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Abstract

This paper studies the spread of the Black Death as a proxy for the flow of medieval trade between 1346 and 1351. The Black Death struck most areas of Europe and the wider Mediterranean. Based on a modified version of the gravity model, we estimate the speed (in kilometers per day) of transmission of the disease between the transmitting and the receiving cities. We find that the speed depends on distance, political borders, and on the political importance of a city. Furthermore, variables related to the means of transportation like rivers and the sea, religious seasons such as Lent and Advent, and geographical position are of substantial significance. These results are the first to enable us to identify and quantify key variables of medieval trade flows based on an empirical trade model. These results shed new light on many qualitative debates on the importance and causes of medieval trade.

Keywords: Trade, Middle Ages, Black Death, Gravity model, Poisson regression

JEL classification: F10, F15, N13

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1 Introduction

If we want to understand the long-run economic growth and success of Europe we need to study the economic development of the Middle Ages. The foundation of many leading cities of the last millennium and the first urbanization of Europe can be traced to the Late Middle Ages. The driving force of urbanization and early city growth was based on the intensification of regional and long-distance trade among different regions of Europe and the wider Mediterranean area (Lopez (1952 and 1976), North and Thomas (1973), Postan (1975), Bairoch (1988), Cipolla (1993) and Epstein (2000a)). Furthermore, complementary institutional innovations related to trade with impact on the institutional structure nowadays such as early financial instruments like the bill of exchange (De Roover (1953)) or business partnerships in form of early firm structures have their origin in the Late Middle Ages (Sapori (1955), Hunt and Murray (1999), Greif (2006a and 2006b) and Boerner and Ritschl (2009)).

Complementary to this strand of literature, a debate known as *the Great Divergence* (Pomeranz (2001)) emerged, comparing the success of Europe compared to that of China and other parts of the world. This debate over the "rise of Europe" goes back to discussions by Weber (1921), Braudel (1949), Wallerstein (1974), North and Thomas (1973), Landes (1998), Epstein (2000a), more recently Acemoglu, Johnson, and Robinson (2005), Greif (2006b), Clark (2007) and many other prominent social scientists, who have studied the economic and political rise and decline of regions, empires and civilization.

Although trade flows among different cities and regions of Europe are key to understanding the initial growth and urbanization, only a few quantitative statements can be made about the determinants of trade flows among places and regions in Europe during this important epoch. The lack of appropriate data let the economic historians mainly make qualitative assertions about what determined commerce: they have identified transportation routes and the related means of transportation. In addition, political fragmentation and missing bigger territorial states which restricted the trade flows due to limited safety and the existence of a variety tolls and taxes imposed by local rulers along the trading routes have been identified as constraints for the commerce in Europe (van Werveke (1952), North and Thomas (1973) and Postan (1975)). One way to overcome these qualitative restrictions, has been taken up by scholars of integration in pre-industrial Europe based on the law of one price. In these studies grain price data (Persson (1998), Jacks (2004), Bateman (2007) and Ozmucur and Pamuk (2007)) and prices of gold-silver ratios (Volckart and Wolf (2006), Boerner and Volckart (2011) and Chilosi and Volckart (2011)) are used to measure differences in prices in different cities as a proxy for market integration. Most of these studies go back to the 16^{th} century and a few to the late 14^{th} and 15^{th} centuries (Chilosi and Volckart (2011) and Boerner and Volckart (2011)). This is due to a lack of price series available for earlier periods.

Empirical trade economists and economic historians who mainly studied 20^{th} century data can rely on import and export data among countries to measure trade flows. Their empirical analysis is centered around the gravity model (Tinbergen (1962), Helpman and Krugman (1987) and Deardorff (1998)) which takes country size, physical distance, and institutional and cultural variables such as political borderlines and geographical characteristics to explain trade flows among countries. The empirical findings in the baseline models are that economic size of the two comparing countries and similar sociopolitical characteristics raise the intensity of trade, while distance and borderlines can explain trade resistance on an international level. In addition, in some areas of Europe, more precisely those that are the farthest from coastal rivers, religious periods can slow the speed. Furthermore, religious periods play an important role in trade intensity in particular areas: in other words, trade decreases during religious festivities if the cities are far from the ports.

