THE LONDON SCHOOL OF ECONOMICS AND POLITICAL SCIENCE

Economic History Working Papers No: 212/2014

Epidemic Trade

Lars Boerner
LSE

Battista Severgnini
Copenhagen Business School

Economic History Department, London School of Economics and Political Science, Houghton Street, London, WC2A 2AE, London, UK. T: +44 (0) 20 7955 7084. F: +44 (0) 20 7955 7730

Epidemic Trade

By Lars Boerner and Battista Severgnini*

This paper uses the spread of disease as a proxy to measure economic interactions. Based on a case study of the Black Death (1346-51) in the Mediterranean region and Europe, we find geographic, institutional, and cultural determinants of trade. To achieve this we create and empirically test a trade model between cities. Our findings allow us to create a new methodology to measure economic interaction and shed light on open questions in economics, especially pertaining to trade, economic history, and growth.

JEL: 010, F15, N13

Keywords: Trade, Black Death, Gravity model, Poisson Pseudo Maximum Likelihood, Spatial regression discontinuity

* Boerner: London School of Economics. Address: Houghton Street London WC2A 2AE UK. Email: l.boerner@lse.ac.uk. Severgnini: Copenhagen Business School. Address: Porcelænshaven 16A. DK - 2000 Frederiksberg, Denmark. Email: bs.eco@cbs.dk. We would like to thank Daron Acemoglu, Alberto Alesina, Benjamin Arbel, Ole J. Benedictow, Georg Christ, Giovanni Ciappelli, Gregory Clark, Lorenzo Del Panta, Dave Donaldson, Paolo Epifani, Robert Feenstra, Yadira Gonzáles de Lara, Regina Grafe, Avner Greif, Mathias Hoffmann, David Hummels, Nicolai Kaarsen, Timur Kuran, Peter Linderth, Lars Lund, Jakob Madsen, Peter Møllgaard, Gaia Narciso, Alan Olmestead, Giovanni Peri, Karl Gunnar Persson, Moritz Schularick, Nathan Sussman, Silvana Tenreyro, Andrea Vaona, Hans-Joachim Voth and Jacob Weisdorf as well as seminar participants at UC Davis, at London School of Economics, at University of Copenhagen, at Bocconi University, at Zurich KOF-ETH, at Lund University, at Humboldt University in Berlin, at Milano Bicocca, at Copenhagen Business School, at Trinity College Dublin, at University of Mannheim, at University of Luxembourg, at Freie Universität Berlin, at University of Münster, at CEU-Cardinal Herrera University in Valencia, at Verona University, at the Conference *Union in Separation* in Heidelberg, at the European Historical Economics Society Conference in Dublin and at the European Economic Association Congress in Malaga. Battista Severgnini gratefully acknowledges the financial support of the Danish Social Science Research Council-Ministry of Science, Technology and Innovation. All

Epidemics are an integral part of human history. Massive plagues have been documented as far back as Justinian Plague in AD 541-2, to the Black Death (1346-51) during the Middle Ages, and in modern times with the Spanish influenza epidemic of 1918.[1] Such epidemics had a huge economic and social impact. The Black Death killed 30-60 percent of Europes population, and caused Malthusian-wealth effects for the survivors (Bridbury (1962)). Some scholars have argued that this plague engendered long-run growth effects for Western Europe (Voigtlaender and Voth (2013)). Social and institutional changes have also been derived from this epidemic shock (Domar (1970) and Munro (2005)).

Although these and other social scientists have intensively investigated the consequences of plagues, little has been done to apply what is known about the spread of epidemics in social and economic interactions. In the natural sciences, epidemiologists use the link between channels of social interaction and the spread of plagues to predict and prevent pandemics (Brokman and Helbing (2013)). Some recent studies on a unified theory on the cities found that urban life (Bettencourt, Lobo, Strumsky, and West (2007) and Bettencourt and West (2010)) is strongly related to epidemics and economic transition; in cities, diseases spread and firms are born and die at very similar rates.

In this case study, we examine the deadliest plague in human history: the Black Death. We start with the insights of leading scholars in disciplines such as economic history, demography, epidemics, and medicine who found that the plague followed trade routes and that merchants were the main carriers of the disease (see Cipolla (1974), Biraben (1975), Del Panta (1980),

errors are our own.

[1]For a survey, see for example Aberth (2011).

McCormick (2001), and Benedictow (2004)). Other carriers of the plague can be excluded or are marginal for the period of investigation.[2] These insights allow us to use the speed of the spread of the plague (measured in kilometers per day) between city-pairs as a proxy for trade flows and trade intensity. Thus the more merchants move between two cities, the more intensive the trade relationship and the faster a city becomes infected given the trading partner city has already been contaminated. Based on precise information from studies in history, demography, epidemics, and additional primary source studies on the outbreak of the plague in different cities, we create a sample of city-pairs, and measure the speed of transmission of the disease between each city-pair. This way the sample enables us to exploit the variation in the observations to make a relative comparative analysis of trade which does not measure the trade of physical goods but is based on the social interaction of trade activities.

To identify the determinants of trade for the period of investigation, we create a trade model which specifies and replicates the environment of the Commercial Revolution (Lopez (1976)). This period has been characterized by an intensification of inter-regional and long distance trade. To capture these environmental characteristics we start with a theoretical model which contains variables also considered in the traditional gravity model with Armington-type of trade (Armington (1969) and Anderson and van Wincoop (2003)). However, we modify it in the following way: the basic units of analysis are cities instead of countries, and cities have different preferences for locally and foreign produced goods. Consumption and its related trade are driven by preferences for foreign goods which can be interpreted

[2]For a discussion of both points see section I.

as a taste for different types of products and cannot be produced on the home market due to the unique geographic and institutional endowments of each city. To highlight these preferences we introduce taste parameters for local and foreign-produced goods to the model. However, since foreign-produced goods are more costly to transport, we weight these preferences with the time for the goods to travel to the local city. This physical transportation time is based on the geographical constraints between the two trading cities and the transportation technology available. The modeling of a setup with such differentiated goods is traceable to Armington (1969) and more recently to Head and Ries (2001). The idea to specify the preference for differentiated foreign products to time to travel can be found in Hummels and Schaur (2013). Complementary to this motivation for trade we integrate other standard assumptions into the model such as the effect of population densities of trading cities (as a proxy for GDP), transportation costs between trading cities, and other trade-promoting or -restricting institutions. Key predictions of our model are that strong preferences for foreign products can outweigh trade restricting effects such as transportation costs and other transaction costs, for instance political borders. This way we expect an increase of trade between merchant cities if the geographic and institutional setup is sufficiently favorable.

In the next step we test our proxy variable for trade intensity empirically on the theoretically derived trade determinants. As explanatory empirical variables we use the traditional gravity variables, additional geographical, institutional, and cultural variables. To determine the time to travel between two cities we use the Stanford ORBIS data set[3] which measures the time

[3]https:\\orbis.stanford.edu

to travel given geographical amenities during the Roman Empire.[4] Furthermore, we introduce a large set of additional control variables. We first look into the descriptive statistics and then run regressions based on the theoretically derived gravity equation with different specifications and robustness tests. In particular we control for nonlinearity and non observables following an empirical technique by Silva and Tenreyro (2006). To differentiate and disentangle the geographical from the institutional effects we introduce a spatial regression discontinuity design (SRDD).[5] This allows us to make geographical predictions on trade intensities and to identify the institutional effects of geographically determined trade. Looking at the empirical output, we find support for our predicted trade determinants: trade intensities measured based on the speed of transmission depend positively on the time to travel between two cities. In addition, political borders reduce trade. Other city-specific institutions such as the political organizations significantly influence trade activities. Furthermore, cultural variables influence the speed of transmission. We can identify the four weeks of Lent as a religious variable which restricts trade. The geographical distance between two cities increases trade intensities. This is contrary to predictions of traditional gravity models, but in line with our predictions where we expect to find an increase in demand for variety of foreign-produced goods. This is consistent with Crozet, Head, and Mayer (2012), who find the effects of quality and tastes on long distance trade using data on the commerce of French wine. The results of spatial regression discontinuity design support these findings. We find strong trade activities within the same political borders,

[4]This approximation works because revolutions in transportation technology did not take place until after the Black Death. See Pryor (1992).

[5]See Dell (2010) and Michalopoulos and Papaioannou (2014).

but a reduction of trade activities along those political borders. However we find an increase of trade activities in case of cross border trade if cities are geographically distant (and consequently further from the border). Finally the SRDD identifies trade-promoting institutional effects which are in particular located in Western Europe. Our paper contributes in several ways. First we create a new methodology in social science to measure social and economic interaction. We are able to use the spread of epidemics to measure relative trade intensities. This is very useful since it allows us to create new insights with these measurement techniques and in case of missing data as an alternative way to generate quantitative insights which would not have been possible otherwise. Our results confirm the usefulness of our methodology for our case study. We cannot judge how generalizable our approach is to other environments since other social determinants need to be taken into account. However we see this as a first step with the potential for further studies. In addition, our approach allows us to examine a very important historical epoch. Our results shed light on the determinants of trade during the Commercial Revolution, which has been identified as a key period in economic history (Lopez (1976), Cipolla (1993) and Epstein (2000a)). Thus our results can be read as a quantitative exercise for the medieval economic historian to see what determined trade. Such a comprehensive exercise taking into account such an extensive geographical area is due to the limited data otherwise not possible. Some key insights which are highly debated, are that political borders indeed restricted trade and economic growth (North and Thomas (1973)). However at the same time we can document long-distance trade motivated by an Armington-type of trade. Therefore trade-supporting institutions which helped overcome political borders and commitment problems must have been at work as Greif (2006c) suggests. Indeed we can document significant effects of trade-supporting institutions. Furthermore, we show that cultural variables determined economic activities, which is for instance claimed by Le Goff (1988) for religious variables. Third our analysis offers new insights for scholars interested in economic growth and trade. Our results contribute to the literature which seeks to explain long run growth and growth divergence in different regions (Galor and Weil (1999) and Pomeranz (2001)). Our paper cannot contribute to a comparative analysis between China and Europe, but we can contribute to early triggers of a divergence in the Mediterranean (Kuran (2003)) and within Europe (Allen (2001)). Our identification of trade-promoting institutions in Western Europe support arguments that the growth of Western Europe might be based on institutional achievements beginning in the Commercial Revolution (Cipolla (1993), Epstein (2000b) and Greif (2006c)). In addition, our findings of the Armington type of trade in pre-modern Mediterranean and Europe contributes to a literature which explains different trade patterns in the long run (O'Rourke and Williamson (1999)). Furthermore, our findings that religious variables play a role in explaining trade activities, support this line of research which tries to explain long run growth effects based on cultural variables (Weber (1921), more recently, Guiso, Sapienza, and Zingales (2006), Becker and Woessmann (2009), among others). Finally, a debate has been on for a long period which discusses the impact of geography versus institutions on economic growth (Diamond (1997); Gallup, Mellinger, and Sachs (1999); North and Thomas (1973); Hall and Jones (1996) Acemoglu, Johnson, and Robinson (2005b), Greif (2006c)). Our findings support the positive role of both effects. Our empirical analysis also allows us to disentangle these effects from a new perspective. Our results support the argument that there exist distinct institutional effects which are independent of geographical amenities.

