined before. In particular, the greater exposure to plague outbreaks is expected to be reflected by an earlier onset of the fertility transition.

This paper tests this hypothesis by relating the timing of the demographic transition to the

[2] Conversely, the spread of epidemics like the plague has been used as proxy for relative trade intensities, which is consistent with the approach taken here, see, e.g., Boerner and Severgnini (2014).

geographical distance from the entry ports of the plague outbreaks, based on the hypothesis that an epidemic was more likely to reach a city if it was closer to an entry port.

3 Data and Empirical Approach

3.1 Data

Demographic Transition Data. The demographic information central to our analysis is the timing of the demographic transition. The main data source is Knodel (1974), who provides detailed data on the on fertility and age distribution of the population in German on a regional level within the boundaries of 1900 (district boundaries from 1901).

Marital fertility rates, which provide the most reliable source of fertility data, are used to calculate the onset of the fertility transition for 243 cities in 71 German regions based on data covering the time from 1871 to 1939. Among a variety of definitions of fertility rates, Knodel (1974) puts most emphasis on the marital fertility instead of total fertility, which also includes illegitimate births since these are more likely to be misreported as result of social pressure. The martial fertility rates take into account different age distributions in different regions, and thus provide a comparable measure of fertility in terms of the actual number of births during a year relative to the potential fertility.[3] The onset of the fertility transition is defined as the year in which marital fertility reached a threshold.[4] There is some arbitrariness associated with this definition, since it does not measure the onset of the decline in fertility, but the time of reaching a threshold. However, at the same time this definition is transparent and avoids confusion of the onset of the demographic transition with a temporary decline or fluctuations in fertility, e.g., due to a war or German unification.Figure 2 provides a map that illustrates the timing of the fertility transition.

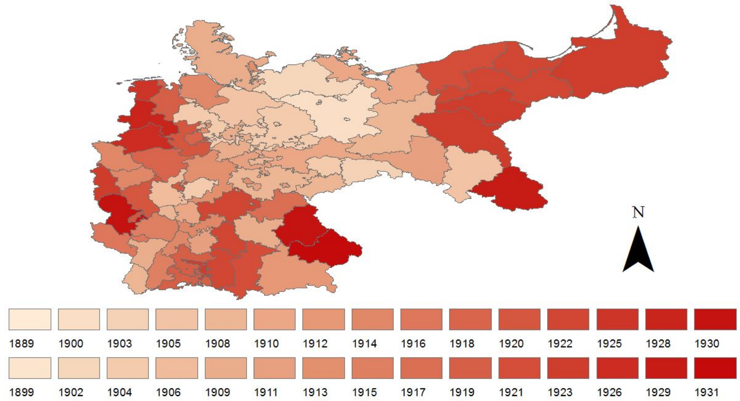
As alternative source of demographic data, we use the data set assembled by Galloway (1994, 2007). These data contain detailed information on vital statistics at the level of Prussian regions. To construct a measure of the timing of the demographic transition, we make use of the standard thresholds for fertility and mortality used in demography and code the demographic transition as the year in which the thresholds are surpassed for the first time.[5]

[3]The marital fertility is defined as $I_g = B_L/(\sum_i m_i F_i)$ where B_L is the number of legitimate births, m_i is the number of women in the (five-year) age interval i, and F_i is the age-specific natural fertility, proxied by the fertility of a married Hutterite woman in 1921-1930, see also Table A.1 in the Appendix.

[4]Consistent with the interpretation by Knodel (1974), this threshold is taken to be 0.5 or, alternatively, 0.6.

[5]The thresholds are a crude birth rate lower than 35 per 1000 and a crude death rate lower than 30 per 1000, see

Figure 2: The Timing of the Fertility Transition in Germany



Notes: Districts colored by the year of the fertility transition (threshold 0.5) according to Knodel (1974).

Travel Distance from Plague Entry Ports. The exposure to plague reintroductions from Asia to Europe is measured by the geographic travel distance from the entry ports depicted in Figure 1. These ports are: Danzig (Gdansk), Hamburg and Lübeck, Venice, Genova, Marseille, Montpellier, Bordeaux, and Barcelona. The final dataset is constructed on the basis of about 5.7 million road/river segments with elevation data at both the start and end of each of these line segments. The data covers continental Europe West of, and including, Poland and the Czech Republic. In order the measure the travel times from the harbors to the different cities, we combine data from two sources. The data for the road and river network of Europe is taken from Openstreetmap.org via MapCruzin.com. These data comprise of about 8 million line segments, representing roads and about 2 million line segments representing waterways in all over Europe and parts of western Asia. The dataset includes countries ranging from Portugal to parts of western Russia and Turkey.

The additional data for the elevation is taken from DIVA-GIS. This data is available for each country and provides precise elevation data for a fine raster. The elevation data for the individual countries was merged to create an elevation profile for Western and central continental Europe.[6]

The travel distance is constructed from a road map that is based on contemporaneous road network, adjusted for historic travel times. In order to ensure the validity of this measure, the basic

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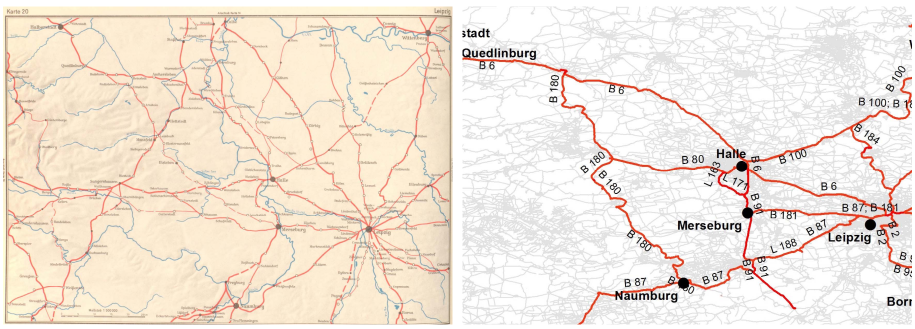
Chesnais (1992) and Cervellati and Sunde (2011). To account for the fact that the mortality transition precedes the fertility transition and to account for measurement error in the Galloway data, we use the average of the two years in which the two thresholds are passed.

[6]In order to check the accuracy of the elevation data, the DIVA-GIS elevation data was compared to the elevation data provided by Bosker, Buringh, and van Zanden (2013). The reported elevation difference was in the range of up to four meters. The difference could be a result of a different raster size of the elevation data. Furthermore, the maximal elevation difference of four meters lies well in the range one can expect to be within a certain city.

dataset is adjusted as follows. Historically, the existing roads in Europe were continuously developed up to the road network observed today. This has been done mainly by expanding existing roads. The most prominent example for this is probably the "Via Appia" in Italy, an old roman road that is still used today. Obvious deviations are, e.g., the system of motor ways (Autobahn) which was built for a completely different purpose and without historic predecessors. Hence, motor ways and other constructions that were obviously not in place in medieval and early modern times, such as tunnels and canals, were excluded from the dataset. This implies a rather realistic dataset for measuring the distances, especially in areas with mountains such as the Alps.[7]

A comparison between maps of the historical road network in Germany during the 19th century and the network obtained by this methodology confirms its validity. To illustrate this, Figure 3 provides a direct comparison for the region around Leipzig, Halberstadt and Wittenberg. Panel (a) shows the map of this region with historical trade routes as depicted in the atlas of hanseatic routes by Bruns and Weczerka (1962). Panel (b) shows the digitized data for roads. All streets that have been used for determining travel distance are shown in grey, the most important hanseatic routes are marked with red (including the modern street labels and numbers). These are the basis for the computation of travel distance in terms of time as discussed below.

Figure 3: Comparing Historical and Current Road Networks



(a) Historical Road Map (b) Digitized Road Map

Notes: Panel (a) depicts a map of historical hanseatic trade routes reproduced from Bruns and Weczerka (1962). Panel (b) depicts the digitized road map that is used to determine the distances and travel times for the empirical analysis.

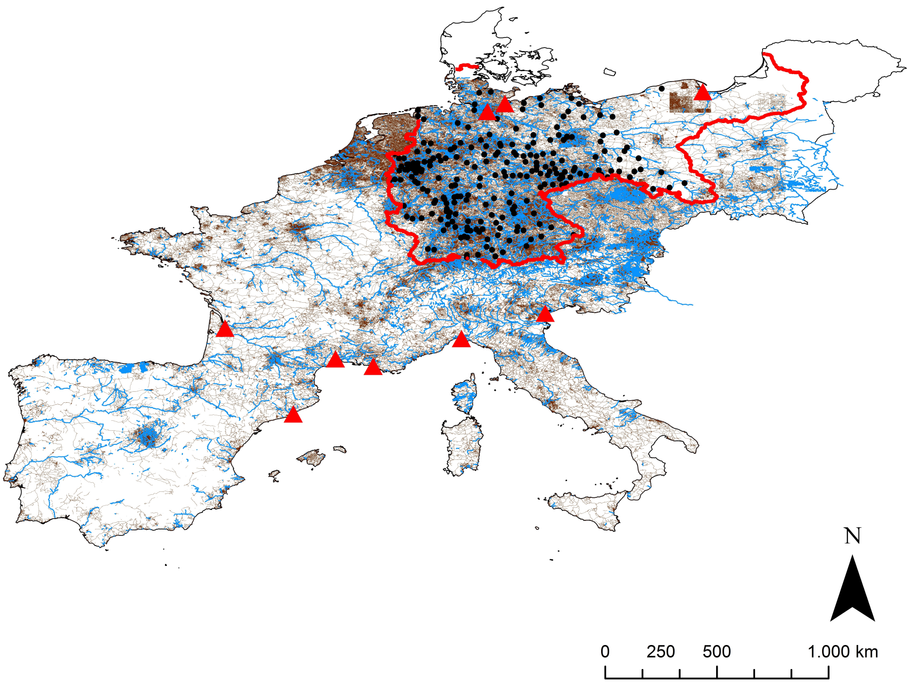
In a second step, the road map was projected into "Europe Equidistant Conic", a coordinate system that preserves distances between points. This is necessary to avoid distortions due to projecting the three-dimensional world on a two-dimensional map. An equidistant projection does not distort the distances between cities and entry ports, which is crucial for measuring the travel times.[8] Figure

[7]Furthermore, areas that are not relevant for the empirical analysis, such as Turkey and Russia, were excluded from data.