This paper takes a different approach from previous studies on medieval trade. Due to the lack of data for the Late Middle Ages, we use the spread of the Black Death from 1347-1351 as a proxy to study trade flows among different cities. Cipolla (1974) identified traveling merchants and population density as the main transmitters of the disease among cities. This statement has been confirmed by several studies in economic history, demography and epidemiology (Biraben (1975), Del Panta (1980) and Benedictow (2004)). Furthermore, medieval historians who studied the Black Death were able to date the start of the infection in many cities and the spread of the disease from one city to the next. In this way we are able to identify city-pairs in which we can measure the speed of the spread of the disease along different trade routes and use this as a proxy to measure trade flows. We use the speed (kilometers per day) as the dependent variable in a modified gravity model. We run the model along a set of explanatory and control variables which can be derived from historical investigations or have been identified as important by empirical trade economists.

Our main findings are that the speed of trade depends on the means of transportation, the political borderlines, the distance, religious holidays, and the institutional function of a city. We show that transportation on rivers and seas was faster than along land trade routes. This is in line with findings of qualitative studies by medieval economic historians. Political borderlines slowed down the speed. This confirms the findings by empirical trade economists (McCallum (1995)). This supports the argument by North and Thomas (1973) that political border lines were a major obstacle to medieval trade and growth. Furthermore we find that distance has a positive impact of the speed of transmission. This contrasts with the findings of the recent empirical trade literature but is in line with the argument that long distance trade was the critical factor in medieval trade (Braudel (1949), Lopez (1952 and 1976), Cipolla (1993)). Furthermore we show that the religious holidays of Advent and Lent slowed down trade and we show that political residential cities, in particular of bishop cities had a significantly faster inflow. We explain this faster inflow by the relatively stronger consumption of residential cities. Neither the religious holidays nor political function have to the best of our knowledge been taken into consideration to explain trade flows in the literature. City size (used as a medieval proxy for economic size) plays a negative or non significant role in determining the speed of transmission. These results are not in line with the standard results in gravity models based on country level data, but confirm insights from studies in urban economics (Von Thunen (1826), Krugman (1991) and Ades and Glaeser (1995)). Finally, we show that inflows, outflows and the net speed (inflow minus outflow) depend on the geographical location of a place. We find high speeds in the Mediterranean area and in North West Europe. We detect strong outflows from North West Europe and strong inflows into the Eastern Mediterranean area and North Africa. These results confirm general studies in late Medieval Economic history, which conclude an uprise of Northwest Europe and a decline of North Africa and the Eastern Mediterranean area.

The findings of this paper contribute in three ways. First, the results offer insights to many open debates in economic history related to what determined trade in late medieval Europe. Furthermore, it is worthwhile to note that we consider the Black Death not as a cause to explain ensuing (economic) historical events (Bridbury (1962), Domar (1970) and Munro (2005)), but use the Black Death to explain what happened before the spread of the plague. Second, the economic development of late medieval Europe has been recognized as the origin of the successful economic divergence of Western Europe from many other regions of the world (Epstein (2000a)). This way we might gain insights on what shapes a successful developing economy in terms of trade. Finally, this methodology offers a new way to measure trade flows where we lack other data. This approach can be extended to many other applications. Interestingly, epidemiologists now use channels of communications to predict the spread of flus and other diseases. Thus they exploit the data in reverse order.[1] Furthermore, recent

[1] A recent medical article (Pepperell and al. (2011)) shows how French Canadian fur merchants spread tuberculosis

studies on 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.