The remainder of the paper is structured as follows. Section I gives a short introduction to the late medieval economic history of Europe and the spread of the Black Death. In addition, the link between the spread of the plague and trade activities are explained. Section II introduces a new trade model for cities and discusses the predictions of the key variables of the model. Furthermore different sets of related empirical variables are identified. Section III presents the data and the descriptive statistics. Section IV outlines the empirical strategy and discusses the estimation results. Section V displays the regression discontinuity analysis. Section VI concludes.

I. The Link: Medieval Trade and the Black Death

A. The Late Medieval Trade Environment

The second half of the Middle Ages is a turning point in the history of Western Europe. After the decline of the Roman Empire and an economic disintegration of Europe, a new phase of city growth and intensification of trade appeared in Western Europe, starting in the late 10th and 11th centuries (Bairoch (1988) and Bosker, Buringh, and van Zanden (2013)). The period from the 11th until the middle of the 14th century has been characterized by Lopez (1976) as the "Commercial Revolution". Small cities grew and many new cities were founded. This urbanization was triggered by regional trade and long-distance trade among cities across Europe and the wider Mediterranean area (Lopez (1952 and 1976), North and Thomas (1973), Postan (1975), Bairoch (1988), Cipolla (1993) and Epstein (2000a)).

The revitalization of trade was based on the reestablishment and increase of trade connections between different European and Mediterranean cities. Trade routes on land, rivers, and the sea were used to exchange a large variety of goods. High-value-per-weight goods for example textiles, spices, or jewelry were traded due to high transportation costs. Cities started to develop a demand for luxury products, which also contained low-end products which also modestly wealthy citizens could consume (Stuard (2006)). However there is evidence of inter-regional trade of bulk goods such as grain (which could not been produced in sufficient quantities in the hinterland of the cities) were shipped. Thus most of the growing cities during the Late Middle Ages can be identified as merchant cities which produced manufacturing products for export and imported all kinds of input and consumption goods (van Werveke (1952) and Hibbert (1963)). Some cities were also residences of bishops and dukes and served political and administrative purposes. Some cities already hosted universities. These cities could rely on external income streams, for example in form of fiscal incomes. This way these cities were very likely consuming more than they produced. The two channels of transportation on land and on waterways (rivers and on the sea) can be characterized in different ways. Land trade was based on the use of old Roman roads. Streets were the slowest and most costly way to transport goods. Horses and mules with carts could transport only limited amounts of goods. A cheaper and faster option to transport larger quantities of goods was along waterways, especially on sea ships. Shipping technology was based on Roman expertise. Major technological innovations did not take place until after the period under investigation (Pryor (1992)). However shippers on the sea had to deal with unpredictable weather and pirates.

Transportation on the river and on land was rather safe since land routes were under the control of local dukes (Lopez (1952 and 1976) and Postan (1975)). Furthermore, Europe was only partially characterized by territorial states such as England and France; small territorial or city states as in Italy or Germany were more the rule. Passing through many political territories along a trade route implied not only reliance on rulers who guaranteed safety and property rights, but on more frequent payments of taxes and tolls. The extent to which this political fragmentation hindered trade and growth of Europe is an open question. North and Thomas (1973) claim that the territorial fragmentation restricted law enforcement to small local territories. The missing central enforcement on bigger territorial states explains why Europe was not able to escape the Malthusian trap and to reach sustained growth path by the end of the 13th century. Other scholars have emphasized that institutional solutions such as the community responsibility or other reputation based mechanisms maintained cross-border legislation also in politically very fragmented parts of Europe (Greif (2006a and 2006c)).

B. Nature and Transmission of the Virus

According to McNeill (1980) and Findlay and Lundahl (2002), the virus originated in Mongolia during the 11th century and was transmitted by merchants from Asia to Western Europe during the 14th century. The unification and pacification of large stretches of the Asian continent based on the *Pax Mongolica* enabled inter-continental trade and made the spread of the disease from Asia to Europe possible. The 14th-century Italian notary and historian Gabriele de' Mussi, in his book *Istoria de Morbo sive Mortalitate que fuit de 1348*, stated that the plague was transmitted to Europe from Kaffa (now the Ukrainian city of Feodosiya), one of the most important commercial trade hubs of the Republic of Genoa on the Black Sea. The plague was easily introduced to Italy by the Genoese boats into the Sicilian harbor of Messina and from there into Europes busiest commercial harbors in 1347. In Middle East Asia and Northern Africa, the main bases of propagation were Constantinople and Alexandria.

Figure 1 depicts the main routes of the Black Death in Europe and the wider Mediterranean area based on our dataset:[6] the yellow, red, blue, green, orange and black lines represent the main propagation of the disease in 1346, 1347, 1348, 1349, 1350, and 1351 respectively. The second city to be struck was Constantinople, from which the Black Death moved towards the Egyptian city of Alexandria, the Balkans and the internal part of Anatolia. From Alexandria, the disease spread towards to the South (Cairo) and the North (along the Silk Road, involving the cities of Damascus and Aleppo in 1348 and Baghdad in 1349).

From Messina, the disease emanated to the western part of Northern Africa (Tunis and Fez) and the main ports in the Mediterranean (Pisa, Genoa, Marseilles, Barcelona, Valencia, Ragusa and Venice) between December of 1347 and early 1348. Italy, with Pisa and Venice as the two main centers of contagion, and large stretches of France and Spain were infected until June 1348. From Spain the virus moved to the main Atlantic ports of Lisbon and Bordeaux and to the North and Baltic Seas. Infected cities here included London, Amsterdam, Bergen, Oslo, and Copenhagen. Germany was infected directly from the south via the trade routes from Italy/Austria and France/Switzerland. In addition, the plague was trans-

[6]The sources are listed in Appendix C. Unfortunately, we do not have precise data for the cities in Central and Eastern Europe after 1351 (see Benedictow (2004)).

Figure 1. The Dispersion of the Black Death

mitted via sea trade from the North and Baltic Seas. In 1351 the disease reached its maximum expansion. Despite several studies claiming that the propagation of the Black Death was driven by "psychological facts" (Bloch (1953)) or, following a Malthusian mechanism, by malnutrition (Bridbury (1973) and Romano (1972)), historians and epidemiologists now concur that there is a solid and clear connection between the Black Death and trade. Cipolla (1974) was the first scholar stating that population size and trade were the only factors driving the pandemic. His thesis was confirmed by demographers Livi-Bacci (1983 and 1997) and was later accepted by medieval historians (Bridbury (1977), Herlihy (1985) and Cipolla (1993)). Moreover, epidemiologists also agree upon the causal link between trade and the spread of the disease: the typology of virus which spread across Europe during the 14th century is a typical case of a bubonic plague (*yersinia pestis*), which is usually transmitted to humans by rats and fleas which traveled on the goods along the trade routes.[7] The spread must have been supported by the social interaction of people. Rats by themselves were not able to spread the disease over such a wide area (Indian Plague Research Commission (1907) and McCormick (2003)). This argument should be further tested. In Appendix A, Figure A.1 provides additional information on the nature of the transmission of the disease exploiting the dataset we are going to describe in the following section: the horizontal axes represents the number of months that elapsed after the appearance of the Black Death in the city of Kaffa, while the vertical ones contain the cumulative number of cities affected. We can observe that the contagion evolved according to a S-shape spread. According to several studies in medical geography (Pyle (1979)), the logistic spread is an indicator of the importance of human networks in the diffusion process, excluding the role of other animal or natural agents.

Economic activities (and this means for the period of investigation of trade activities) were the main form of social interaction between cities. Thus traders were the main carriers of the virus. Two other types of travelers which could have had an impact were soldiers or pilgrims. However there were in general no major movements of soldiers because of wars in the area of investigation during the years of the Black Death. We found just two city pairs in which the disease could have been propagated by war. Their exclusion, however, does not affect our results. Furthermore, pilgrimage routes do not indicate that pilgrims initiated the spread of the Black Death

[7]According to Pollitzer (1954) the bearers of the virus were the fur fleas found on black rats. The virus survives only if the flea can bite a human within 12-24 hours, if it can find grain seeds (their preferred food) or if it is in a humid environment like on ship cargos (Estrade (1935)). Scott and Duncan (2004) and Bossak and Welford (2010) have suggested that the Black Death was transmitted only by humans. This hypothesis strengthens the link between trade and the pandemic.

(Benedictow (2004)).[8] Other forms of mobility can be documented only for the time after the Black Death (Domar (1970)).

The incubation period of the illness was only 3-5 days; it was therefore very difficult to take any preventive measures. Furthermore, medieval sources do not indicate that medieval Europeans knew how they could to protect themselves from the plague (Cipolla (1981)).Thus the arrival, outbreak, or spread could not been endogenously influenced by peoples actions.[9]

Furthermore, the spread of the Black Death within a city was systematic. Merchants and other locals who had to deal with trade (e.g. lawyers and notaries) were infected before rulers or aristocrats with less contact with the "outside world" (Livi-Bacci (1978) and Gelting (1991)). This way the process from the arrival to the outbreak until the highpoint was not random, but followed a clear path of diffusion. In addition, the information of the death of different classes of people reveals information on the course of the plague through each town. In this way medieval historians have been able to pinpoint the outbreaks of the plague in different cities. With the use of different types of sources the dates can be aligned and assigned to single days of a month.[10] This allows us to identify city-pairs with different speeds of transmission (measured in kilometers per day). The speed of the spread of the Black Death can be taken as a proxy to study medieval trade flows between cities. The speed of the plague indicates the direction and

[8]In addition, we made an empirical test on this where we control for the pilgrims routes. But we could not find any significance.