[8]The potential distortions are quite small for cities close together, but increase with the distance between the cities.

4 shows the projected road and river map of Europe. In addition to the road and river network shown in Figure 4, the data use about 5.7 million line segments including detailed elevation data. Using elevation data at both ends of these line segments, we computed the absolute difference in elevation over the length of the line segment and calculated the corresponding slope of the line segments (in degrees) as the arctangens of the elevation difference relative to the length of the segment.

Figure 4: Travel Distances from Entry Ports



Notes: Map of roads (brown) and waterways (blue) used to compute travel distances from entry ports (red triangles). Region centroids are depicted as black dots. Red line represents German border as of 1900.

Based on the information from the road and river network map and the slopes of the street segments, we calculated the travel time from the individual ports to each city. The travel times depend crucially on the assumptions about travel speeds for the different means of transportation. Transport via ships on rivers used to be substantially faster than traveling by foot. Transport of people and goods over land was mostly performed by horse coaches, which were just little faster than walking. The average speed of travel was around five to seven kilometers per hour (Ritter, 1966, p. 28). This corresponds to alternative sources according to which goods transport was possible at a speed of about 30 kilometers per day (in flat areas up to 40 kilometers), which corresponds to about six to eight hours at a speed of five kilometers per hour (Bruns, 1962, 1967). Similarly, historical accounts of mail deliveries over long distances managed travel speeds of approximately 5.5 to 6.5

Hence, if not projected to an equidistant format, the distortions would increase with the distance to the harbor and thus introduce systematic and potentially substantial measurement error that might lead to misleading results.

kilometers per hour (Hitzer, 1971). Since for horse coaches it was virtually impossible to travel on very steep roads, the travel time decreases with the slope and roads with a slope of more than 45^o constituted a natural barrier. Hence, following this literature, we assume specific travel speeds by surface type and slope of line segment.[9]

The travel time is consequently defined as the minimum time necessary to travel the distance of the line segment given the speed restriction of the slope. The travel times to entry ports are then calculated in two steps. First the time to cover the particular line segment is assigned to the individual line segment given surface type and slope as described above. In the second step the path with the shortest sum of travel times is selected among all paths, and the total travel time from each port to each city is computed. The variable *Number of Ports*, which measures the number of ports that can be reached from the respective city within 100 hours, is then used as proxy for the exposure to the reintroduction of the Black Death. Alternatively, the variable *Travel Time* represents the travel time in hours from the closest port to the respective city. Both variables serve as proxies for the relative risk of being exposed to epidemic shocks as shocks can be expected to occur more often if more ports are close to a city and the closer the nearest port. The use of the travel times, rather than the simple distance, is essential to the analysis, since the spread of the plague requires human contact to infected hosts and vectors. The simple horizontal distance is therefore an inadequate proxy for the relative risk of being exposed to plague epidemics, since remote places were less likely to be affected by an outbreak.

Data on proximity to medieval trade routes comes from Cervellati and Sunde (2016) and measures a citys distance to the two most important trading routes in medieval Germany, the Via Regia and the Via Imperii. Additionally, the analysis controls for access to the trade network of the Hanseatic League, as well as distance to trade ports that became important after the discovery of the Americas and to the main trade ports of the 19th century.

[9]See Table A.2 in the Appendix for details. For slopes steeper than 45^o, the transport was mostly done by physical man labor for purposes other than travel. Even today the transport of food and other necessary equipment to remote cottages in the hills is done by carrying. Line segments with a slope larger than 45^o are assigned a speed of zero and are thus assumed to be bypassed on other roads. Obviously, the measured time depends on the assumed travel speed. The precise assumptions about the travel speed itself are irrelevant for the empirical analysis (and only affect the size of the coefficient). The important feature is the relative decline in the travel speed for the different slope brackets. Since assigning the travel speed contains an arbitrary element, this constitutes the most serious threat to validity. The main problem is that there are not many sources that provide reliable travel speeds at the medieval times, other than that traveling was exhausting and took a long time. In order to check for possible systematic error, the regression is performed with the slow speed schedule, with similar results.

Other Variables. To account for relevant heterogeneity across cities and regions, we use additional information from various sources.

City-level controls for religion, the associated cultural differences, as well as for specific institutions, are taken from data constructed by Cantoni (2012). This data set includes 259 cities in Germany and Austria. Binary indicators denote whether a city was considered protestant after the 15th and 16th century, respectively. Additional binary variables indicate whether a city belonged to the Hanseatic League, whether a city was considered a free imperial city or whether a city had a printing press by the year 1517.[10]

Geographical data by Bosker, Buringh, and van Zanden (2013) can be used for 77 cities within the boundaries of 1900 Germany, 65 of which correspond to cities included in the data by Cantoni (2012).[11] In particular, we use information on population growth, calculated as the simple difference of the population between the 8th and 18th Century.[12] In addition, we use information the urban potential of a city, measured as the ratio between the population of a city and the greater circle distance between this city and other cities in the surroundings, following de Vries (1986).[13] Based on Ramankutty et al. (2002), Bosker, Buringh, and van Zanden (2013) provide information on land suitability for agriculture (soilquality).[14] Together with the measure for ruggedness, these variables provide valuable insight in the agricultural potential of a region. Additional indicator variables include information whether a city has been plundered, whether it has an acting parliament and whether it has a university.[15] Additional indicator variables contain information for whether the city is located on a roman road, at a roman road intersection, on a river, or on the sea.

[10]Additional variables indicate the number of monasteries within a 10 km radius of the respective city for all monasteries and monasteries of the Order of Saint Augustine.

[11]This includes cities in Germany, France and Poland in terms of contemporaneous boundaries.

[12]Population of a city is reported in 1000s and set to 0 for cities with less than 5000 inhabitants. Alternative measures of population growth are used in the robustness analysis like population growth in terms of the log-differences for every century or population growth computed as the city population relative to the overall population of the country and then takes the simple difference between the 8th and 18th Century.

[13]The variable is the simple difference between the urban potential of a city in the 8th and the 18th Century.

[14]The index designed by Ramankutty et al. (2002) uses the daily sum of temperature over a base temperature of 5 degree Celsius, the pH-level of the soil, the soil carbon density and a moisture index, calculated by the actual evapotranspiration over the potential evapotranspiration, in order to calculate a single number that indicate the suitability for agriculture.

[15]The variables are constructed as the sum of these dummy variables over centuries. Thus, a larger value for *university*, for example, means that the city had a university for a longer period of time, while a higher value of *plundered* indicates that the city was more frequently attacked.

3.2 Descriptive Statistics

Table 1 provides descriptive statistics for the core variables of the analysis, in terms of the travel time in hours to the closest entry port for plague reintroductions, the number of entry ports within a 100-hour radius, population density in 1890, the (log) populaiton in 1500, and population growth from 1300 to 1500.

Table 1: Descriptive Statistics

	Mean	SD	Min	Max
Distance to Nearest Plague Port	46.7	18.5	.19	79
Distance to Nearest Plague Port (Roman Road)	5.9	14.9	0	56
Distance to Nearest Plague Port (non-Roman Road)	40.8	17.6	.19	79
Number of Plague Ports (< 100 hrs)	3.0	0.8	2	6
Population Density (per km^2)	236.2	1,456.0	39	22,708
Population in 1500 (log)	0.7	1.0	0	3.8
Population Growth 1300-1500	0.3	0.5	-.88	4
Distance to Via Imperii in 100km	1.7	1.2	0	4.2
Distance to Via Regia in 100km	0.8	0.9	1.4e-08	3.9

3.3 Empirical Strategy

The empirical analysis tests the hypothesis that cities closer to major entry ports for plague reintroductions in medieval Europe and with closer access to the main trade network of the time experienced an earlier fertility transition during the 19th Century. The analysis is based on a simple linear regression model

$$Transition_i = \beta_0 + \beta_1 Plague\ Exposure_i + \gamma X_i + \varepsilon_i \tag{1}$$

where i indicates city, transition is the year of the demographic transition according to Knodel (1974) or Galloway (1994), $Plague\ Exposure_i$ is the exposure of city i to the reintroduction of the Black Death from Asia, measured by the travel distance to the closest entry port and/or the number of entry ports within a 100 hour travel radius, and X is a vector of control variables, which include other relevant determinants of the timing of the demographic transition. The empirical analysis accounts for cities located within the same administrative region by clustering the standard errors

correspondingly.[16]

According to the empirical hypothesis, β_1 is expected to be negative, in the sense that greater exposure (in terms of proximity to entry ports or number of entry ports) led to an earlier demographic transition. In addition, the analysis investigates the channels in terms of severity of plague outbreaks, or the instrumental effect on population density and urbanisation for the timing of the demographic transition (see, e.g., Voigtländer and Voth, 2013a, Clark, 2008)).

The identification of the effect rests on the assumption that exposure to the reintroduction of the plague (in terms of location relative to entry ports) is conditionally exogenous to the timing of the demographic transition of a city. The key issue for identification is therefore to account for confounding factors, such as access to trade, or other historical or geographical features that might be picked up by the measure of exposure to the reintroduction of the plague. Below, we present an extensive number of robustness checks to rule out spurious results.

4 Results

Before proceeding to the main results, we document the relation between plague outbreaks and exposure to the reintroduction of the plague, measured by entry ports. This serves as a sanity check that documents that the proximity to entry ports is indeed correlated (positively) with the frequency of outbreaks.