The remainder of the paper is structured as follows: Section 2 gives a short introduction to the late medieval economic history of Europe and the spread of the Black Death. In addition, the main candidates for explaining medieval trade are identified. Section 3 introduces the gravity equation model and specifies the empirical model applied to measure the speed of the spread of the Black Death. Section 4 presents the data and the descriptive statistics. Section 5 discusses the estimation results. Section 6 introduces a wide range of robustness checks. Section 7 displays the marginal effects of the most relevant variables with respect to the geographical positions of the cities. Section 8 concludes.

2 The Missing Link: Medieval Trade and the Black Death

2.1 Determinants of Medieval Trade Flows

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 10^{th} and 11^{th} centuries (Bairoch (1988)). The period from the 11^{th} until the middle of the 14^{th} 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 Bosker, Buringh, and van Zanden (2008)).

The revitalization of trade was based on the reestablishment and increase of trade connections between different European cities. Trade routes on land, rivers, and the sea were used to exchange a large variety of goods. However, although there is evidence of inter-regional trade of bulk goods such as basic foodstuff, for example grain, transportation costs were still high and preferable high-value-per-weight goods for example textiles or spices were transported along these routes. According to this line of argumentation, Lopez sees the commercial revolution rather as an increase in the number of trade connections among cities and less as a dramatic change in quantities traded. Furthermore, the increase in connections was uneven. Trade between sometimes distant merchant cities was more intense than the connection of such merchant cities with local surrounding cities.[2] This way late medieval trade and related city growth is driven by an increase in long distance trade. However making more definitive corollaries based on the existing rather qualitative source material is difficult. Therefore, it is not surprising that there is an open debate about the economic integration of Europe based on trade which goes back to scholars including, Weber (1921), Braudel (1949) and Wallerstein (1974).

The two different channels of transportation on land and on waterways (rivers and on the sea) can be differently characterized. Land trade was based on the use of old Roman roads. How these streets were preserved and maintained during this period remains a matter of scholarly debate. However

among indigenous people in western Canada from 1710 until 1870. For an economic study of the relation between disease and economic activity, see Oster (2007). For the use of gravity models and epidemics, see Viboud and al. (2006).

[2]For a regional study of the 15^{th} century Germany, see Chilosi and Volckart (2011).

it stands to reason that streets were the slowest and most costly way to transport goods. Horses and mules with carts could only transport limited amounts of goods. A cheaper and faster option to transport larger quantities of goods was on rivers, especially on sea ships. However shippers on the sea had to deal with unpredictable weather. For this reason shipping on the sea was comparably slower than on rivers (Lopez (1952 and 1976) and Postan (1975)).

Furthermore, whereas transportation on the river as on land was rather safe since it was under the control of dukes, as soon ships left the coast and were on the open sea, they were vulnerable to pirates. However the safety of trade routes on land and rivers depended on the political structure of a region. Western Europe was only partially characterized by territorial states such as England; small territorial or city states as in Italy or Germany were the rule. Passing many different political territories on a trade route implied not only to rely on different 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. For example traders during the 14^{th} century who shipped their goods along the Rhine had to pass through more than three dozen toll stations mainly run by local ecclesiastical princes and states (Postan (1975), pp.182ff.). Nevertheless, the Rhine was one of the largest and safest transport routes of Germany In contrast, in territorial England tolls were rather rare and the legislation centrally enforced. Does this imply that trade flows in England were faster than in Germany? Postan claims that on many trade axes a sufficiently large number of routes existed which made the toll setting competitive enough not to harm long distance trade too much. This statement is confirmed by our data on the Black Death: the speed of the dispersion of the Black Death along rivers in England is about 8 kilometers per day, while along the Rhine and other important rivers in Germany the disease propagated almost three times faster. North and Thomas (1973), pp. 69ff., 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 13^{th} century. However, Planitz (1919) and later Greif (2002 and 2006b) and Boerner and Ritschl (2002 and 2009) showed that the institution of community responsibility maintained cross-border legislation also in politically very fragmented parts of Europe.