[9]Even if inhabitants had been informed about the approaching disease and been able to flee, then they would have needed a transportation infrastructure, which strongly correlated with the quality of the trade infrastructure (which was based on the trade intensity). Thus the infection/ trade causality still holds.

[10]For a more extensive discussion of the source material and a detailed case study of Tuscany see our working paper Boerner and Severgnini (2011).

the intensity of trade.[11]

II. A Trade Model for Cities

A. Assumptions

In this section we introduce the main assumptions of our theoretical framework for studying how the intensity of trade (proxied by the speed of the dispersion of the disease) can be explained by different factors. The complete version of the model is reported in Appendix B. We start from a new setup of a gravity model, which in international trade is one of the most considered theoretical (Helpman and Krugman (1987) and Deardorff (1998)) and empirical (Eaton and Kortum (2002) and Anderson and van Wincoop (2003)) framework for predicting the determinants of trade between two geographical areas. The standard gravity model states that bilateral trade flows are positively correlated to the economic sizes of the trading entities and inversely proportional to some resistances, which can be assumed as the geographical distance or also other type of factors like trade costs or sociopolitical and cultural barriers, we have to take into consideration several additional issues of our model which are going to be different from the standard gravity model. First, we study trade flows between cities, which

[11]To strengthen this assumption we use another hypothesis in the medieval trade literature. Spufford (1988) and Le Goff (2012) claim that trade intensity between two cities can be measured by the value of foreign coins used in the local city. Thus foreign coins with a high value (e.g. a strong gold content or big dimension) indicate strong trade with this foreign city. We use the information in the merchant handbook by Pegolotti (Pegolotti (1340; eds. 1936) and Grierson (1957)) to make a case study in the Mediterranean. We analyze if in cities with high value coins we can also find fast transmission of the plague. This is indeed the case. Figure A.2. in Appendix A shows the relationship between the speed of the disease among different French, Italian, Spanish and Byzantine cities and the value of the foreign coins, which we measure as exchange rate in terms of Genoese coin *Soldo*. The red line in the figure shows the predicted values obtained by the OLS regression displaying a strict positive relation between the two factors. Data and output of the regression are available upon request.

are smaller units of observations than the countries and regions that are usually considered in the literature. Second, we need to take into account the infrastructure of medieval trade routes, which is strongly based on the transportation technology and geographic amenities. Third, trade is based on the production of distinctive products in different cities with specific geographic and institutional amenities. Fourth, since we do not directly observe trade we have to link the relationship between commercial flows and the speed of the dispersion of the Black Death with consistent assumptions. In addition, we want to study the different roles played by geographical amenities and institutions in more detail. To do so we will adapt the model accordingly in Section V. We formulate our model in the spirit of Armington (1969), where the productions and the trade flows of differentiated products are explained by their geographical origin. We consider two cities: i and j. Both cities have at their disposal the same type of technology and cost of production, while their utility is based on the two-tier utility function introduced by Head and Ries (2001). This form of utility highlights the product differentiation (or even specialization) of medieval cities. Production functions are expressed by indicators of population densities and wage. Finally, we introduce Samuelson (1948)'s iceberg trade costs. In addition, trade restrictions can be expressed adopting the technique proposed by McCallum (1995), who model the bilateral transactions as a function of observable social and political variables. Our theoretical model derived the amount of trade between sender city i and recipient city j (T_{ij}) in the following way:

$$(1) \quad \ln T_{ij} = \ln \frac{n^i}{n^j} + (\sigma - 1) \ln \frac{v^j}{v^i} - border_{ij} + (\sigma - 1) \ln avspeed_{ij} + \ln C_j$$

Assuming that σ, the parameter of elasticity of substitution, is higher than

1,[12] (1) shows that, on the one hand, T_{ij} is positively driven by the consumption of internal goods of the importing city, C_j, by the average speed of trade, $avspeed_{ij}$, (which stands for the transportation technology and the geographical amenities of the trade route) by the variety of goods from the sending city i, n^i, by the indicator of quality of goods produced in the sending city i, v^i. On the other hand, trade is reduced by the presence of a political border, $border_{ij}$,[13] by the variety of goods from city j, n_j and by the home bias v^j.

B. *Speed of Disease and Trade*

As an additional step in our analysis we consider the relationship between speed ($SPEED_{ij}$) and trade (T_{ij}) between the first infector city i and the second infected city j as

$$\ln T_{ij} = \theta_0 + \theta_1 \ln SPEED_{ij} + e_{ij} \tag{2}$$

where θs are parameters. This relationship has been motivated in Section 2 and by Figure 1 where we explained the connection between medieval trade and spread of the Black Death. This comes into the previous section. Substituting (2) into (1), we obtain a functional form which can be estimated as:

$$\ln SPEED_{ij} = \beta_0 + \beta_1 \ln C_j + \beta_2 border_{ij} + \beta_3 \ln avspeed_{ij} + \tag{3}$$

[12]Head and Ries (2001) report estimates for σ between 7.9 and 11.4.

[13]The variable stands for any transaction cost for a good transported between city i and j if the cities are under different political regimes, whereas the costs are weighted by the quality of the good

$$+\beta_4 K_i + \beta_5 K_j + \epsilon_{ij}$$

where K_i and K_j is a vector collecting all the different characteristics for city i and j, respectively. Given that $\theta_1 > 0$, we expect a positive effect of C_j and *avspeed* and a negative effect of *border*.

C. Explanatory Variables: Candidates and Data

Next we need to identify from the medieval source material different sets of observables, which are potential candidates to determine economic exchanges, and discuss the predicted coefficients. In addition we need to describe the dependent variable in more detail.[14] We cover the period 1346-51. We restrict our set of observations to this time interval to avoid any feedback loops of the plague to already infected cities or areas which would bias our data set. The dependent variable of our analysis, $Speed_{ij}$, is the speed of transmission of the plague between two cities expressed in kilometers per day. We take the arrival of the disease in each town as the mark.

Five groups of explanatory variables can be considered. A first set of variables is inspired by the standard gravity model: economic importance, geographical distance and barriers to trade. We add an extra variable "average speed" to this group since it is related and a crucial part of our model prediction.

To measure economic importance we use population density of each city as a proxy variable since we cannot find data on GDP available for the 14th century. This is a good proxy for economic development. We follow here Boserup (1965) and Alesina, Giuliano, and Nunn (2013). We construct this variable (*dens*) based on the ratio of total population over the

[14]The sources used for our dataset are listed in Appendix C.

extension occupied by the city.[15] We expect to find a stronger trade flow towards richer cities. This is directly reflected in our theoretical prediction by higher consumption of wealthier importing cities. Second, we expect to find significant effects of geographical distance (*dinst*). However contrary to the theoretical predictions and empirical evidence of a negative coefficient using modern data we expect a positive effect. Modern trade economists argue that the negative effect is based on the fact that it is easier to keep up with transportation and communication channels over short distances. This might be different in the historical context since geographic proximity in the period of investigation does not necessarily mean a better connection. Furthermore, as described in the previous section, a large fraction of trade was long-distance. More distant cities had a larger variety of products to offer due to their different amenities. Thus following the prediction of our model more distant cities (via the variety of products) increase incentives to trade. To control for the quality of the transportation channel (instead of the geographical distance which is used as a proxy in the modern trade literature) we introduce as in the model a variable which measures the average speed of trade between two cities. This variable is strongly driven by the geographic amenities of a specific trade route. We identify trade routes along lands and rivers, and city connections via the sea. Following the historical literature, we expect more intensive trade on waterways in general and stronger trade on rivers than on the sea. However a use of dummies would be too restrictive to measure the quality of infrastructures and geographical characteristics.[16]

[15]Other studies (De Long and Shleifer (1993) and Acemoglu, Johnson, and Robinson (2005a)) show a strong positive link between income and population growth. In our analysis, if we consider the number of inhabitants of the two cities during the year 1300 instead of density, we obtain very similar results for all the regressions, except for population, which is not significant. Results available upon request.

[16]For such an analysis see our former working paper (Boerner and Severgnini (2011)).

We consider the travel time during the Roman Empire for all the different routes (*avspeed*) provided by the database Stanford Geospatial Network Model of the Roman World ORBIS. We expect to find a positive effect of this variable on the spread of the plague. Finally we measure border effects. We distinguish political borders (*border*), and local borders (*localborder*) (regional borders within the same state). In addition we refine the analysis by measuring border effects of neighboring states (*contiguity*). This is the standard differentiation in the empirical trade literature.[17] In the modern trade literature we find that both political and local borders have a negative impact on trade and a relatively faster exchange if the geographical areas are located next to each other. As outlined in the previous section following North and Thomas (1973) we also should find negative border effects. However some contemporary medieval historians have claimed that political borders were not that clear-cut as they are now (Abulafia et al. 2002) and therefore trade flow restricting effects do not necessarily need to be observed.

In a second set of variables we check for more "standard" geographical control variables: the elevation (*elevation*), longitude (*longitude*) and latitude (*latitude*) of a city, and the remoteness of a city from the next harbor (*remote*).[18] We will discuss some of these geographical effects in more detail in Section V.

In the third set of variables we look into the political organization and functional nature of the city. We analyze if the city is the residence of a

[17]See, for example, McCallum (1995)'s study on intra- and international Canadian trade with the US.