Plague Outbreaks and Distance to Entry Ports. Table 2 presents the results of regressions of exposure to plague-related population shocks, measured as the total number of recorded plague outbreaks, an indicator of whether the plague ever broke out, as well as of a binary indicator for a plague outbreak after 1349, i.e., a plague outbreak as consequence of a reintroduction of the plague in Europe after the first wave, as dependent variables. The main regressors of interest are the number of entry ports within 100 hours travel distance, the distance to the closest entry port for plague reintroduction, as well as controls for access to medieval trade routes. Consistent with the hypothesis, the results indicate that plague outbreaks are more frequent the greater the exposure to plague reintroductions, in terms of the number of entry ports within 100 hours travel distance and shorter travel time to these ports. The travel time appears to matter less for the number of outbreaks. These results are robust to controlling access to trade routes as well as an indicator whether there was ever an outbreak on the extensive margin: Conditional on observing an outbreak, the frequency

[16] The data by Knodel (1974) are based on 51 regions.

is higher the more entry ports are within a reasonably close distance. Additional results suggest that whether there was ever any outbreak (including the first wave) appears to be weakly related to the number of entry ports in the vicinity. When considering the timing of outbreaks, immediate outbreaks (within the first two years of the first advent of the Black Death in Europe) are somewhat more frequent the higher the number of entry ports. Importantly, however, delayed outbreaks (after 1349) are less likely the greater the travel distance from the nearest entry port, conditional on the number of entry ports.[17] The results are very similar when accounting for Roman versus non-Roman roads.[18]

For few cities, we have access to data on the mortality during the plague epidemics. When regressing the severity of the plague outbreaks, in terms of aggregated mortality numbers, for these cities on the exposure to plague reintroductions, the evidence again points to more severe outbreaks in cities that are located closer to an entry port.[19]

Table 2: Proximity to Entry Ports and Plague Outbreaks

	# Outbreaks					Outbreak >1349	Outbreak >1349
Number of Plague Ports (< 100 hrs)	1.369**		1.052	2.373**	1.834*	-0.024	-0.015
	(0.668)		(0.721)	(1.046)	(0.954)	(0.030)	(0.043)
Distance to Nearest Plague Port		0.054*	0.037	0.003	0.007	-0.006***	-0.005***
		(0.029)	(0.031)	(0.039)	(0.035)	(0.001)	(0.002)
Located on Navigable River				2.838**	3.049***		-0.002
				(1.121)	(1.020)		(0.046)
Distance Via Imperii (log km)				1.609	2.071		0.092
				(1.490)	(1.357)		(0.062)
Distance Via Regia (log km)				-2.333	-2.074		0.111*
				(1.542)	(1.403)		(0.064)
Plague Outbreak after 1347					8.289***		
					(1.192)		
Constant	2.381	3.970***	1.622	-2.104	-7.727**	0.501***	0.305**
	(2.075)	(1.464)	(2.173)	(3.320)	(3.125)	(0.089)	(0.138)
Observations	232	232	232	232	232	236	236
R^2	0.018	0.015	0.024	0.062	0.227	0.109	0.135
Adjusted R^2	0.014	0.010	0.015	0.041	0.207	0.101	0.116

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Distance to Entry Ports and Timing of the Demographic Transition. After having documented a reduced form effect of distance to entry ports to plague outbreaks, we now consider the effect of exposure to population shocks on the timing of the demographic transition.

[17]The same holds when additionally controlling for whether there was an early outbreak (which is positively affected by the number of entry ports).

[18]See Table A.3.

[19]The results reveal no effect for the number of ports. Generally, these results have to interpreted with some caution due to the small number of observations with information on plague-related mortality, see Table A.4 in the Appendix.

Table 3 presents the main results concerning the research question. The table reports estimation results for the timing of the demographic transition, measured as the year in which a city experienced the demographic transition in terms of a marital fertility below 0.5 as dependent variable.

Panel A contains results for distance measured along all roads, Panel B distinguishes between Roman and non-Roman roads. The results provide evidence that a lower exposure to population shocks in terms of reintroductions of the Black Death in Europe, proxied by a greater travel distance from a plague entry port, was associated with a significantly later onset of the demographic transition. In particular, a greater number of entry ports within 100 hours travel distance is associated with an earlier onset, whereas a greater travel distance to the nearest plague port is associated with a later onset of the demographic transition. Both coefficients are consistent with the working hypothesis. Together, these two variables explain almost 30 percent of the variation in the timing of the demographic transition.

Adding additional demographic controls for population density during the 19th century or in 1500, as well as for population growth between 1300 and 1500 does not affect the results and increases the explanatory power only moderately to around 0.4. The findings indicate that the transition occurred earlier in more densely populated (and presumably richer since more urbanized) areas. These findings are robust across different specifications that become increasingly more comprehensive. Likewise, adding controls for religion (in terms of protestantism, the number of all monasteries and of Augustinian monasteries)leaves the main results unaffected. Adding information on religious denomination and religious institutions reveals an earlier onset of the demographic transition in Protestant cities.

Adding controls for institutions (the existence of a university, membership in the Hanseatic league, the status of a free imperial city, or the presence of a printing press by the time of the protestant reformation) reveals that free imperial cities experienced a later demographic transition, but leaves the results for the exposure to the plague unchanged. Finally, adding access to medieval trade in terms of the location on a river or the distance to the two major medieval trade routes does not affect the result for the exposure to the plague, but reveals that trade (in terms of a smaller distance to the major trade routes of the time) implied an earlier demographic transition.[20]

These results are consistent with the main mechanism underlying the onset of the demographic transition in the canonical unified growth model, which relates to greater population density and greater demand for human capital as the main factors behind the onset. However, the results suggest that the exposure to population shocks, such as reflected by the repeated reintroduction of the Black

[20] Table A.5 in the Appendix reports all coefficient estimates.

Table 3: Timing of the Demographic Transition

Dependent Variable	Onset of the Demographic Transition (Year)					
Panel A: Alternative Threshold for Demographic Transition						
Number of Plague Ports (< 100 hrs)	-2.253**	-3.338***	-3.434***	-3.553***	-3.548***	-2.176**
	(1.004)	(1.013)	(0.946)	(0.922)	(0.929)	(1.022)
Distance to Nearest Plague Port	0.238***	0.269***	0.235***	0.235***	0.236***	0.236***
	(0.040)	(0.041)	(0.040)	(0.042)	(0.042)	(0.046)
Observations	237	237	237	237	237	236
R^2	0.292	0.400	0.463	0.495	0.496	0.560
Adjusted R^2	0.285	0.387	0.444	0.468	0.467	0.530
Clustered SEs	X	X	X	X	X	X
Number of Clusters	56	56	56	56	56	56
Panel B: Alternative Data for Demographic Transition (Galloway, 2007)						
Number of Plague Ports (< 100 hrs)	-4.322***	-4.904***	-4.858***	-4.744***	-4.744***	-2.837***
	(1.052)	(1.074)	(0.997)	(1.006)	(1.018)	(1.047)
Distance to Nearest Plague Port via Roman Roads	0.413***	0.413***	0.371***	0.356***	0.358***	0.326***
	(0.059)	(0.058)	(0.059)	(0.061)	(0.060)	(0.061)
Distance to Nearest Plague Port via Non-Roman Roads	0.188***	0.220***	0.203***	0.209***	0.210***	0.190***
	(0.039)	(0.039)	(0.038)	(0.040)	(0.040)	(0.045)
Observations	237	237	237	237	237	236
R^2	0.403	0.479	0.519	0.536	0.537	0.588
Adjusted R^2	0.396	0.465	0.500	0.509	0.508	0.557
Clustered SEs	X	X	X	X	X	X
Number of Clusters	56	56	56	56	56	56
Controls (both panels)						
Demographic Controls		✓	✓	✓	✓	✓
Religion Controls			✓	✓	✓	✓
Institution Controls				✓	✓	✓
Geography					✓	✓
Trade						✓

Standard errors clustered by region in parentheses.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Death in Europe, potentially was a factor that had already shifted the Malthusian equilibrium as suggested by Voigtländer and Voth (2013a).

Robustness and Additional Results To verify the robustness of the results, we conduct different robustness checks. The first set of robustness refers to the measurement of the timing of the demographic transition. To this end, we use an alternative measure based on a threshold of marital fertility of 0.6 instead of 0.5 to indicate the onset of the demographic transition, using the same data source (Knodel, 1974). As alternative measure, we construct the timing of the demographic transition from vital rates provided by Galloway (2007). The advantage of the Galloway data is that they allow for a robustness check with data from a second source, the disadvantage is that they only contain information for a subset of the cities in the baseline data set.

The results obtained for the two alternative measures of the timing of the demographic transition are very similar to the baseline results. The alternative threshold for marital fertility delivers almost

Table 4: Timing of the Demographic Transition: Robustness

Dependent Variable	Onset of the Demographic Transition (Year)					
Panel A: Alternative Threshold for Demographic Transition						
Number of Plague Ports (< 100 hrs)	-3.745***	-4.383***	-4.626***	-4.828***	-4.827***	-4.481***
	(1.400)	(1.495)	(1.431)	(1.401)	(1.408)	(1.671)
Distance to Nearest Plague Port	0.393***	0.411***	0.378***	0.370***	0.370***	0.391***
	(0.082)	(0.081)	(0.082)	(0.082)	(0.082)	(0.088)
Observations	237	237	237	237	237	236
R^2	0.354	0.369	0.408	0.432	0.432	0.448
Adjusted R^2	0.348	0.356	0.387	0.402	0.399	0.410
Clustered SEs	X	X	X	X	X	X
Number of Clusters	56	56	56	56	56	56
Panel B: Alternative Data for Demographic Transition (Galloway, 2007)						
Number of Plague Ports (< 100 hrs)	-0.090	1.501	0.591	0.526	0.581	-1.171
	(1.775)	(1.796)	(1.743)	(1.859)	(1.818)	(1.445)
Distance to Nearest Plague Port	0.157***	0.124**	0.151***	0.146***	0.140***	0.121**
	(0.050)	(0.049)	(0.046)	(0.047)	(0.043)	(0.051)
Observations	131	131	131	131	131	130
R^2	0.101	0.172	0.221	0.243	0.246	0.258
Adjusted R^2	0.087	0.139	0.169	0.166	0.162	0.161
Clustered SEs	X	X	X	X	X	X
Number of Clusters	27	27	27	27	27	27
Controls (both panels)						
Demographic Controls		✓	✓	✓	✓	✓
Religion Controls			✓	✓	✓	✓
Institution Controls				✓	✓	✓
Geography					✓	✓
Trade						✓

Standard errors clustered by region in parentheses.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

identical results compared to the baseline, as documented in Panel A of Table 4. The alternative data deliver qualitatively similar results, even though it is mostly the distance to the nearest plague port that delivers evidence for a later onset of the demographic transition, whereas the number of plague entry ports within a 100-hour perimeter does not have any significant impact.[21] The results of unreported estimates also reveal similar results when weighting the distance to the nearest port by the number of plague outbreaks as reported in Figure 1, or when distinguishing between Roman and non-Roman roads.