Furthermore, trade was conductive to city growth. Indeed 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)). However, many of these cities can also be identified by other functional meanings (van Werveke (1952), pp.22ff). Some cities were residences of bishops and local dukes and served political and administrative purposes. Some cities already hosted universities. All these cities could also be merchant cities, but could rely on external income streams, for example in form of fiscal incomes. This way these cities were very likely consuming more than producing. The follow up question we can raise is if these cities with different institutional functions influenced trade flows differently from sole merchant cities. In addition and more generally we need to ask if the size of the cities influenced the intensity of trade flows.

Finally we like to bring in an aspect of medieval life, which has to the best of our knowledge not been discussed in medieval trade literature: the effect of religious holidays on trade activities. Although there is a consensus about the importance of the church in daily (and economic) life (Le Goff (1988)), no researcher has asked whether or not Advent and Lent had an impact on the intensity of trade.

The phase of commercialization came to an end with the outbreak of the Black Death. Medieval scholars have seen the period between the end of the 10^{th} century until the 14^{th} century as one of ongoing economic progress. Lopez (1952), pp. 360ff., identifies the last hundred years before the

Black Death as the heyday of medieval trade. Thus taking the moment of the outbreak of the Black as a benchmark for the achievements of the Commercial Revolution in terms of trade can be justified. However during the early 14^{th} century several famines led to regional economic stagnation (Bridbury (1962)).

2.2 Nature and Transmission of the Virus

According to McNeill (1977) and Findlay and Lundahl (2002), the virus originated in Mongolia during the 11^{th} century and was transmitted by merchants from Asia to the Western Europe during the 14^{th} century. The unification and pacification of big parts 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 14^{th} 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 Caffa (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 the most important commercial harbors in Europe in 1347. Considering the Middle East Asia and the Northern African, the main hubs of propagations were Costantinople and Alexandria.

Figure 1 provides a general view of the main spread routes of the Black Death in Europe and the wider Mediterranean area based on our dataset:[3] the yellow, red, blue, green, orange and black lines represent the main propagation of the disease during 1346, 1347, 1348, 1349, 1350, and 1351 respectively. The second city contaminated 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). Looking at Continental Europe, from Messina the disease emanated to the western part of Northern Africa (Tunis and Fez) and the main ports in the Mediterranean sea (Pisa, Genoa, Marseilles, Barcelona, Valencia, Ragusa and Venice) between December, 1347 and the first months of 1348. Italy, with Pisa and Venice as the two main centers of propagations, and large areas of France and Spain were contaminated until June 1348. From Spain the virus moved to the main ports on the Atlantic Ocean (Lisbon and Bordeaux) and to the North and Baltic Sea. Infected cities included London, Amsterdam, Bergen, Oslo, and Copenhagen. Germany was infected directly from the South via the trading routes coming from Italy/Austria and France/Switzerland. In addition, the plague was transmitted via sea trade from the North and Baltic Sea. In 1351 the disease reached the maximum expansion. Cipolla (1963) estimated a mortality rate of about 30 percent of the total European population, the worst catastrophe in history.[4]

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

[4] As a matter of comparison, during World War II the mortality rate in Europe was between 6 and 16 percent.

Figure 1: Spread of the Black Death and Trade Routes in Europe

Despite several studies in the past 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 strict connection between the Black Death and trade. Cipolla (1974) was the first scholar stating that just two factors, population size and trade, drove 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 agreed upon the causal link between trade and the spread of the disease: the typology of virus which spread across Europe during the 14^{th} century is a typical case of a bubonic plague (*yersinia pestis*), which is typically transmitted to humans by rats and fleas which traveled on the goods along the trade routes.[5] The time from the incubation to the appearance of the illness took only 3-5 days. This way it was very difficult for the inhabitants to take any preventive measures. Furthermore, medieval sources do not reveal any information that the medieval inhabitants were aware of any way to protect themselves against the plague (Cipolla (1981)).