[18]We define remoteness as the (log of) ratio of distance with respect to population with respect to the nearest seaport. In modern trade theory remoteness is calculated as the natural logarithm of the distance of a country with respect to all the others weighted by the GDP (Wei (1996)).

bishop (*bishop*), a prince (*prince*), or if the city hosts a university (*university*). All these variables can also be considered as indicators for the economic importance: cities with these extra characteristics may have additional income streams. Thus they might consume more than they produce. This way we expect them to have fewer outgoing than incoming trade streams. Consequently such a city is less likely to be a transmitter of the disease and more likely to be a receiver. Furthermore, by taking these city-specific effects into account we are able to control for other political and human capital effects.[19]

In a fourth set of variables we analyze cultural determinants. We measure if a city pair has a common language has a positive effect on trade. Again this is a standard control variable in modern trade analysis. However medieval economic historians claim that the difference in language did not interfere with commercial flow since merchants adopted either a special language for trade or Latin, which was the universal language for nobility and religious elites (Pirenne (1969) and Lopez (1979)). Another important set of variables in this group is represented by religious periods, more precisely, Lent (*lent*) and Advent (*advent*). Following the Catholic liturgical year, which was observed during the Middle Ages, Lent was the 40 days preceding Easter. Lent is not observed during the same date of the calendar, but it is fixed between March 22 and April 25 just after the first full moon of spring.[20] Advent, in contrast, is a fixed period of the calendar, consisting of

[19]Blum and Dudley (2003) assume that a bishop is a good indicator of human capital. The same could be assumed for university cities. A higher level of human capital could be an indicator for more trade activities. Such an indicator assume De Long and Shleifer (1993) also for Southern European prince cities. They argue that prince cities were less autocratic and thus more open to trade.

[20]Lent covers the five Sundays: *Invocabit*, *Reminiscere*, *Oculi*, *Laetare*, and *dominica in passione Domini*. The only exception to this timing of Lent is in the area of Milan, where the period is slightly different.

the four weeks before Christmas. Those two liturgical seasons are characterized by fasting and abstinence from meat and from sexual intercourse. Thus assuming that religious life had a critical impact on peoples daily activities (Le Goff (1988)) we can expect trade to change significantly during these religious periods.

Finally, we control for seasonal and time effects. Even if the epidemiological literature agrees that the Black Death was not affected by season since the virus could be transmitted by rats and fleas (Pollitzer (1954)), several epidemiologists have claimed that the speed of the Black Death could be indeed affected by temperature.[21] We add to all the regressions a difference of temperature between the two cities (*tempx*).[22] In addition, we consider month (*month*) and year (*year* dummies, which could be related to any other unobservable time effect we do not control for.

III. Descriptive Statistics

We were able to collect data from 206 pairs of cities. Table 1 depicts the descriptive statistics of the variables related to both the bilateral and singular characteristics of the cities.[23] Similar to the descriptive statistics provided by Benedictow (2004), the speed of the disease is heterogeneous: in our dataset we can find values from about 110 meters to about 285 km per day. The average speed of transmission is about 7 km per day. If we split up the observations by land, sea, and river trade we arrive at different speeds of transmission. The transmission by land is the slowest, at roughly

[21] For a discussion see Benedictow (2004 and 2011).

[22] We are going to describe the climate data in more detail in Section V.

[23] Tables C2 and C3 in the Appendix display the names and brief descriptions of the variables chosen for the estimation. A complete list of the political regions taken into consideration and their location with actual countries can be found in Appendix C.

3.5 km per day; sea trade takes 10 km per day and river trade 7.2 km per day. If we compare these velocities with a merchants actual traveling time, we observe that the average spread of the disease is much slower than the potential maximum speed the infection could take, just based on the physical restriction imposed by the means of transportation. We consider also the measure of the average merchants traveled 15-30 km per day on land. On boats, merchants could make around 30 km per day and by sea 100-130 km per day (Pryor (1992) and McCormick (2001)). This also supports our argument that the spread of the disease is a measure of the trade intensity between two cities. This data are also consistent with the average speed. The mean of transportation is a partial function of this trade intensity as elaborated earlier in the text. More results related to the speed will be discussed when we analyze and interpret the estimation coefficients in the next sections.

Let us characterize the sample further: The city size in the sample ($dens1$, $dens2$) is rather heterogeneous, since the sample contains less populated cities with with about four inhabitants per hectares squared to more than 3,000 inhabitants per hectares squared.[24] The distance ($dist$) between city-pairs covers distances as short distances as six kilometers to more than 3,335 kilometers. About 42 % of the city-pairs are divided by a common border. About 20 % of the sample considers cities which are involved in trade with cities located by the sea. Finally, the maximum elevation considered is about 1,800 meters with an average of about 160 meters. The other variables related to geography and sociopolitical factors have heterogeneous

[24]In terms of population, we have small towns with 1,000 inhabitants in Sicily to 400,000 inhabitants in Cairo (and 150,000 in Europe with Paris). Statistics on population available upon request.

TABLE 1—DESCRIPTIVE STATISTICS

Variable	**Mean**	**Standard deviation**	**Min**	**Max**
1. Standard gravity model				
speed	7.01	21.30	0.11	285.60
*dens*1	236.24	192.60	16.67	1500.00
*dens*2	270.27	349.37	4.17	3333.33
avspeed	60.41	42.92	21.00	190.00
dist	319.56	537.21	6.37	3355.00
border	0.42	0.50	0.00	1.00
localborder	0.01	0.12	0.00	1.00
contiguity	0.18	0.38	0.00	1.00
2. Geographical variables				
*longitude*1	9.80	9.46	-8.55	46.28
*longitude*2	9.50	9.70	-8.64	44.39
*latitude*1	44.66	5.88	31.21	60.38
*latitude*2	44.76	6.30	30.05	60.38
*elevation*2	167.42	247.63	1.00	1815.00
*elevation*1	114.44	202.41	1.00	1350.00
*remote*1	123.01	138.76	0.00	649.62
*remote*2	162.47	153.93	0.00	910.44
3. Social and political variables				
*bishop*1	0.47	0.50	0.00	1.00
*bishop*2	0.39	0.49	0.00	1.00
*prince*1	0.59	0.49	0.00	1.00
*prince*2	0.59	0.49	0.00	1.00
*university*1	0.09	0.28	0.00	1.00
*university*2	0.09	0.29	0.00	1.00
language	0.65	0.48	0.00	1.00
4. Religious variables				
lent	0.39	0.49	0.00	1.00
advent	0.11	0.32	0.00	1.00
5. Climate and time variables				
*temp*1	13.56	6.33	-24.00	25.6
*temp*2	12.75	5.82	-8.900.00	25.6
*year*1347	0.29	0.46	0.00	1.00
*year*1348	0.50	0.50	0.00	1.00
*year*1349	0.19	0.40	0.00	1.00
*year*1350	0.01	0.10	0.00	1.00
*year*1351	0.00	0.07	0.00	1.00
Number of observations: 206				

distributions. A final special note must be given to the climate data we use. Unfortunately, we do not have detailed climate measures for all of 14th-century Europe. For those reason, we consider the data absolute surface air temperatures provided by Jones (1999). Those data collect the average of monthly land air temperature on a 5% by 5% grid-box basis depurated by temperature anomalies of the last of the global warming. We assume that those data can be considered a good approximation. Our assumption is confirmed by other local or more aggregated studies in climatology and economics (e.g., Mann, Bradley, and Hughes (1999), Chuine (2004) and Kelly and O' Grada (2012)).[25]

IV. Estimation Strategies and Results

For estimating (3), we take into account not only the 206 observations that we collected, but we also consider the potential transmission link between other city pairs. Thus, we incorporate all the possible land-trade contacts which are less than or equal to the maximum distance observed in the first cities of 206 city-pairs and all the connections of cities on waterways at a distance less or equal than 500 kilometers.[26] In this way we obtain a new set based on 298 observations. Furthermore, as noted by Silva and Tenreyro (2006), the traditional estimates of the OLS estimation techniques on trade data can be affected by several biases once the dependent variable consists of the logarithm of the positive values of the dependent variable and excludes the observations equal to 0. In the first instance, this procedure could violate the Jensen inequality biasing the estimation results. Second, the exclusion of the observations identical to 0 can raise problems related to

[25]In a previous version (Boerner and Severgnini (2011)) we obtained very similar results considering three different dummies if the Black Death appeared in autumn, spring, or summer and from 1347 to 1351.

[26]In our study, we should control especially for those problems since we have several pairs of cities, sometimes, located in close proximity to each other, in which we do not observe a direct transmission of the disease and which could play an important role in our estimation results. We also tried other distance lengths obtaining similar results. Output are available upon requests.

truncation. Third, the choice of different sets of explanatory variables could be not completely specified. Furthermore, the presence of heteroskedasticity can worsen those biases once a log-linearization of the specification is chosen. In Appendix C we consider both different specifications and several estimation techniques. An investigation of several test (such as the RESET, Gauss Newton-regression, and the Park-type test) suggests that the best econometric strategy is the one introduced by Silva and Tenreyro (2006), which is based on a Pseudo Poisson Maximum Likelihood (PPML) and is considered to be particularly versatile in dealing with measurement errors and sample selection. Our dependent variable is becoming now $Speed_{ij}$. Tables 2 and 3 display the main results of our trade model with the PPML estimation following different types of specifications. In all columns we control for time, climate effects and longitude and latitude.[27] Columns (1), (2) and (3) consider the basic specification including the variables used for the standard gravity model: with different levels of significance, we find that population densities, the average of speed, distance, and state contiguity enters in a positive way, while both national and local borders have a negative impact on the speed of the dispersion of the disease. While most of the signs are consistent with traditional trade theory, the coefficient for distance suggests that the longer the distance, the more intense the trade. This is indeed what we predicted based on the medieval trade environment. The negative impact of borders on trade also supports these group of economic historians who identify political fragmentation as a serious obstacle to trade. Next, the residual columns, (4), (5) and (6), report the coefficients of the basic model extended by additional geographical, religious, and social and

[27]In Section V we investigate the geographical effects on trade in a more detailed way.

political variables, respectively. Concerning the geographical variables, we find that remoteness (*remote*1 and *remote*2) is significant and negative for the first city, and positive for the second city. In addition, a higher located city has a significantly slower inflow. These additional geographical variables show that beside the already identified geographic distance and nature of the trade routes other geographical amenities indeed determine trade. Furthermore, during the *lent* period, trade slows in comparison to the other periods of the year. This supports this line of research which argues that culture matters. However not all cultural variables are significant. Thus we need to be careful when taking these determinants into account. Finally, we introduce the institutional political variables *bishop*, *prince*, and *university*. The coefficients for the receiving residential cities *bishop*2 and *university*2 are positive and significant. Incorporating the results from columns (6) and (7) we also find a negative sign for transmitting residential cities *bishop*1. This slightly confirms our hypothesis that relative stronger consuming cities receive the plague faster and transmit the disease more slowly. These results also neatly show that political institutions matter for trade activities. Other specific lines of argumentation related to human capital or autocratic rulers discussed in the previous sections cannot be supported by our empirical analysis. Finally, the RESET tests reported at the end of Table 2 reject in all the cases the hypothesis of any misspecification of the model. Taken together, the empirical results clearly support our exercise to use the spread of diseases to measure economic activities: The spread of the Black Death is indeed a good case to measure relative trade intensity.