Instead of exploring the role of the exposure to repeated population shocks as consequence of plague reintroductions using city-level data, one might alternatively analyze the data on the level of regions. Given that the main information source on the timing of the demographic transition is on the regional level (Knodel, 1974), this could be seen as a more natural level of the analysis. On the other hand, however, this means using variation in the data at a higher level of aggregation. Checking the sensitivity of the empirical results with respect to the level of aggregation also provides

[21]Detailed results are contained in tables A.6 and A.7 in the Appendix.

a sensible robustness check in general.[22]

Table 5 presents the corresponding results. The number of ports and travel times are computed as average of the cities located in the region.[23] Again, the estimates reveal that regions with more entry ports in a reasonably close distance are associated with a significantly earlier demographic transition. Likewise, regions that are less exposed to plague outbreaks as measured by a greater distance in terms of travel time to the nearest plague entry port experience a significantly later onset of the demographic transition. The addition of control variables does not affect these results. At the same time, the findings regarding an earlier transition for more densely populated regions, for regions that are predominantly of Protestant denomination, and for regions that have better access (in terms of lower distance) to major trade routes are confirmed using regional data.[24]

Table 5: Regression Results on a Region Level - Regions (based on Knodel, 1974)

Dependent Variable	Onset of the Demographic Transition (Year)					
Number of Plague Ports (< 100 hrs)	-1.615	-2.584**	-3.587***	-4.253***	-4.267***	-3.675**
	(1.172)	(1.122)	(1.096)	(1.342)	(1.226)	(1.603)
Distance to Nearest Plague Port	0.238***	0.256***	0.204***	0.208***	0.227***	0.239***
	(0.045)	(0.044)	(0.045)	(0.061)	(0.055)	(0.059)
Demographic Controls		✓	✓	✓	✓	✓
Religion Controls			✓	✓	✓	✓
Institution Controls				✓	✓	✓
Geography					✓	✓
Trade						✓
Observations	56	56	56	56	56	56
R^2	0.291	0.513	0.617	0.674	0.714	0.749
Adjusted R^2	0.264	0.465	0.551	0.583	0.626	0.655
Clustered SEs	X	X	X	X	X	X
Number of Clusters	56	56	56	56	56	56

Robust standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Another robustness check investigates whether the results depend on excluding ports in the Mediterranean sea, through which the Black Death is supposed to have entered Europe for the first time in 1347. Restricting attention to the entry ports in the North that were mostly relevant for the reintroduction of the plague at later stages and eliminating ports in the Mediterranean sea delivers very similar results.[25]

A possible confound for the results is that instead of distance to entry ports for reintroductions

[22]Sensitivity of results with respect to the choice of the geographic unit of observation might be related to the problem of aggregation related to the "Modifiable Area Unit Problem", see, e.g., Briant, Combes, and Lafourcade (2010).

[23]Alternatively, one could use the centroid of the region.

[24]Detailed results are contained in Table A.8 in the Appendix.

[25]See Table A.9 in the Appendix.

of the plague in the middle ages, the number of entry ports in the perimeter and the distance to the closest entry port merely proxy access to maritime trade. A possible falsification test to rule out spurious results from this concern is to include similar variables regarding the number of maritime ports in a perimeter of 100 hours travel time and the distance to the closest maritime port for maritime ports that were not entry ports for the plague. The results, shown in Table 6 reveal that the main results are not merely driven the distance to maritime harbors, with unchanged results for the exposure to plague reintroductions and no evidence for an influence of the placebo ports on the timing of the demographic transition.[26]

Table 6: Timing of the Demographic Transition: Placebo Ports

	Placebo incl. Hamburg		Placebo excl. Hamburg	
Number of Placebo Ports	-0.205	1.049	0.508	0.453
	(0.743)	(1.405)	(1.482)	(1.337)
Average Travel Time to Placebo Port	0.058	-0.020		
	(0.044)	(0.095)		
Average Travel Time to Placebo Port			0.049	-0.050
			(0.067)	(0.073)
Number of Plague Ports (< 100 hrs)		-2.179*		-1.851
		(1.230)		(1.212)
Distance to Nearest Plague Port		0.262***		0.263***
		(0.058)		(0.048)
Demographic Controls	✓	✓	✓	✓
Religion Controls	✓	✓	✓	✓
Institution Controls	✓	✓	✓	✓
Geography	✓	✓	✓	✓
Trade	✓	✓	✓	✓
Observations	241	236	236	236
R^2	0.416	0.569	0.409	0.572
Adjusted R^2	0.377	0.536	0.369	0.538

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

As further robustness check, we estimated extended specifications that also include the travel distance to the closest hanseatic cities, accounting for the shortest way along which goods could be shipped or transported over land. The results, shown in Table 7 again deliver similar results regarding the exposure to population shocks due to reintroductions of the plague.[27] Unreported results also confirm the main findings when accounting for the distance to Cologne (the only hanseatic city that was located inland on the river Rhine). Alternatively, we tested the robustness of the results with respect to accounting for the proximity to ports that were only founded (or gained importance) after the middle ages and that were important trade hubs in the 19th century (such as Rotterdam). Again, the results indicate the robustness of the exposure to plague reintroductions.[28]

[26] Table A.10 presents the full set of coefficient estimates.
[27] Table A.11 in the Appendix shows the full set of coefficient estimates.
[28] See Table A.12 in the Appendix for detailed results.

Table 7: Timing of the Demographic Transition: Placebo Ports and Hanseatic Ports

Specification	Baseline	Closest Ports		Excl. South		Weighted	
Number of Plague Ports (< 100 hrs)	-2.176**	-2.526**	-3.356***	-2.884***	-3.088**	-3.108***	-3.277***
	(1.022)	(1.093)	(1.234)	(1.059)	(1.207)	(1.028)	(1.142)
Distance to Nearest Plague Port	0.236***	0.107	0.143**				
	(0.046)	(0.074)	(0.058)				
Average Travel Time North				0.318***	0.248***		
				(0.101)	(0.057)		
Weighted by Outbreaks						0.273**	0.279***
						(0.103)	(0.066)
Number of Placebo Ports		0.495	-0.992	-0.862	-1.136	-1.635	-1.984*
		(1.075)	(1.506)	(0.971)	(1.223)	(1.181)	(1.173)
Average Distance to Placebo Port		-0.024*	-0.020	0.006	-0.006	0.008	0.009
		(0.012)	(0.013)	(0.016)	(0.012)	(0.018)	(0.015)
Average Travel Time to Hanseatic Cities		0.359**		-0.101		0.077	
		(0.139)		(0.205)		(0.174)	
Travel Time to nearest Hanseatic City			0.272**		0.068		0.057
			(0.115)		(0.131)		(0.132)
Demographic Controls	✓	✓	✓	✓	✓	✓	✓
Religion Controls	✓	✓	✓	✓	✓	✓	✓
Institution Controls	✓	✓	✓	✓	✓	✓	✓
Geography	✓	✓	✓	✓	✓	✓	✓
Trade	✓	✓	✓	✓	✓	✓	✓
Observations	236	236	236	236	236	236	236
R^2	0.560	0.592	0.596	0.631	0.632	0.624	0.624
Adjusted R^2	0.530	0.558	0.563	0.601	0.601	0.593	0.593
Clustered SEs	X	X	X	X	X	X	X
Number of Clusters	56	56	56	56	56	56	56

Standard errors clustered by region in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Another potential confound that has not been addressed directly so far is the possibility of different institutions or industry structures across the units of observations, which might have affected the timing of the demographic transition during the 19th century. Controlling for these factors is problematic, as they constitute potentially bad controls. After all, in light of unified growth theory, education is a joint outcome of the demographic transition, as is potentially the degree of industrialization around the time of the demographic transition. In order to probe the robustness of the results, we nevertheless conducted estimations with controls for education in terms of the number of schools in a city, or the enrolment rate (in terms of the ratio of students among the population). Data on these education variables are only available for the subset of cities located in Prussia, however. The results concerning the exposure to population shocks during the middle ages are effectively unchanged.[29] A similar conclusion applies to estimation results for specifications that control for industry structure in terms of the share employed in agriculture or industry, respectively.[30]

Finally, we test an instrumental implication that provides some information about the mechanism.

[29]Detailed results are contained in Table A.13 in the Appendix.

[30]See Table A.14 in the Appendix for details. Unreported results also show that accounting for soil quality does not affect the main findings.

In particular, the hypothesis that population shocks such as those of the Black Death influences the timing of the demographic transition was motivated by the idea that reactions to the epidemic might shift the Malthusian equilibrium with the result of higher population and living standards (e.g., along the lines of Voiglaender and Voth, 2013a). Hence, one would expect an effect on population density. Table 8 presents results for regressions of the urban population in 1500 on the exposure to plague reintroductions. The results indeed suggest that cities with a greater exposure had a higher population by 1500, and exhibited faster population growth, as indicated by the result in Column (3).

Table 8: Implications for Population Growth

Dependent Variable	ln Population(1500)		
Number of Plague Ports (< 100 hrs)	0.220**	0.265**	0.046
	(0.087)	(0.121)	(0.081)
Distance to Nearest Plague Port	-0.007	-0.009*	-0.004
	(0.004)	(0.005)	(0.003)
Population Growth 1300-1500			0.404***
			(0.127)
Demographic Controls			✓
Religion Controls			✓
Institution Controls			✓
Geography		✓	✓
Trade		✓	✓
Observations	237	236	236
R^2	0.032	0.048	0.563
Adjusted R^2	0.024	0.027	0.538
Clustered SEs	X	X	X
Number of Clusters	56	56	56

Standard errors clustered at region in parentheses.
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

5 Conclusion

Summing up, this paper has presented an empirical investigation of the hypothesis that regions that that were more (and more often) exposed to major population shocks such as the outbreak of the Black Death experienced an earlier demographic transition. This hypothesis follows from recent work on the long-run implications of the Black Death and complements existing evidence that has not considered the timing of the demographic transition. The findings provide novel evidence for the mechanisms behind the demographic transition that are in line with the predictions of the canonical unified growth framework. Given the importance of this timing for long-run development, the evidence here provides new insights into the reasons for regional development differences that might be related to historical coincidences.