An interesting case which documents the unequal speed of the spread is related to the transmission of the infection from Florence, one of the most important cities in Italy with about 100,000 inhabitants. After the outbreak of the plague in the Tuscan city at the beginning of March 1348 (Corradi (1865) and Del Panta (1980)) the Black Death moved during the same months to Bologna and Modena, about 110 and 160 kilometers away. In contrast, the virus took almost two months to be transmitted to Siena, just 70 kilometers from Florence. Even at first glance it is difficult to identify the causes of this different timing. Benedictow (2004) claims that "*the Black Death showed its ability to perform middle-range metastatic leaps along important commercial roads between large commercial and production centers in areas with great population density*". Thus the speed of the transmission might be explained by the different trade intensities between different cities.

Medieval historians have been able to pinpoint the periods of the outbreak of the plague in different cities. Based on different types of sources the dates can be aligned and assigned to single days of a month: for example, in the Italian city of Orvieto the appearance of the disease and the mortality rate was compared using different types of sources: from the parochial registers, from the chronicles of the writers and from the mortality rate of the upper classes (e.g., lawyers and notaries) (Carpentier (1993)). 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 different cities. The speed indicates the trade flow direction and the intensity of trade.

2.3 Explanatory Variables: Candidates

Next we need to identify explanatory variables, which are potential candidates to determine trade flows and we are able to derive from the medieval source material. A first set of variables is related to the classical approach in gravity models: the population size of the two cities in a city-pair, the distance between the cities, and the existence of common or different borders between the two cities. Following the gravity model (which we discuss in the coming section) we should expect a stronger trade flow between bigger cities, cities which are closer and city-pairs which have a common border. Bigger

[5] According to Pollitzer (1954) the bearers of the virus were the fur fleas of the black rats. The virus only survives if the flea is able within half a day (or a day) either to bite human beings, move on grain seeds (their preferred food) or if it is in humid environments like on ship cargos Estrade (1935). Scott and Duncan (2004) and Bossak and Welford (2010) have recently suggested that the Black Death was transmitted only by humans. This hypothesis would strengthen the link between economic relation and the pandemic.

cities are expected to import and export more goods. Thus a bigger flow increases the likelihood of the spread since more merchants travel between the two cities. Following the argument by Lopez, this does not need to be the case during the commercial revolution, since the period can be characterized by a qualitative improvement of trade flows and less by a quantitative enhancement. Thus the prediction for the medieval trade environment is not unambiguous. With respect to distance, trade economists have predicted and also found empirical confirmation that nearby cities trade more since keeping up with a transportation and communication channel is easier over short distances. Again, this might be different in the historical context since closeness in the period of investigation does not necessarily mean a better connection. A similar motivation can be found in the urban studies by Von Thunen (1826), Krugman (1991) and Fujita and Mori (1996) where trade costs are positively related to city size. This argument is also supported by empirical evidence provided by Ades and Glaeser (1995) and Bosker, Buringh, and van Zanden (2008): during the last millennium, the biggest differences among European and non European cities are related to their size and geographical location. Non European cities in Africa and Asia Minor are almost all megalopolis (e.g., Constantinople and Alexandria and some of them inland like Baghdad and Cairo) where most of the goods consumed were produced internally denoting low trade and a sort of predatory political actions. In comparison, Europe created agglomerations of smaller cities, where a higher quantity of goods is exchanged with other urban areas. Most of them are located in coastal areas, where long-distance trade can be easily exploited. For those reasons, we expect size to be negative or not significant and distance to be positively related with respect to trade intensity. Finally, common borders reduce transaction costs related to a higher number of institutional barriers. This is what trade economists predict and also found in their empirical studies. For example, McCallum (1995) predicts higher intra-national Canadian trade than international trade with the US. In addition, a border can be considered as a valid proxy for tariffs on imported goods. As discussed in the previous section medieval economic historians arrived at different conclusions as to what extent political borders hindered trade. Furthermore, we introduce a variable for exchange in non European countries. Following the literature on the rise of the West and the relative decline of the superior non European Mediterranean area we expect a slower trade outside Europe, *ceteris paribus*.