Table 2—Determinants of trade: PPML Regression (first part)

	(1)	(2)	(3)	(4)	(5)	(6)
			Dep. Variable: $Speed_{it}$			
			Standard gravity model			
*lndens*1	0.35**	0.13	0.13	0.12	0.07	0.05
	(0.14)	(0.11)	(0.11)	(0.11)	(0.11)	(0.10)
*lndens*2	0.06	0.13**	0.11**	0.10	0.11	0.14*
	(0.09)	(0.06)	(0.06)	(0.07)	(0.07)	(0.08)
lnavspeed	1.61***	0.71	0.69**	0.78***	0.78***	0.77***
	(0.40)	(0.37)	(0.34)	(0.23)	(0.21)	(0.17)
border	-0.35	-0.60***	-0.74***	-0.62***	-0.65***	-0.71***
	(0.22)	(0.17)	(0.17)	(0.15)	(0.15)	(0.15)
lndist		0.89***	0.93***	0.94***	0.93***	0.97***
		(0.07)	(0.06)	(0.09)	(0.08)	(0.08)
localborder			-1.20*	-1.12*	-1.37***	-1.47***
			(0.72)	(0.66)	(0.48)	(0.34)
contiguity			0.89***	0.78***	0.80***	0.68***
			(0.20)	(0.16)	(0.18)	(0.18)
			Geographical variables			
*lnremote*1				-0.06	-0.05	-0.07*
				(0.05)	(0.04)	(0.04)
*lnremote*2				0.10*	0.08*	0.08*
				(0.05)	(0.05)	(0.05)
*lnelevation*1				0.01	-0.02	-0.00
				(0.06)	(0.05)	(0.04)
*lnelevation*2				-0.13**	-0.11**	-0.12***
				(0.05)	(0.05)	(0.04)
*longitude*1				-0.01	-0.02	-0.01
				(0.02)	(0.02)	(0.02)
*longitude*2				-0.01	-0.02	-0.02
				(0.02)	(0.02)	(0.01)
*latitude*1				0.01	0.02	0.05
				(0.04)	(0.03)	(0.03)
*latitude*2				0.02	0.02	0.00
				(0.02)	(0.02)	(0.02)
			Religious variables			
lent					-0.60***	-0.58***
					(0.17)	(0.17)
advent					0.17	0.36
					(0.17)	(0.25)

Table 3—Determinants of trade: PPML Regression (second part)

	(1)	(2)	(3)	(4)	(5)	(6)
Social and political variables						
language						-0.03
						(0.12)
*bishop*1						-0.33***
						(0.13)
*bishop*2						0.29**
						(0.14)
*prince*1						0.06
						(0.14)
*prince*2						0.11
						(0.17)
*university*1						0.39
						(0.29)
*university*2						0.34**
						(0.17)
Temporal and climate variables						
*month*1	0.48***	0.45***	0.44***	0.42***	0.36***	0.37***
	(0.05)	(0.04)	(0.03)	(0.04)	(0.03)	(0.03)
*year*1_1347	5.23***	4.86***	4.83***	5.56***	5.24***	5.32***
	(0.54)	(0.49)	(0.47)	(0.63)	(0.50)	(0.46)
*year*1_1348	11.00***	10.49***	10.33***	10.79***	10.22***	10.56***
	(0.85)	(0.64)	(0.64)	(0.63)	(0.53)	(0.54)
*year*1_1349	14.17***	15.14***	15.35***	15.45***	14.64***	15.16***
	(1.04)	(0.85)	(0.87)	(0.81)	(0.63)	(0.69)
*year*1_1350	15.41***	18.84***	18.60***	18.78***	17.63***	18.34***
	(1.64)	(1.43)	(1.54)	(1.38)	(1.12)	(1.27)
*year*1_1351	15.62***	17.81***	18.76***	18.79***	18.10***	18.43***
	(1.32)	(1.09)	(1.07)	(1.03)	(0.81)	(0.81)
*month*2	-0.22***	-0.34***	-0.32***	-0.30***	-0.34***	-0.36***
	(0.05)	(0.05)	(0.05)	(0.04)	(0.04)	(0.04)
*year*2_1348	-5.13***	-4.71***	-4.57***	-4.87***	-4.70***	-4.80***
	(0.61)	(0.51)	(0.49)	(0.41)	(0.44)	(0.44)
*year*2_1349	-8.93***	-9.26***	-9.39***	-9.48***	-9.03***	-9.45***
	(0.84)	(0.73)	(0.72)	(0.55)	(0.52)	(0.59)
*year*2_1350	-11.54***	-13.78***	-13.90***	-14.10***	-13.48***	-14.19***
	(1.13)	(1.10)	(1.08)	(0.91)	(0.87)	(1.01)
*year*2_1351	-12.05***	-13.61***	-14.59***	-14.38***	-13.96***	-14.37***
	(1.05)	(0.86)	(0.81)	(0.73)	(0.63)	(0.65)
tempx	0.00	-0.00	-0.00	-0.00	0.00	-0.00
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Constant	-15.97***	-14.49***	-14.46***	-16.23***	-14.89***	-16.20***
	(1.87)	(1.52)	(1.40)	(1.81)	(1.69)	(1.86)
	0.21	0.87	0.80	0.79	0.82	0.83
$RESET test(p-value)$	0.21	0.87	0.80	0.79	0.82	0.83
$Pseudo-R^2$	0.73	0.80	0.74	0.82	0.74	0.39
N. of observations	298	298	298	298	298	298

*; **; *** indicate significance at 10, 5 and 1% respectively.
All estimates with robust standard error clustered by the first city.
All regressions controlled for trade routes (non reported).

V. Institutional and Geographical Effects: A Spatial Regression Discontinuity Design Approach

The estimation results provided by the previous sections reveal the main drivers of trade and allow for testing the predictions of our theoretical model, but they are not sufficient in disentangling the contribution of geography and institutions. On the one hand, theories supporting geography (e.g, Diamond (1997) and Gallup, Mellinger, and Sachs (1999)) state that the location of a country and its own resource endowments are relevant for explaining trade and economic performance. Furthermore, according to a well-known problem highlighted by Gallup, Mellinger, and Sachs (1999) and Rodrik, Subramanian, and Trebbi (2004), trade and institutions may be both endogenous since they can be potentially affected by long-run effects of geography. Several contributions (e.g. Frankel (1997) and Acemoglu, Johnson, and Robinson (2005a)) adopted instrumental variable regression techniques in order to disentangle these two effects finding a dominant effects for institutions.

Our dataset offers the exceptional opportunity to shed some light on this debate: given the detailed information on the dispersion of the Black Death and cities' characteristics, we can separate both the geographical and institutional contributions to trade. We identify the discontinuity of institutions with the borders. In order to investigate the institutional contribution, we consider a spatial regression discontinuity design (SRDD) approach.

Both historical and econometric facts support the use of the SRDD. First of all, using GIS data on geographical characteristics and border, we do not observe that the variables do overlap.[28] Second, an identification de-

[28] A map can be found in Appendix C.

sign in which geographical variables try to explain borders is not significant. Finally, historical evidence suggests that the creation of borders was not related to economic activities but by wars.
This is similar to the designs considered by Dell (2010) and Michalopoulos and Papaioannou (2014). We detect the impact of different types of institutions on the speed of the propagation of the disease. Furthermore, following the definition of Angrist and Lavy (1999), the regression discontinuity design is an instrumental variable approach which allows us to identify the impact of border, a potential endogenous regressor that can be defined as a known function of an observable assignment variable. As in Dell (2010), we focus just on the effect of the border and construct our SRDD design by fitting

$$Speed_{ij} = f\left(distbord_{ij}\right) + \rho border_{ij} + \eta_{ij} \tag{4}$$

where $f\left(distbord_{ij}\right)$ is a quadratic function of distance. We consider a regression for 200 km from each side of the border on land and river trade.

Figure V represents a visual representation of the SRDD results. We represent the variable $Speed_{ij}$ over the distance to the national border using a 400 km bandwith. the dots represent local averages of 10 km bins. We consider our sample for land and river trade. The continuous lines show the fitting values of the PPML estimates of (4). The area represents 95% of confidence interval. The results show that on average the presence of a political border has a negative impact on trade. The closer the receiving destination is to the border the slower is trade. The image shows trade intensity within the same borders on the left side of the red border line (displaying the distance to the border) and across border trading on the right side of the border threshold. These results also show an increase in trade across borders with an increase in distance from the border. Thus these results support the findings of negative effects of political borders. They also reveal again the positive long distance trade effect discussed in the previous sections. Given our results, we also try to visualize the effect of institutions at the geographical level. First, we follow the estimation strategy suggested by Dell (2010) considering the following regression form:

$$(5) \qquad SPEED_{ij} = g\left(f\left(geographic\ coordinates_{ij}\right), border_{ij}\right) + \mu_{ij}$$

where $f\left(geographic\ coordinates_{ij}\right)$ controls for smooth functions of geographic locations and Θ_{ij} are the variables we considered in the previous sections for our estimates. We define the geographical function as a polynomial of longitude and latitude coordinates. These are the aggregate marginal effects if we move on the map from one state to the next. It gives us an estimate how fast the plague spread in different regions. The upper part of Figures 3, 4, and 5 show the predictions of this model for land, river, and sea trade, respectively. We discuss these effects at the end of this section.

Second, we define the effect of the institution as the difference given by

$$(6) \qquad Institution_{ij} = g\left(f\left(geographic\ coordinates_{ij}\right), border_{ij} = 0\right)$$

$$-g\left(f\left(geographic\ coordinates_{ij}\right), border_{ij} = 1\right)$$

This allows us to separate the institutional from geographic effects. Thus we measure the impact of institutions on the spread of the plague or trade intensities in different regions. The results are depicted in the lower part of Figures 3, 4, and 5.