References

Becker, S. O., F. Cinnirella, and L. Woessmann (2010): "The Trade-off between Fertility and Education: Evidence from before the Demographic Transition," *Journal of Economic Growth*, 15(3), 177.

——— (2013): "Does Womens Education Affect Fertility? Evidence from Pre-Demographic Transition Prussia," *European Review of Economic History*, 17(1), 24.

Becker, S. O., and L. Woessmann (2008): "Luther and the Girls: Religious Denomination and the Female Education Gap in 19th Century Prussia," *Scandinavian Journal of Economics*, 110(4), 777.

——— (2009): "Was Weber Wrong? A Human Capital Theory of Protestant Economic History," *Quarterly Journal of Economics*, 124(2), 531.

——— (2010): "The effect of Protestantism on education before the industrialization: Evidence from 1816 Prussia," *Economics Letters*, 107(2), 224.

Bhattacharya, J., and S. Chakraborty (2016): "Contraception and the Demographic Transition," *Economic Journal, forthcoming*.

Boerner, L., and B. Severgnini (2014): "Epidemic Trade," *LSE Economic History Working Papers*, 212/2014.

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," *Review of Economics and Statistics*, 95(4), 1418–1437.

Briant, A., P.-P. Combes, and M. Lafourcade (2010): "Dots to boxes: Do the size and shape of spatial units jeopardize economic geography estimations?," *Journal of Urban Economics*, 67(3), 287–302.

Bruns, F., and H. Weczerka (1962): *Hansische Handelsstrassen. 1. Atlas*. Böhlau.

——— (1967): *Hansische Handelsstrassen: Textband*.

Cantoni, D. (2012): "Adopting a New Religion: The Case of Protestantism in the 16th Century," *Economic Journal*, 122(560), 502–531.

Cantor, N. F. (2002): *In the Wake of the Plague: The Black Death and the World It Made*. Simon and Schuster, New York.

Cervellati, M., and U. Sunde (2011): "Life Expectancy and Economic Growth: The Role of the Demographic Transition," *Journal of Economic Growth*, 16, 99–133.

——— (2013): "Life Expectancy, Schooling, and Lifetime Labor Supply: Theory and Evidence Revisited," *Econometrica*, 81(5), 2055–208.

——— (2015): "The Economic and Demographic Transition, Mortality, and Comparative Development," *American Economic Journal: Macroeconomics*, 7(3), 1–39.

——— (2016): "On the Emergence of Religious Norms – Theory and Evidence from the Protestant Reformation," *mimeo*.

Chakraborty, S., C. Papageorgiou, and F. Perez-Sebastian (2010): "Diseases, Infection Dynamics, and Development," *Journal of Monetary Economics*, 57(7), 859–872.

Chesnais, J.-C. (1992): *The Demographic Transition: Stages, Patterns and Economic Implications. A Longitudinal Study of Sixty-Seven Countries Covering the Period 1720-1984*. Clarendon Press, Oxford.

Clark, G. (2008): *A Farewell to Alms: A Brief Economic History of the World*. Princeton University Press, Princeton, N.J.

Davis, D. E. (1986): "The Scarcity of Rats and the Black Death: An Ecological History," *Journal of Interdisciplinary History*, 16(3), 455–470.

de Vries, J. (1986): *European Urbanization: 1500-1800*. Methuen & Co, London.

Galloway, P. (1994): "Fertility decline in Prussia 1875 to 1910: a pooled cross-section time series analysis," *Population Studies*, 48(1).

——— (2007): "Galloway Prussia Database 1861 to 1914," *www.patrickgalloway.com*.

Galor, O. (2005a): "The Demographic Transition and the Emergence of Sustained Economic Growth," *Journal of the European Economic Association*, 3(2).

——— (2005b): "From Stagnation to Growth: Unified Growth Theory," in *Handbook of Economic Growth*, ed. by P. Aghion, and S. Durlauf, chap. 4. Elsevier Science B.V., Amsterdam.

——— (2011): *Unified Growth Theory*. Princeton University Press, Princeton, N.J.

Galor, O., and O. Moav (2002): "Natural Selection and the Origin of Economic Growth," *Quarterly Journal of Economics*, 117(4), 1133–92.

Galor, O., and D. N. Weil (2000): "Population, Technology, and Growth: From Malthusian Stagnation to the Demographic Transition and Beyond," *American Economic Review*, 90(4), 807–828.

Henry, L. (1961): "Some Data on Natural Fertility," *Eugenics Quarterly*, 8(2), 81–91.

Hitzer, H. (1971): *Die Strasse: vom Trampelpfad zur Autobahn. Lebensadern von der Urzeit bis heute*. Callwey.

Jebwab, R., N. D. Johnson, and M. Koyama (2016): "Bones, Bacteria and Break Points: The Heterogeneous Spatial Effects of the Black Death and Long-Run Growth," *mimeo, George Mason University*.

Kausrud, K. L., H. Viljugrein, A. Frigessi, M. Begon, S. Davis, H. Leirs, V. Dubyanskiy, and N. C. Stenseth (2007): "Climatically driven synchrony of gerbil populations allows large-scale plague outbreaks," *Proceedings of the Royal Society B (Biological Sciences)*, 274(1621), 1963–1969.

Keeling, M., and C. Gilligan (2000): "Metapopulation dynamics of bubonic plague," *Nature*, 407, 903–906.

Keyser, E. (1941): *Bevölkerungsgeschichte Deutschlands*. Hirzel, Leipzig.

Knodel, A. J. (1974): *The Decline of Fertility in Germany, 1871-1939*. Princeton University Press, Princeton, N.J.

Lagerlöf, N.-P. (2003): "From Malthus to Modern Growth: Can Epidemics Explain the Three Regimes?," *International Economic Review*, 44(2), 755–777.

Perry, R. D., and J. D. Fetherston (1997): "Yersinia pestis - Etiologic Agent of Plague," *Clinical Microbiology Reviews*, 10(1), 35–66.

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(5), 377–392.

Reijniers, J., S. Davis, M. Begon, and H. Leirs (2012): "A curve of thresholds governs plague epizootics in Central Asia," *Ecology Letters*, 15(6), 554–560.

Ritter, G. (1966): "Zur Entwicklung des geburtshilflichen Phantoms im 19. und 20. Jahrhundert," *Medizinhistorisches Journal*, 1(4), 224–234.

Samia, N. I., K. L. Kausrud, H. Heesterbeek, V. Ageyev, M. Begon, K.-S. Chan, and N. C. Stenseth (2011): "Dynamics of the plague-wildlifehuman system in Central Asia are controlled by two epidemiological thresholds," *Proceedings of the National Academy of Sciences*, 108(35), 14527–14532.

Schmid, B. V., U. Büntgen, W. R. Easterday, C. Ginzler, L. Walloe, B. Bramanti, and N. C. Stenseth (2015): "Climate-driven introduction of the Black Death and successive plague reintroductions into Europe," *Proceedings of the National Academy of Sciences*, 112(10), 3020–3025.

Skog, L., and H. Hauska (2013): "Spatial Modeling of the Black Death in Sweden," *Transactions in GIS*, 17(4), 589–611.

Slack, P. (2012): *Plague: A Very Short Introduction*. Oxford University Press, Oxford.

Stenseth, N. C., N. I. Samia, K. L. Kausrud, M. Begon, S. Davis, H. Leirs, V. Dubyanskiy, J. Esper, V. Ageyev, N. L. Klassovskiy, S. B. Bole, and K.-S. Chan (2006): "Plague dynamics are driven by climate variation," *Proceedings of the National Academy of Sciences*, 103(35), 13110–13115.

Voigtländer, N., and H.-J. Voth (2013a): "How the West "Invented" Fertility Restriction," *American Economic Review*, 103(6), 2227–2264.

——— (2013b): "The Three Horsemen of Riches: Plague, War, and Urbanization in Early Modern Europe," *Review of Economic Studies*, 80(3), 774–811.

A Appendix

Table A.1: Hutterite Fertility: Number of births per married woman conditional on age

Age group (i)	Number of Births (F_i)
20-14	0.55
25-29	0.502
30-34	0.447
35-39	0.406
40-44	0.222
45-49	0.061

Notes:Standard schedule according to Henry (1961). The numbers are a benchmark for the natural fertility without active birth control.

Table A.2: Assumptions about Travel Speed

Type of line segment	Slope	Speed normal	Speed slow
River		15 km/h	10 km/h
Road	0	7 km/h	5 km/h
Road	(0;15]	5 km/h	3 km/h
Road	(15;30]	3 km/h	2 km/h
Road	(30;45]	1 km/h	1 km/h
Road	>45	0 km/h	0 km/h

Notes: Assumed travel speeds per hour by type (river, road) and slope of the line segment (in degrees). The main analysis uses assumptions about normal speed.