The colors on all maps indicate differences in significance strength. The colors follow the rainbow spectrum.[29] The maps reveal interesting estimation results which need interpretation. However we need to be careful not to over-interpret details and rather take estimators as a rough guide. First we find different significance and strength in aggregate vs institutional effects in different regions. On the one hand we find strong aggregate effects in the Eastern Mediterranean, mainly between the Adriatic area and Constantinople,(in addition some effects in the westermost areas of Europe) At the same time we identify strong institutional effects in Western Europe. If we differentiate inflow from outflow effects we find much stronger outflow than inflow effects in North West Europe. In other regions these effects are more balanced. These results can be interpreted the following way. First these estimations indicate stronger trade activities east of Italy and in the eastern Mediterranean. This supports the literature which still sees until the period of the Black Death a dominance of trade in the Eastern Mediterranean (Abulafia (1987)). This is rooted in the wealth of these regions at the time. Whereas the Italian city states Venice and Genoa created the trade axis between the East Mediterranean and Western Europe. However if we separate institutional from aggregate effects (which incorporate geographic effects), then we find pronounced trade-supporting institutional effects in Western Europe. These findings are in line with the literature which finds the creation of trade-supporting institutions during the late Middle Ages in Western Europe (Lopez (1976), Cipolla (1993), Epstein (2000a) and Greif (2006b)). It also indicates the important role of institutions for economic

[29]Since the Matlab program creates an individual color spectrum for each picture, the color scale with matching numbers on the right hand side of each picture must be inspected before a comparison with another map can be made. Furthermore, those predictions are measured on a scale of 10 meters in order to make the graphs clearer.

growth in Western Europe identified by these scholars and sheds light on early institutional triggers of the Great Divergence in Western Europe (compared to the East Mediterranean/ Middle East).(See Kuran (2003)). Finally the stronger outflows in North West Europe indicate stronger exporting effects. Such observations might point out the beginnings of the Little Divergence within Europe. Scholars starting with Allen (2001) have measured continuous growth from the 14th-18th centuries for North West Europe (and comparably stagnant patterns for other regions). Thus these estimators do not only allow us to quantify these important historical developments for the first time on such an aggregate level; they also highlight the institutional importance of this development and distinguish them from geographic effects.

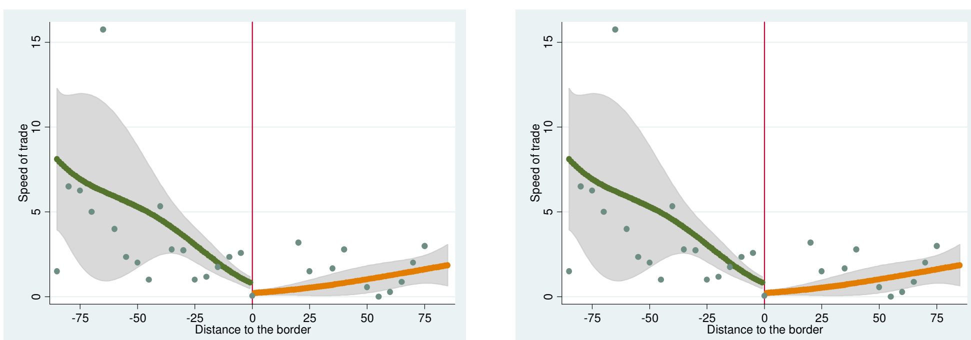

Figure 2. SRRD for land and river trade (left) and for land only (right).

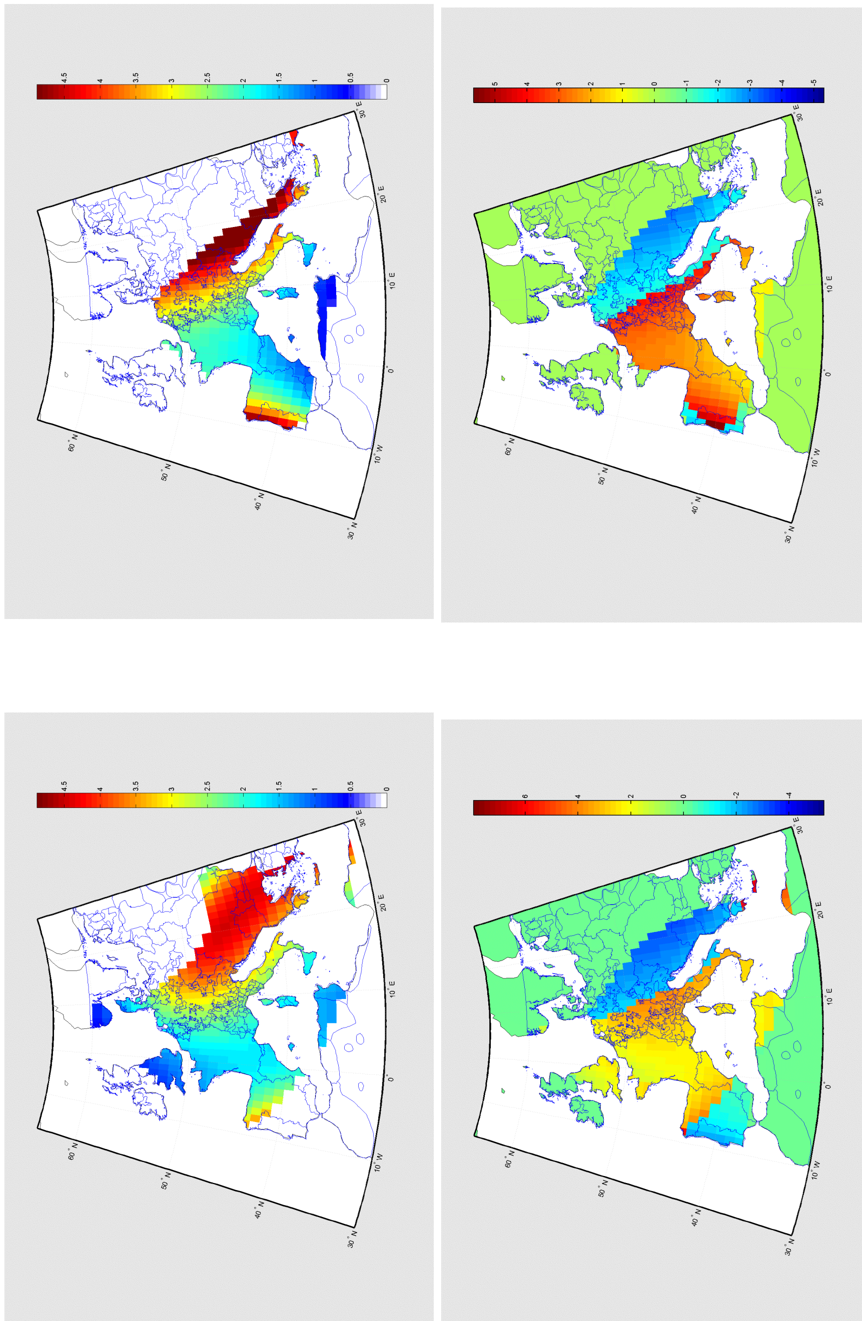

FIGURE 3. TRADE ALONG LAND: OUTFLOWS AND INFLOWS OF PREDICTIONS (UPPER PART) AND INSTITUTIONAL EFFECTS (LOWER PART).

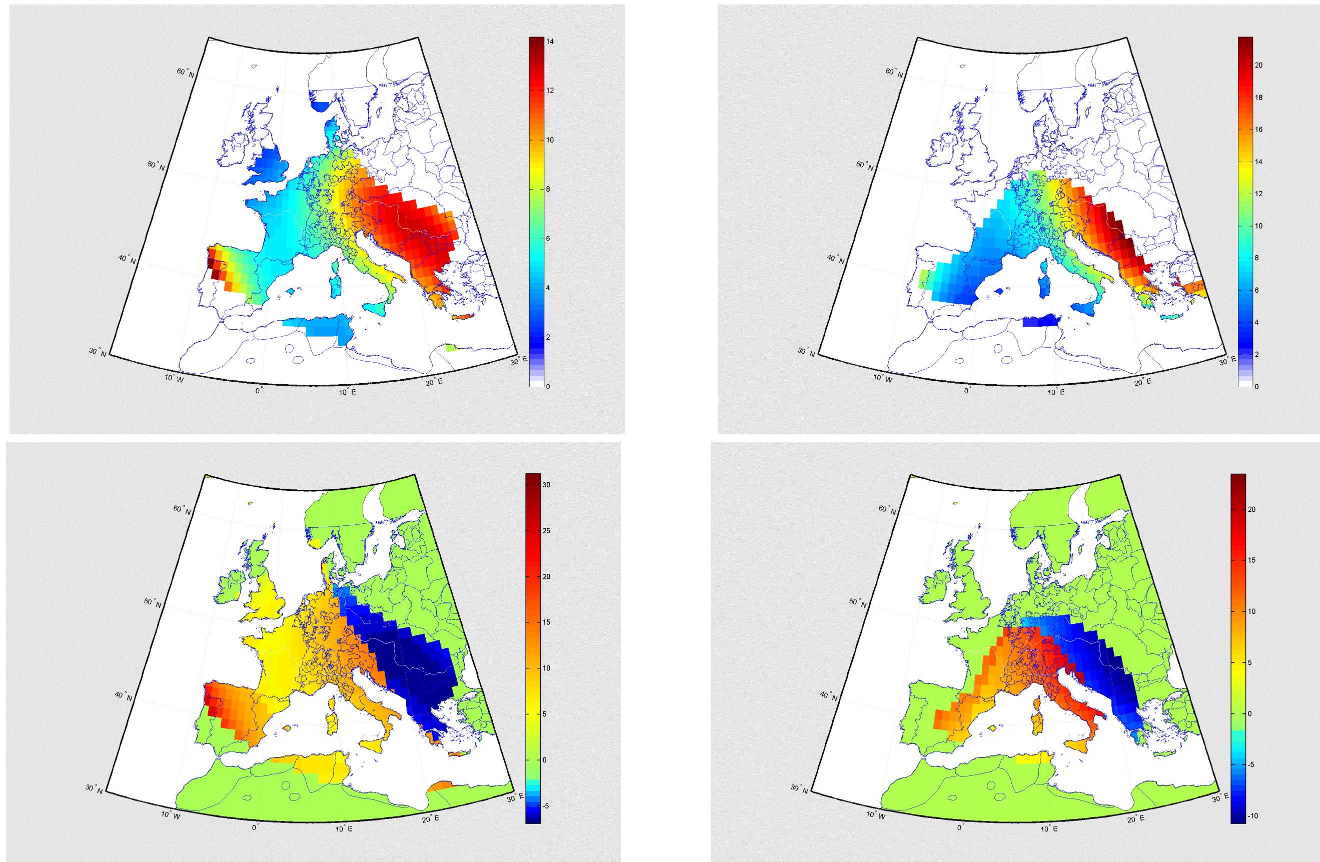

Figure 4. Trade along river: Outflows and inflows of predictions (upper part) and institutional effects (lower part).)