Table A.3: Proximity to Entry Ports and Plague Outbreaks: Accounting for Roman Roads

	# Outbreaks					Outbreak >1349	Outbreak >1349
Number of Plague Ports (< 100 hrs)	1.369**		1.519*	2.526**	2.001**	-0.025	-0.002
	(0.668)		(0.846)	(1.087)	(0.991)	(0.035)	(0.045)
Distance to Nearest Plague Port (Roman Road)		0.137*	-0.003	-0.014	-0.012	-0.006***	-0.007***
		(0.082)	(0.049)	(0.050)	(0.046)	(0.002)	(0.002)
Distance to Nearest Plague Port (non-Roman Road)		0.068**	0.048	0.015	0.019	-0.006***	-0.004**
		(0.035)	(0.033)	(0.044)	(0.040)	(0.001)	(0.002)
d_roman		-3.670					
		(3.065)					
Located on Navigable River				2.804**	3.012***		-0.005
				(1.125)	(1.023)		(0.046)
Distance Via Imperii (log km)				1.610	2.072		0.093
				(1.493)	(1.359)		(0.062)
Distance Via Regia (log km)				-1.897	-1.599		0.148**
				(1.752)	(1.594)		(0.072)
Plague Outbreak after 1347					8.294***		
					(1.194)		
Constant	2.381	3.520**	0.014	-3.135	-8.854**	0.506***	0.216
	(2.075)	(1.571)	(2.655)	(3.857)	(3.602)	(0.109)	(0.160)
Observations	232	232	232	232	232	236	236
R^2	0.018	0.021	0.028	0.063	0.229	0.109	0.140
Adjusted R^2	0.014	0.008	0.016	0.038	0.205	0.097	0.117

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A.4: Severity of Plague Outbreaks

	Outbreak >1349	Mortality	Mortality	Mortality
Number of Plague Ports (< 100 hrs)	-0.064		1.928	4.576
	(0.064)		(5.275)	(6.329)
Distance to Nearest Plague Port (Roman Road)	-0.006**	-0.411***	-0.441**	-0.502**
	(0.003)	(0.145)	(0.208)	(0.220)
Distance to Nearest Plague Port (non-Roman Road)	-0.003	-0.216	-0.207	-0.418
	(0.003)	(0.136)	(0.141)	(0.246)
Located on Navigable River	-0.167**		5.203	5.409
	(0.066)		(5.998)	(6.287)
Distance Via Imperii (log km)	-0.198**			1.911
	(0.087)			(10.472)
Distance Via Regia (log km)	0.145			-12.286
	(0.103)			(11.383)
Constant	1.034***	40.568***	31.583*	37.673
	(0.227)	(5.319)	(17.234)	(28.242)
Observations	236	30	30	30
R^2	0.102	0.246	0.269	0.307
Adjusted R^2	0.078	0.191	0.152	0.127

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A.5: Timing of the Demographic Transition

	None	Basic	Religion	Insitutions	Trade	Routes
Number of Plague Ports (< 100 hrs)	-4.322***	-4.904***	-4.858***	-4.744***	-4.744***	-2.837***
	(1.052)	(1.074)	(0.997)	(1.006)	(1.018)	(1.047)
Distance to Nearest Plague Port (Roman Road)	0.413***	0.413***	0.371***	0.356***	0.358***	0.326***
	(0.059)	(0.058)	(0.059)	(0.061)	(0.060)	(0.061)
Distance to Nearest Plague Port (non-Roman Road)	0.188***	0.220***	0.203***	0.209***	0.210***	0.190***
	(0.039)	(0.039)	(0.038)	(0.040)	(0.040)	(0.045)
Population Density (log)		-3.199***	-2.984***	-2.960***	-2.941***	-2.994***
		(0.917)	(0.855)	(0.823)	(0.823)	(0.705)
Population in 1500 (log)		0.227	-0.110	-0.553	-0.581	-0.321
		(0.315)	(0.372)	(0.453)	(0.445)	(0.413)
Population Growth 1300-1500		-0.256	-0.082	0.098	0.103	0.485
		(0.658)	(0.587)	(0.550)	(0.551)	(0.582)
Adopted Protestantism			-4.320***	-4.852***	-4.815***	-3.663**
			(1.442)	(1.379)	(1.407)	(1.455)
Monasteries (p.c.)			-0.499*	-0.573**	-0.606**	-0.572**
			(0.275)	(0.261)	(0.260)	(0.228)
Augustian Monasteries (p.c.)			0.714	0.658	0.726	0.257
			(1.119)	(1.097)	(1.107)	(1.063)
University				-1.560	-1.638	-1.716
				(1.622)	(1.630)	(1.600)
Hanseatic League				1.753	1.704	0.429
				(1.373)	(1.392)	(1.268)
Free Imperial City				2.362**	2.403**	1.795*
				(0.912)	(0.912)	(0.940)
Printing Press by 1517				-0.169	-0.252	-0.083
				(1.318)	(1.339)	(1.328)
Located on Navigable River					0.526	0.219
					(0.957)	(0.899)
Distance Via Imperii (log km)						4.911***
						(1.669)
Distance Via Regia (log km)						0.312
						(1.820)
Constant	1915.201***	1930.793***	1934.847***	1934.607***	1934.291***	1924.527***
	(3.523)	(6.358)	(6.366)	(6.347)	(6.306)	(5.648)
Observations	237	237	237	237	237	236
R^2	0.403	0.479	0.519	0.536	0.537	0.588
Adjusted R^2	0.396	0.465	0.500	0.509	0.508	0.557
Clustered SEs	X	X	X	X	X	X
Number of Clusters	56	56	56	56	56	56

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A.6: Timing of the Demographic Transition: Alternative Threshold

	None	Basic	Religion	Insitutions	Trade	Routes
Number of Plague Ports (< 100 hrs)	-3.745***	-4.383***	-4.626***	-4.828***	-4.827***	-4.481***
	(1.400)	(1.495)	(1.431)	(1.401)	(1.408)	(1.671)
Distance to Nearest Plague Port	0.393***	0.411***	0.378***	0.370***	0.370***	0.391***
	(0.082)	(0.081)	(0.082)	(0.082)	(0.082)	(0.088)
Population Density (log)		-2.008	-1.602	-1.453	-1.450	-0.947
		(1.777)	(1.743)	(1.681)	(1.683)	(1.637)
Population in 1500 (log)		0.442	-0.076	-0.727	-0.732	-0.335
		(0.507)	(0.657)	(0.878)	(0.860)	(0.792)
Population Growth 1300-1500		0.895	1.084	1.162	1.163	1.150
		(1.114)	(0.998)	(0.928)	(0.925)	(0.941)
Adopted Protestantism			-6.215***	-6.990***	-6.985***	-6.024***
			(2.262)	(2.185)	(2.198)	(2.165)
Monasteries (p.c.)			-0.749	-0.872*	-0.877**	-0.782*
			(0.502)	(0.475)	(0.432)	(0.416)
Augustian Monasteries (p.c.)			1.548	1.344	1.355	0.806
			(1.397)	(1.315)	(1.287)	(1.314)
University				-1.857	-1.870	-1.895
				(2.852)	(2.838)	(2.797)
Hanseatic League				1.591	1.584	0.162
				(2.464)	(2.521)	(2.391)
Free Imperial City				4.817***	4.825***	3.943**
				(1.585)	(1.618)	(1.656)
Printing Press by 1517				-1.066	-1.080	-1.070
				(1.685)	(1.756)	(1.715)
Located on Navigable River					0.085	-0.321
					(1.578)	(1.693)
Distance Via Imperii (log km)						2.485
						(2.707)
Distance Via Regia (log km)						3.165
						(3.315)
Constant	1895.990***	1906.074***	1912.618***	1913.388***	1913.336***	1904.505***
	(4.780)	(11.829)	(11.982)	(11.650)	(11.692)	(9.970)
Observations	237	237	237	237	237	236
R^2	0.354	0.369	0.408	0.432	0.432	0.448
Adjusted R^2	0.348	0.356	0.387	0.402	0.399	0.410
Clustered SEs	X	X	X	X	X	X
Number of Clusters	56	56	56	56	56	56

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A.7: Timing of the Demographic Transition: Galloway Data

	None	Basic	Religion	Insitutions	Trade	Routes
Number of Plague Ports (< 100 hrs)	-0.090	1.501	0.591	0.526	0.581	-1.171
	(1.775)	(1.796)	(1.743)	(1.859)	(1.818)	(1.445)
Distance to Nearest Plague Port	0.157***	0.124**	0.151***	0.146***	0.140***	0.121**
	(0.050)	(0.049)	(0.046)	(0.047)	(0.043)	(0.051)
Population Density (log)		3.136*	3.289*	3.381**	3.325**	3.078*
		(1.545)	(1.636)	(1.543)	(1.496)	(1.597)
Population in 1500 (log)		-0.104	-0.439	-1.088	-1.108	-1.275
		(0.718)	(0.795)	(0.952)	(0.967)	(0.935)
Population Growth 1300-1500		0.495	-0.161	-0.352	-0.057	-0.160
		(1.437)	(1.551)	(2.054)	(2.061)	(2.258)
Adopted Protestantism			2.009	1.803	1.711	1.541
			(2.290)	(2.285)	(2.325)	(2.407)
Monasteries (p.c.)			-0.370	-0.396	-0.305	-0.382
			(0.352)	(0.372)	(0.388)	(0.352)
Augustian Monasteries (p.c.)			-4.544	-4.672	-4.945	-4.867
			(3.696)	(3.620)	(3.642)	(3.609)
University				-5.175*	-4.783*	-5.120
				(2.708)	(2.517)	(3.013)
Hanseatic League				0.300	0.410	0.748
				(2.043)	(2.163)	(2.191)
Free Imperial City				1.695	1.667	1.589
				(2.612)	(2.606)	(2.664)
Printing Press by 1517				7.812**	8.089**	8.327**
				(3.345)	(3.359)	(3.571)
Located on Navigable River					-0.991	-0.833
					(1.453)	(1.496)
Distance Via Imperii (log km)						-2.744*
						(1.593)
Distance Via Regia (log km)						-1.777
						(2.199)
Constant	1876.596***	1858.966***	1859.043***	1859.371***	1860.034***	1870.393***
	(5.283)	(10.151)	(10.629)	(10.345)	(10.135)	(10.282)
Observations	131	131	131	131	131	130
R^2	0.101	0.172	0.221	0.243	0.246	0.258
Adjusted R^2	0.087	0.139	0.169	0.166	0.162	0.161
Clustered SEs	X	X	X	X	X	X
Number of Clusters	27	27	27	27	27	27

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A.8: Timing of the Demographic Transition: Regions (based on Knodel, 1974)

	Basic	Religion	Insitutions	Trade	Routes	routes
(mean) ports_100_med	-1.615	-4.551***	-4.998***	-5.088***	-5.248***	-4.007**
	(1.172)	(1.384)	(1.420)	(1.685)	(1.568)	(1.730)
(mean) closest	0.238***					
	(0.045)					
(mean) closest_R_med		0.409***	0.322***	0.280***	0.312***	0.283***
		(0.079)	(0.078)	(0.087)	(0.084)	(0.088)
(mean) closest_nR_med		0.216***	0.191***	0.198***	0.216***	0.217***
		(0.047)	(0.046)	(0.064)	(0.058)	(0.067)
(mean) ln_areadens		-4.324***	-4.082***	-4.281***	-4.571***	-4.318***
		(0.817)	(0.756)	(0.870)	(0.800)	(0.681)
(mean) logpop_1500		1.448	0.564	0.783	0.531	1.316
		(1.383)	(1.358)	(2.350)	(1.870)	(1.787)
(mean) popgrowth_1315		0.508	1.527	0.687	1.170	1.634
		(1.742)	(1.721)	(1.511)	(1.589)	(1.759)
(mean) protestant_at_t			-9.036***	-10.987***	-10.907***	-9.700***
			(2.847)	(2.764)	(2.661)	(2.850)
(mean) monpc			-1.666**	-2.148**	-2.473**	-2.257**
			(0.827)	(0.834)	(0.928)	(0.904)
(mean) monaugpc			3.096	4.367	8.174	6.400
			(4.870)	(5.154)	(5.693)	(5.506)
(mean) university				-7.562	-11.945	-11.861
				(7.982)	(7.602)	(7.205)
(mean) hansa				-1.542	-2.313	-5.475
				(5.056)	(4.155)	(3.799)
(mean) reichsstadt				5.846**	5.629**	4.779*
				(2.849)	(2.491)	(2.697)
(mean) pressby1517				-3.810	-3.798	-3.978
				(4.374)	(3.817)	(3.852)
(mean) river					5.643**	3.872
					(2.416)	(2.424)
(mean) lnkm13						4.650**
						(2.146)
(mean) lnkm23						1.771
						(3.168)
Constant	1906.653***	1934.665***	1945.717***	1948.996***	1947.865***	1937.395***
	(3.713)	(5.586)	(6.629)	(8.806)	(7.762)	(8.460)
Observations	56	56	56	56	56	56
R^2	0.291	0.560	0.635	0.681	0.723	0.752
Adjusted R^2	0.264	0.507	0.564	0.582	0.629	0.651
Clustered SEs	X	X	X	X	X	X
Number of Clusters	56	56	56	56	56	56

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A.9: Timing of the Demographic Transition: Port Regions

	Baseline	Without Southern Ports I500	Without Southern Ports I600
Distance to Nearest Plague Port	0.236***		
	(0.046)		
Travel Time ex South		0.227***	0.376***
		(0.038)	(0.078)
Number of Ports	-2.176**	-2.674**	-5.297***
	(1.022)	(1.058)	(1.772)
Population Density (log)	-3.018***	-3.014***	-0.941
	(0.706)	(0.708)	(1.617)
Population in 1500 (log)	-0.162	-0.096	-0.226
	(0.441)	(0.461)	(0.814)
Population Growth 1300-1500	0.725	0.432	0.666
	(0.571)	(0.583)	(1.007)
Adopted Protestantism	-4.465***	-3.907**	-5.104**
	(1.509)	(1.520)	(2.139)
Monasteries (p.c.)	-0.493*	-0.564**	-0.898**
	(0.249)	(0.233)	(0.400)
Augustian Monasteries (p.c.)	0.456	0.435	0.775
	(1.018)	(0.956)	(1.291)
University	-1.617	-1.455	-1.624
	(1.699)	(1.676)	(2.766)
Hanseatic League	0.306	0.452	0.395
	(1.273)	(1.246)	(2.374)
Free Imperial City	2.514**	1.642	2.505*
	(1.093)	(1.004)	(1.425)
Printing Press by 1517	-0.417	-0.862	-1.807
	(1.306)	(1.365)	(1.789)
Located on Navigable River	-0.035	0.345	0.308
	(0.934)	(0.919)	(1.646)
Distance Via Imperii (log km)	4.738**	4.695***	2.421
	(1.805)	(1.691)	(2.585)
Distance Via Regia (log km)	2.261	1.302	1.562
	(1.883)	(1.631)	(2.977)
Constant	1920.918***	1922.579***	1907.271***
	(5.873)	(5.780)	(9.626)
Observations	236	236	236
R^2	0.560	0.579	0.471
Adjusted R^2	0.530	0.550	0.435
Clustered SEs	X	X	X
Number of Clusters	56	56	56

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A.10: Timing of the Demographic Transition: Placebo Ports

	Placebo incl. Hamburg	Placebo incl. Hamburg	Placebo excl. Hamburg	Placebo excl. Hamburg
Average Distance to Nearest Placebo Port	0.124*	-0.068		
	(0.067)	(0.088)		
Number of Placebo Ports (< 100 hrs)	1.222	-0.110		
	(1.467)	(1.465)		
Population Density (log)	-2.782***	-3.279***	-2.921***	-3.374***
	(0.812)	(0.686)	(0.812)	(0.686)
Population in 1500 (log)	-0.393	-0.156	-0.442	-0.150
	(0.533)	(0.457)	(0.542)	(0.454)
Population Growth 1300-1500	0.814	0.845	0.877	0.819
	(0.701)	(0.635)	(0.726)	(0.599)
Adopted Protestantism	-6.002***	-4.108***	-6.650***	-3.945***
	(1.751)	(1.467)	(1.695)	(1.462)
Monasteries (p.c.)	-0.306	-0.554**	-0.346	-0.590**
	(0.284)	(0.233)	(0.281)	(0.228)
Augustian Monasteries (p.c.)	0.928	0.447	1.355	0.467
	(1.190)	(1.054)	(1.168)	(1.039)
University	-0.988	-1.844	-0.641	-1.971
	(2.079)	(1.668)	(2.114)	(1.681)
Hanseatic League	-1.191	0.187	-2.239	0.281
	(1.616)	(1.272)	(1.753)	(1.290)
Free Imperial City	3.710***	2.205**	4.522***	1.912*
	(1.376)	(1.013)	(1.460)	(0.983)
Printing Press by 1517	-0.587	-0.255	-0.421	-0.200
	(1.591)	(1.318)	(1.590)	(1.299)
Located on Navigable River	-0.352	0.116	-0.362	0.153
	(0.987)	(0.932)	(1.017)	(0.927)
Distance Via Imperii (log km)	8.592***	4.032*	7.465***	4.019*
	(1.979)	(2.079)	(2.231)	(2.168)
Distance Via Regia (log km)	-2.138	2.756	-2.141	2.787
	(1.878)	(1.932)	(1.933)	(1.913)
Number of Plague Ports (< 100 hrs)		-1.739		-1.851
		(1.219)		(1.212)
Distance to Nearest Plague Port		0.272***		0.263***
		(0.057)		(0.048)
Average Distance to Nearest Placebo Port (alt.)			0.049	-0.050
			(0.067)	(0.073)
Number of Placebo Ports (< 100 hrs, alt.)			0.508	0.453
			(1.482)	(1.337)
Constant	1911.184***	1923.788***	1922.002***	1922.296***
	(11.713)	(10.457)	(9.921)	(8.502)
Observations	236	236	236	236
R^2	0.437	0.567	0.409	0.572
Adjusted R^2	0.398	0.533	0.369	0.538

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A.11: Timing of the Demographic Transition: Placebo Ports and Hanseatic Ports

	Baseline	Closest	Closest	Average_N	Average_N	Weighted	Weighted
Distance to Nearest Plague Port	0.236***	0.107	0.143**				
	(0.046)	(0.074)	(0.058)				
Average Travel Time North				0.318***	0.248***		
				(0.101)	(0.057)		
Weighted by Outbreaks						0.273**	0.279***
						(0.103)	(0.066)
Number of Ports	-2.176**	-2.526**	-3.356***	-2.884***	-3.088**	-3.108***	-3.277***
	(1.022)	(1.093)	(1.234)	(1.059)	(1.207)	(1.028)	(1.142)
Average Distance to Placebo Port		-0.024*	-0.020	0.006	-0.006	0.008	0.009
		(0.012)	(0.013)	(0.016)	(0.012)	(0.018)	(0.015)
Number of Placebo Ports		0.495	-0.992	-0.862	-1.136	-1.635	-1.984*
		(1.075)	(1.506)	(0.971)	(1.223)	(1.181)	(1.173)
Average Travel Time to Hanseatic Cities		0.359**		-0.101		0.077	
		(0.139)		(0.205)		(0.174)	
Travel Time to nearest Hanseatic City			0.272**		0.068		0.057
			(0.115)		(0.131)		(0.132)
Population Density (log)	-3.018***	-3.620***	-3.044***	-3.207***	-3.244***	-3.225***	-3.093***
	(0.706)	(0.672)	(0.699)	(0.680)	(0.661)	(0.694)	(0.634)
Population in 1500 (log)	-0.162	-0.076	-0.105	-0.149	-0.120	-0.060	-0.068
	(0.441)	(0.451)	(0.464)	(0.444)	(0.441)	(0.458)	(0.460)
Population Growth 1300-1500	0.725	0.556	0.398	0.526	0.456	0.446	0.408
	(0.571)	(0.544)	(0.624)	(0.550)	(0.558)	(0.507)	(0.536)
Adopted Protestantism	-4.465***	-3.664**	-4.146***	-3.070**	-3.173**	-3.375**	-3.497**
	(1.509)	(1.609)	(1.373)	(1.398)	(1.456)	(1.499)	(1.469)
Monasteries (p.c.)	-0.493*	-0.648***	-0.609**	-0.751***	-0.741***	-0.754***	-0.745***
	(0.249)	(0.205)	(0.241)	(0.206)	(0.205)	(0.210)	(0.211)
Augustian Monasteries (p.c.)	0.456	0.333	1.100	0.537	0.622	0.787	0.967
	(1.018)	(1.024)	(0.952)	(0.989)	(0.968)	(0.941)	(0.940)
University	-1.617	-2.505	-1.033	-1.725	-1.690	-1.881	-1.547
	(1.699)	(1.629)	(1.518)	(1.458)	(1.479)	(1.499)	(1.481)
Hanseatic League	0.306	1.058	1.785	0.523	1.004	0.392	0.507
	(1.273)	(1.143)	(1.294)	(1.212)	(1.223)	(1.166)	(1.259)
Free Imperial City	2.514**	0.996	1.088	0.528	0.392	0.537	0.568
	(1.093)	(1.025)	(0.908)	(0.940)	(0.974)	(0.996)	(1.026)
Printing Press by 1517	-0.417	-0.318	-0.705	-0.704	-0.735	-0.898	-0.996
	(1.306)	(1.247)	(1.261)	(1.304)	(1.290)	(1.298)	(1.349)
Located on Navigable River	-0.035	-0.274	0.100	0.692	0.505	0.361	0.443
	(0.934)	(0.893)	(0.904)	(0.902)	(0.866)	(0.898)	(0.873)
Distance Via Imperii (log km)	4.738**	1.898	3.173	2.347	1.822	0.538	0.803
	(1.805)	(2.388)	(2.231)	(2.166)	(1.965)	(2.025)	(2.066)
Distance Via Regia (log km)	2.261	-0.464	0.489	1.664	0.732	-0.418	-0.304
	(1.883)	(2.022)	(1.859)	(1.834)	(1.460)	(1.565)	(1.483)
Constant	1920.918***	1926.308***	1938.215***	1919.976***	1926.788***	1908.966***	1911.063***
	(5.873)	(8.387)	(12.900)	(7.680)	(13.110)	(10.029)	(16.156)
Observations	236	236	236	236	236	236	236
R^2	0.560	0.592	0.596	0.631	0.632	0.624	0.624
Adjusted R^2	0.530	0.558	0.563	0.601	0.601	0.593	0.593
Clustered SEs	X	X	X	X	X	X	X
Number of Clusters	56	56	56	56	56	56	56