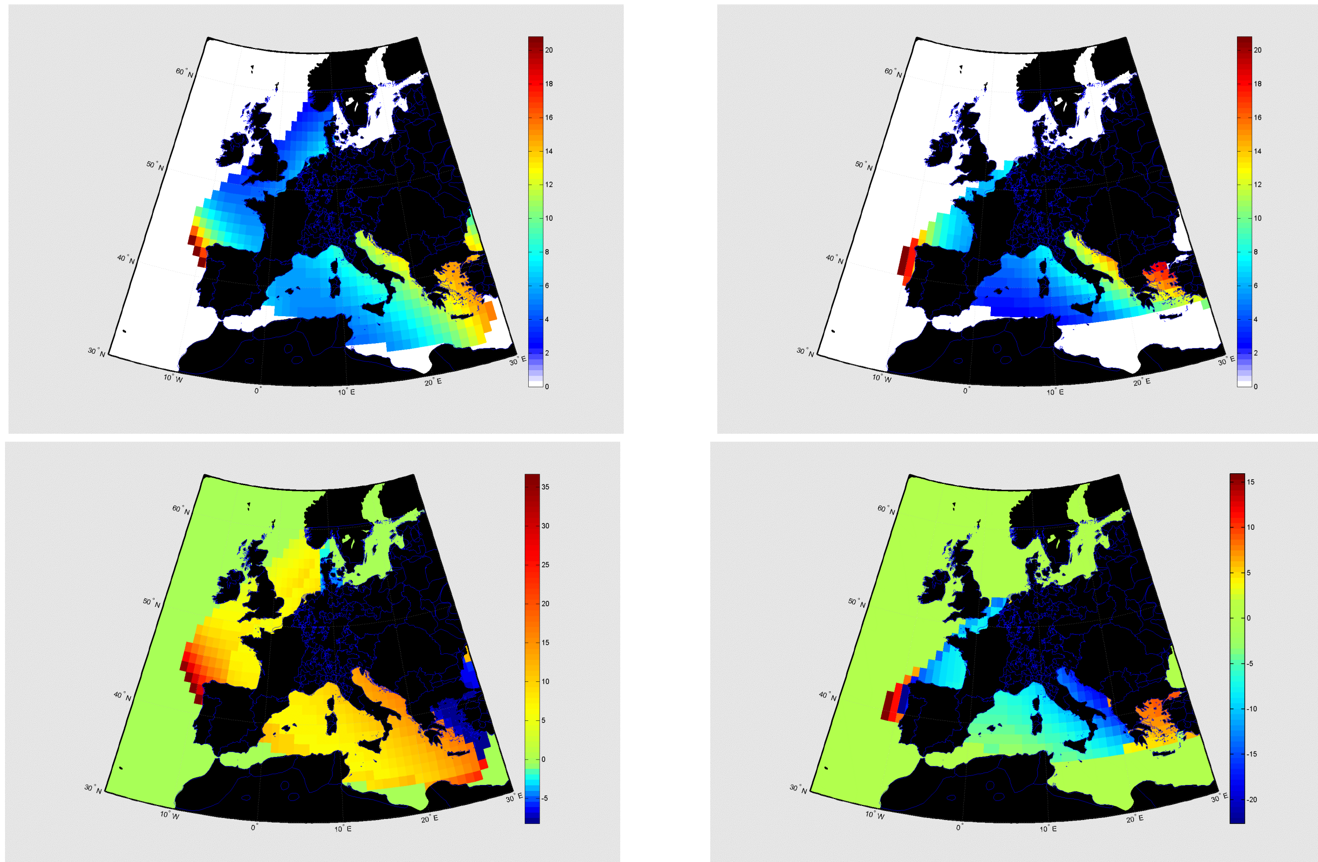

Figure 5. Trade along sea: Outflows and inflows of predictions (upper part) and institutional effects (lower part))

VI. Conclusion

This paper studied medieval trade flows based on the spread of the Black Death. We created an epidemic version of the gravity model to predict and empirically determine the spread of the plague. We used the speed of transmission (in kilometers per day) between two city pairs as proxy for trade flows between these two cities and estimated differences in speed of transmission based on geographic, institutional, and cultural variables. The goals of this case study were to find out 1) if we can use the spread of disease to measure social and economic interactions of societies; and 2) if we can learn something from the new measurement technique for open questions in economics and economic history. Our results support the predicted results of the trade literature and the specific medieval historical environment. Thus we are confident that our approach is a valid alternative way to measure relative trade intensities. Of course this is a single case study and further investigations need to be made to generalize our results even further. In different contexts we will need to incorporate other economic and social aspects of human interaction. The empirical results offer new insights in many open debates in economics and economic history. The results allow us to create a quantitative comparative perspective of the determinants of trade during the Commercial Revolution in Europe and the Mediterranean. For instance we can document the positive role of long-distance trade and the trade-restricting role of political borders. Furthermore the results reveal interesting regional differences. Notably differences in institutional drivers of trade can be identified in Western Europe. Such results contribute to the debate on divergences in regional growth and especially to the discussion as to whether such a divergence was rooted in institutional changes in Western

Europe during the Middle Ages. In addition we can document the important role of institutions and geography for trade and related growth. Our methodology uses a new way of disentangling these two effects.

REFERENCES

ABERTH, J. (2011): *Plagues in World History*. Rowman & Littlefield.

ABULAFIA, D. (1987): "Asia, Africa and the Trade of Medieval Europe, ed. M.M. Postan et al.," in *The Cambridge Economic History of Europe II*, pp. 402–473. Cambridge University Press, 1987 2nd edn.

ACEMOGLU, D., S. JOHNSON, AND J. ROBINSON (2005a): "The Rise of Europe: Atlantic Trade, Institutional Change, and Economic Growth," *American Economic Review*, 95(3), 546–579.

ACEMOGLU, D., S. JOHNSON, AND J. A. ROBINSON (2005b): "The Colonial Origins of Comparative Development: An Empirical Investigation," *American Economic Review*, 91(5), 1369–1401.

ALESINA, A., P. GIULIANO, AND N. NUNN (2013): "On the Origins of Gender Roles: Women and the Plough," *The Quarterly Journal of Economics*, 128(2), 469–530.

ALLEN, R. C. (2001): "The Great Divergence in European Wages and Prices from the Middle Ages to the First World War," *Explorations in Economic History*, (5), 411–417.

ANDERSON, J. E., AND E. VAN WINCOOP (2003): "Gravity with Gravitas: A Solution to the Border Puzzle," *American Economic Review*, 93(1), 170–92.

ANGRIST, J. D., AND V. LAVY (1999): "Using Maimonides' Rule To Estimate The Effect Of Class Size On Scholastic Achievement," *The Quarterly Journal of Economics*, 114(2), 533–575.

Armington, P. (1969): "A Theory of Demand for Products Distinguished by Place of Production," Discussion paper.

Bairoch, P. (1988): *Cities and Economic Development: From the Dawn of History to the Present*. University of Chicago Press, Chicago.

Becker, S. O., and L. Woessmann (2009): "Was Weber Wrong? A Human Capital Theory of Protestant Economic History," *The Quarterly Journal of Economics*, 124(2), 531–596.

Benedictow, O. J. (2004): *The Black Death 1346-1353: The Complete History*. Boydell Press, Woodbridge.

——— (2011): *What Disease was Plague? On the Controversy over the Microbiological Identity of Plague Epidemics of the Past*. Brill, Boston.

Bettencourt, L., J. Lobo, D. Strumsky, and G. West (2007): "Urban Scaling and Its Deviations: Revealing the Structure of Wealth, Innovation and Crime across Cities," *Proceedings of the National Academy of Sciences of the United States of America*, 104, 7301–7306.

Bettencourt, L., and G. West (2010): "A Unified Theory of Urban Living," *Nature*, 467(1), 912–913.

Biraben, J.-N. (1975): *Les Hommes et la Peste en France et dans les Pays Europeens et Mediteraneens*. Mouton, Paris.

Bloch, M. (1953): *The Historian's Craft*. Vintage Books, New York.

Blum, U., and L. Dudley (2003): "Standardised Latin and Medieval Economic Growth," *European Review of Economic History*, 7(02), 213–238.

Boerner, L., and B. Severgnini (2011): "Epidemic trade," Discussion paper.

Boserup, E. (1965): *The Conditions of Agricultural Growth*. Allen and Unwin.

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, 8001800," *The Review of Economics and Statistics*, 95(4), 1418–1437.

Bossak, B. H., and M. R. Welford (2010): "Did Medieval Trade Activity and a Viral Etiology Control the Spatial Extent and Seasonal Distribution of Black Death Mortality?," *Geography Compass*, 4(6), 749–752.

Bridbury, A. R. (1962): *Economic Growth: England in the Later Middle Ages*. G. Allen & Unwin, London.

——— (1973): "The Black Death," *Economic History Review*, 26(2), 582–592.

——— (1977): "Before the Black Death," *Economic History Review*, 30(3), 393–410.

Brokman, D., and D. Helbing (2013): "The Hidden Geometry of Complex, Network-Driven Contagion Phenomena," *Science*, 342(6164), 1337–1342.

Chuine, I. e. a. (2004): "Grape Ripening as a Past Climate Indicator," *Nature*, 432, 289–290.