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A.12: Timing of the Demographic Transition: Placebo Ports (19th century)

	Baseline	Closest	Average_N
Number of Plague Ports (< 100 hrs)	-2.837***	-2.136*	-2.547**
	(1.047)	(1.151)	(1.013)
Distance to Nearest Plague Port (Roman Road)	0.326***	0.371***	
	(0.061)	(0.068)	
Distance to Nearest Plague Port (non-Roman Road)	0.190***	0.219***	
	(0.045)	(0.048)	
Population Density (log)	-2.994***	-3.201***	-3.293***
	(0.705)	(0.725)	(0.667)
Population in 1500 (log)	-0.321	-0.350	-0.142
	(0.413)	(0.440)	(0.437)
Population Growth 1300-1500	0.485	0.666	0.599
	(0.582)	(0.585)	(0.521)
Adopted Protestantism	-3.663**	-3.292**	-3.049**
	(1.455)	(1.346)	(1.421)
Monasteries (p.c.)	-0.572**	-0.627***	-0.745***
	(0.228)	(0.219)	(0.201)
Augustian Monasteries (p.c.)	0.257	0.076	0.394
	(1.063)	(1.147)	(0.988)
University	-1.716	-1.981	-1.896
	(1.600)	(1.562)	(1.535)
Hanseatic League	0.429	0.196	0.576
	(1.268)	(1.286)	(1.214)
Free Imperial City	1.795*	1.560*	0.555
	(0.940)	(0.931)	(0.955)
Printing Press by 1517	-0.083	0.082	-0.676
	(1.328)	(1.339)	(1.321)
Located on Navigable River	0.219	0.399	0.578
	(0.899)	(0.911)	(0.880)
Distance Via Imperii (log km)	4.911***	3.769*	1.287
	(1.669)	(1.954)	(1.837)
Distance Via Regia (log km)	0.312	0.116	0.949
	(1.820)	(1.920)	(1.457)
Average Distance to Placebo Port		-0.012	-0.006
		(0.008)	(0.006)
Number of Placebo Ports (< 100 hrs)		-1.005	-1.717*
		(1.295)	(0.974)
Average Travel Time North			0.287***
			(0.036)
Constant	1924.527***	1933.006***	1928.315***
	(5.648)	(9.530)	(7.685)
Observations	236	236	236
R^2	0.588	0.596	0.636
Adjusted R^2	0.557	0.563	0.608
Clustered SEs	X	X	X
Number of Clusters	56	56	56

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A.13: Timing of the Demographic Transition: Controlling for Education (Prussia)

	Baseline	Schools	Schools	Studentratio	Studentratio
Number of Ports	-4.775**	-4.677**	-4.677***	-4.808**	-4.808***
	(2.044)	(2.057)	(1.396)	(2.023)	(1.357)
Distance to Nearest Plague Port	0.122	0.128	0.128**	0.117	0.117**
	(0.079)	(0.079)	(0.053)	(0.080)	(0.054)
Population Density (log)	-3.106***	-3.000***	-3.000***	-3.099***	-3.099***
	(0.728)	(0.691)	(0.455)	(0.730)	(0.471)
Population in 1500 (log)	-0.091	-0.056	-0.056	0.010	0.010
	(0.751)	(0.745)	(0.671)	(0.774)	(0.693)
Population Growth 1300-1500	0.253	-0.149	-0.149	0.028	0.028
	(1.125)	(1.176)	(1.277)	(1.151)	(1.303)
Adopted Protestantism	-3.109*	-2.991	-2.991**	-2.853	-2.853**
	(1.755)	(1.760)	(1.197)	(1.705)	(1.216)
Monasteries (p.c.)	-0.653**	-0.674**	-0.674***	-0.666**	-0.666***
	(0.259)	(0.262)	(0.240)	(0.266)	(0.238)
Augustian Monasteries (p.c.)	1.636	1.923*	1.923*	1.723	1.723
	(1.073)	(1.034)	(1.028)	(1.088)	(1.065)
University	1.665	1.422	1.422	1.800	1.800
	(2.498)	(2.514)	(2.776)	(2.565)	(2.759)
Hanseatic League	-0.160	-0.424	-0.424	-0.272	-0.272
	(1.541)	(1.556)	(1.447)	(1.546)	(1.448)
Free Imperial City	-0.559	-0.377	-0.377	-0.563	-0.563
	(1.325)	(1.270)	(1.339)	(1.368)	(1.333)
Printing Press by 1517	0.294	0.636	0.636	0.250	0.250
	(2.098)	(2.230)	(2.433)	(2.154)	(2.344)
Located on Navigable River	-0.022	0.220	0.220	0.210	0.210
	(1.004)	(1.141)	(1.007)	(1.053)	(1.030)
Distance Via Imperii (log km)	6.563**	6.146**	6.146***	6.673**	6.673***
	(2.786)	(2.537)	(1.493)	(2.631)	(1.446)
Distance Via Regia (log km)	-0.533	-0.391	-0.391	-0.637	-0.637
	(2.522)	(2.312)	(1.603)	(2.441)	(1.614)
Schools		-0.024	-0.024		
		(0.020)	(0.016)		
Student Ratio				0.003*	0.003*
				(0.002)	(0.002)
Constant	1931.385***	1932.195***	1932.195***	1930.680***	1930.680***
	(11.374)	(11.096)	(6.570)	(11.230)	(6.708)
Observations	123	123	123	123	123
R^2	0.630	0.639	0.639	0.637	0.637
Adjusted R^2	0.579	0.584	0.584	0.582	0.582
Clustered SEs	X	X	X	X	X
Number of Clusters	25	25	116	25	116

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Table A.14: Timing of the Demographic Transition: Controlling for Industry Structure (Prussia)

	Baseline	Agriculture	Agriculture	Industry	Industry
Number of Ports	-5.115**	-4.965**	-4.965***	-4.980**	-4.980***
	(2.222)	(2.222)	(1.565)	(2.221)	(1.579)
Distance to Nearest Plague Port	0.162*	0.164**	0.164***	0.164**	0.164***
	(0.078)	(0.078)	(0.056)	(0.078)	(0.056)
Population Density (log)	-2.169**	-2.137**	-2.137***	-2.146**	-2.146***
	(0.836)	(0.856)	(0.746)	(0.845)	(0.735)
Population in 1500 (log)	0.519	0.580	0.580	0.559	0.559
	(0.951)	(0.924)	(0.901)	(0.942)	(0.906)
Population Growth 1300-1500	0.911	0.857	0.857	0.773	0.773
	(1.020)	(1.037)	(1.408)	(0.985)	(1.434)
Adopted Protestantism	-6.204***	-5.863***	-5.863***	-5.871***	-5.871***
	(1.477)	(1.616)	(1.374)	(1.732)	(1.392)
Monasteries (p.c.)	0.304	0.319	0.319	0.277	0.277
	(0.571)	(0.573)	(0.521)	(0.583)	(0.526)
Augustian Monasteries (p.c.)	3.853**	3.899**	3.899***	3.870**	3.870***
	(1.683)	(1.610)	(1.267)	(1.674)	(1.300)
University	5.451**	5.858***	5.858***	5.770**	5.770**
	(2.025)	(2.028)	(2.212)	(2.117)	(2.242)
Hanseatic League	-0.543	-0.764	-0.764	-0.751	-0.751
	(1.836)	(1.802)	(1.877)	(1.806)	(1.870)
Free Imperial City	0.388	0.184	0.184	0.189	0.189
	(1.533)	(1.530)	(1.313)	(1.574)	(1.306)
Printing Press by 1517	-1.675	-1.754	-1.754	-1.801	-1.801
	(2.502)	(2.456)	(2.585)	(2.523)	(2.656)
Located on Navigable River	1.617	1.579	1.579	1.617	1.617
	(0.968)	(0.994)	(1.220)	(0.993)	(1.214)
Distance Via Imperii (log km)	7.640**	7.808***	7.808***	7.668**	7.668***
	(2.755)	(2.732)	(1.514)	(2.784)	(1.515)
Distance Via Regia (log km)	-0.745	-0.423	-0.423	-0.445	-0.445
	(2.538)	(2.378)	(1.765)	(2.403)	(1.786)
Share Agriculture		-4.417	-4.417		
		(6.119)	(6.131)		
Share Industry				5.826	5.826
				(9.775)	(9.140)
Constant	1926.843***	1926.347***	1926.347***	1925.133***	1925.133***
	(11.779)	(11.692)	(7.642)	(11.762)	(8.196)
Observations	91	91	91	91	91
R^2	0.704	0.705	0.705	0.705	0.705
Adjusted R^2	0.644	0.642	0.642	0.641	0.641
Clustered SEs	X	X	X	X	X
Number of Clusters	21	21	88	21	88

Standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$