Cipolla, C. M. (1974): "The Plague and the pre-Malthus Malthusians," *The Journal of European Economic History*, 3, 277–284.

——— (1981): *Faith, Reason, and the Plague in Seventeenth-century Tuscany.* Norton, New York.

——— (1993): *Before the Industrial Revolution: European Society and Economy, 1000-1700.* Routledge, London.

Crozet, M., K. Head, and T. Mayer (2012): "Quality Sorting and Trade: Firm-level Evidence for French Wine," *Review of Economic Studies*, 79(2), 609–644.

De Long, J. B., and A. Shleifer (1993): "Princes and Merchants: European City Growth before the Industrial Revolution," *Journal of Law and Economics*, 36(2), 671–702.

Deardorff, A. (1998): "Determinants of Bilateral Trade: Does Gravity Work in a Neoclassical World?," in *The Regionalization of the World Economy*, NBER Chapters, pp. 7–32. National Bureau of Economic Research, Inc.

Del Panta, L. (1980): *Le Epidemie nella Storia Demografica Italiana (Secoli $XIV - XIX$).* Loescher, Turin.

Dell, M. (2010): "The Persistent Effects of Peru's Mining Mita," *Econometrica*, 78(6), 1863–1903.

Diamond, J. (1997): *Guns, germs, and Steel: the fates of human societies.* Norton and Co., New York.

Domar, E. D. (1970): "The Causes of Slavery or Serfdom: A Hypothesis," *Journal of Economic History*, 30(1), 18–32.

Eaton, J., and S. Kortum (2002): "Technology, Geography, and Trade," *Econometrica*, 70(5), 1741–1779.

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

Epstein, S. r. (2000b): "The Rise and Decline of Italian City States," in *A Comparative Study of Thirty City-State Cultures.* H.M. Hansen, Copenhagen.

Estrade, F. (1935): "Observations Relatives á la Biologie de Xenopsylla Cheopis en Emyrne," *Bulletin de la Société dde Pathologie Exotique*, 28, 293–298.

Findlay, R., and M. Lundahl (2002): "Towards a Factor Proportions Approach to Economic History: Population, Precious Metals and Prices from the Black Death to the Price Revolution," Discussion paper.

Frankel, J. (1997): *Regional Trading Blocs in the World Economic System.* Institute of International Economics, Washington.

Gallup, J. L., A. Mellinger, and J. D. Sachs (1999): "Geography and Economic Development," CID Working Papers 1, Center for International Development at Harvard University.

Galor, O., and D. N. Weil (1999): "From Malthusian Stagnation to Modern Growth," *American Economic Review*, 89(2), 150–154.

Gelting, M. (1991): "The Mountains and the Plague: Maurienne, 1348," *Collegium Medievale*, (3), 7–45.

Greif, A. (2006a): "Family Structure, Institutions, and Growth: The Origins and Implications of Western Corporations," *American Economic Review*, 96(2), 308–312.

——— (2006b): *Institutions and Path to the Modern Economic*. Cambridge University Press, Oxford.

——— (2006c): *Institutions and the Path to the Modern Economy*. Cambridge University Press, Cambridge.

Grierson, P. (1957): "The Coin List of Pegolotti," in *Studi in onore di Armando Sapori*, vol. I, pp. 1319–1338. Milano, Cisalpino.

Guiso, L., P. Sapienza, and L. Zingales (2006): "Does Culture Affect Economic Outcomes?," *Journal of Economic Perspectives*, 20(2), 23–48.

Hall, R. E., and C. I. Jones (1996): "The Productivity of Nations," NBER Working Papers 5812, National Bureau of Economic Research, Inc.

Head, K., and J. Ries (2001): "Increasing Returns versus National Product Differentiation as an Explanation for the Pattern of U.S.-Canada Trade," *American Economic Review*, 91(4), 858–876.

Helpman, E., and P. Krugman (1987): *Market Structure and Foreign Trade: Increasing Returns, Imperfect Competition, and the International Economy*, vol. 1 of *MIT Press Books*. The MIT Press.

Herlihy, D. (1985): *The Black Death and the Transformation of the West*. Harvard University Press, Cambridge.

Hibbert, C. (1963): *The Roots of Evil: A Social History of Crime and Punishment*. Weidenfeld & Nicolson Ltd, London.

Hummels, D. L., and G. Schaur (2013): "Time as a Trade Barrier," *American Economic Review*.

IPRC (1907): "Reports on Plague Investigations in India. XXV. "Observations in the Punjab Villages of Dhand and Kassel.," *The Journal of Hygiene*, 7, 895–985.

Jones, P. e. a. (1999): "Surface Air Temperature and its Variations over the Last 150 Years.," *Review of Geophysics*, 37, 173–199.

Kelly, M., and C. O' Grada (2012): "Change Points and Temporal Dependence in Reconstructions of Annual Temperature: Did Europe Experience a Little Ice Age?," Working Papers 201210, School Of Economics, University College Dublin.

Kuran, T. (2003): "The Islamic Commercial Crisis: Institutional Roots of Economic Underdevelopment in the Middle East," *Journal of Economic History*, 63, 414–446.

Le Goff, J. (1988): *Your Money or Your Life: Economy and Religion in the Middle Ages*. MIT Press, Cambridge.

——— (2012): *Money and the Middle Ages*. Polity Press, Cambridge.

Livi-Bacci, M. (1978): "La Societe Italienne devant les crises de mortalite," Discussion paper.

——— (1983): "The Nutrition-Mortality Link in Past Times: A Comment," *Journal of Interdisciplinary History*, XIV, 293–298.

——— (1997): *A Concise History of World Population*. Blackwell, Oxford.

Lopez, R. S. (1952): "The Trade of Medieval Europe in South, ed. M.M. Postan and E. Miller," in *The Cambridge Economic History of Europe*, pp. 257–354. Cambridge University Press.

——— (1976): *The Commercial Revolution of the Middle Ages, 950 1350.* Cambridge University Press, Oxford.

Lopez, R. S. (1979): "The Culture of the Medieval Merchant," *Medieval and Renaissance Studies: Proceedings of the Southeastern Institute of Medieval and Renaissance Studies*, 8, 52–73.

Mann, A., R. Bradley, and M. Hughes (1999): "Northern Hemisphere Temperatures During the Past Millenium: Inferences, Uncertainties, and Limitations," *Geophysical Research letters*, 26, 759–762.

McCallum, J. (1995): "National Borders Matter: Canada-U.S. Regional Trade Patterns," *American Economic Review*, 85(3), 615–23.

McCormick, M. (2001): *Origins of the European Economy: Communications and Commerce, AD 300–900*, MIT Press Books. Cambridge University Press.

——— (2003): "Rats, Communications, and Plague: Toward an Ecological History," *Journal of Interdisciplinary History*, XXXIV(1), 1–25.

McNeill, W. (1980): *Plagues and Peoples.* Anchor Press/Doubleday, Garden City, NY.

Michalopoulos, S., and E. Papaioannou (2014): "National Institutions and Subnational Development in Africa," *Quarterly Journal of Economics*, 88(5), 1264–76.

Munro, J. H. A. (2005): "Before and After the Black Death: Money, Prices, and Wages in Fourteenth-Century England," Working papers, University of Toronto, Department of Economics.

North, D. C., and R. P. Thomas (1973): *The Rise of the Western World: A New Economic History*. Cambridge University Press, Cambridge.

O'Rourke, K. H., and J. G. Williamson (1999): *Globalization and History: The Evolution of the Nineteenth-Century Atlantic Economy*, no. 026258087x in MIT Press Books. The MIT Press.

Pegolotti, F. B. (1936): *La Pratica della Mercatura, edited by Allan Evans*. The Mediaeval Academy of America, Cambridge.

Pirenne, H. (1969): *Medieval Cities: Their Origins and the Revival of Trade*. Princeton University Press, Princeton, NJ.

Pollitzer, R. (1954): *Plague. Historical Facts. A Manual for Public Health Workers.* World Health Organization, Geneva.

Pomeranz, K. (2001): *The Great Divergence: China, Europe, and the Making of the Modern World Economy*. Princeton University Press, Princeton.

Postan, M. (1975): *The Medieval Economy and Society: an Economic History of Britain in the Middle Ages*. Penguin, London.

Pryor, J. H. (1992): *Geography, Technology, and War: Studies in the Maritime History of the Mediterranean, 649-1571*. Cambridge University Press, Cambridge.

Pyle, G. F. (1979): *Applied Medical Geography*. Winston, Washington.

Rodrik, D., A. Subramanian, and F. Trebbi (2004): "Institutions Rule: The Primacy of Institutions Over Geography and Integration in Economic Development," *Journal of Economic Growth*, 9(2), 131–165.

Romano, R. (1972): *Storia d'Italia. Annali. Volume I.* Einaudi, Turin.

Samuelson, P. A. (1948): "International Trade and Equalization of Factor Prices," *Economic Journal*, LVIII(230), 163–184.

Scott, S., and C. Duncan (2004): *Return of the Black Death: The World's Greatest Killer*. John Wiley & Sons Ltd., Chichester.

Silva, J. M. C. S., and S. Tenreyro (2006): "The Log of Gravity," *The Review of Economics and Statistics*, 88(4), 641–658.

Spufford, P. (1988): *Money and its Use in Medieval Europe*. Cambridge University Press, Cambridge.

Stuard, S. M. (2006): *Gilding the Market, Luxury and Fashion in Fourteenth Century Italy*. University of Pennsylvania Press, Philadelphia.

van Werveke, H. (1952): "The Rise of Towns," in *Cambridge economic history of Europe, ed. M.M. Postan and E. Miller*, vol. III. Cambridge University Press.

Voigtlaender, N., and H.-J. Voth (2013): "The Three Horsemen of Riches: Plague, War, and Urbanization in Early Modern Europe," *Review of Economic Studies*, 80(2), 774–811.

Weber, M. (1921): *Wirtschaft und Gesellschaft Die Wirtschaft und die Gesellschaftlichen Ordnungen und Mächte*. Tubingen.

Wei, S.-J. (1996): "Intra-National versus International Trade: How Stubborn are Nations in Global Integration?," NBER Working Papers 5531, National Bureau of Economic Research, Inc.