A second set of variables is related to the geographic variables which might influence the speed of transportation. We identify trade routes along lakes and rivers, and city connections via the sea. Following the historical literature, we expect a faster speed on waterways in general and a relatively faster speed on rivers or lakes than on the sea. In addition, we identify harbor cities. This allows us to check if a city with a harbor influences trade flows independently of the means of transportation. A harbor indicates potentially stronger trade activities and potentially a faster spread of the disease. Though, a harbor could also only indicate a trading hub with less local trade and social connections and thus a reduction of the spread of the disease. Furthermore, bringing in or shipping out goods via a harbor takes longer. This way the spread of the disease takes more time. In addition, we check the elevation, longitude and latitude of a city. A relatively high elevation of the first and relatively low level of the second city might speed up the process of transportation. Furthermore, the spread of the disease eventually depends on the elevation, and on the longitude or latitude of the area in which the city is located. However, epidemiologists predict that the virus of the pledge was resistant to any kind of climate influence. Thus we should not expect any influence based on these factors. Finally, we check for seasonality.

Another important set of variables is represented by religious periods, more precisely, Lent and Advent. Following the Catholic liturgical year, which was observed during the Middle Ages, Lent was the forty 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[6] Advent, in contrast, is a fixed period of the calendar, consisting of the four weeks before Christmas. Those two liturgical seasons are characterized by fasting and abstinence from different types of food and sexual intercourse. A general rule for all the cities is the abstinence from all of kind of meat during these periods.

In a last set of variables we look into the functional nature of the city. We analyze if the city is the residence of a bishop, a prince, or if the city hosts a university. Cities with these extra characteristics have additional income streams. Thus they might consume more than they produce. This way we expect that they had smaller outgoing but more incoming trade streams. Consequently such a city is less likely to be a transmitter of the disease and more likely to be a receiver. As with the presence of a university, a bishop or a prince.[7] A higher level of human capital could also be an indicator for more trade activities and thus a higher transmission and receiving of the plague. In contrast, a prince city might have more autocratic government (De Long and Shleifer (1993)) and thus more restricted trade flows.

Finally, we control for seasonal and time effects. Even if the epidemiological literature agrees that the Black Death is not affected by different types of season since the virus can be transmitted by rats and fleas (Pollitzer (1954)), several epidemiologists have claimed that the speed of the Black Death could be affected by the temperature. We add to all the regressions a set of variables related to the period of the epidemic's diffusion: We consider three different dummies if the Black Death appeared in autumn, spring, and summer, respectively, and in different years (from 1346 to 1350). Seasonal effects could be related to temperature changes. Time effects could be related to any other unobservable time effect we do not control for.

3 The Gravity Model

In international economics the gravity model 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 different geographical areas. Inspired by Isaac Newton's law of gravity (1687), which states that in the universe each particle can attract any other element with a force which is directly proportional to the product of their masses and inversely related to the square of the distance between them, the gravity model states that bilateral trade flows are 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 or sociopolitical and cultural barriers.

Introduced in economics by Tinbergen (1962), the traditional framework of the gravity equation represents the bilateral trade T between the two areas i and j as a function of economic size Y, usually represented by Gross Domestic Product (GDP), the geographical distance $DIST$ and a stochastic error term ϵ_{ij}, which is assumed to be independent by other regressors, i.e. $E\left(\epsilon_{ij}|Y_i, Y_j, DIST_{ij}\right) = 1$:

$$T_{ij} = B_0 Y_i^{\beta_1} Y_j^{\beta_2} DIST_{ij}^{\gamma_1} \epsilon_{ij} \tag{1}$$

The log-linearization of (1) provides

$$\ln T_{ij} = \ln B_0 + \beta_1 \ln Y_i + \beta_2 \ln Y_j + \gamma_1 \ln DIST_{ij} + \ln \epsilon_{ij} \tag{2}$$

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

[7]Alternatively, Blum and Dudley (2003) assume that a bishop is a good indicator of human capital.

In our analysis we cannot estimate (2) since data on bilateral trade and GDP are not available for the 14^{th} century. Moreover, the assumption that the geographical distance is the only term of resistance could be reductive since other social and political variables can play an important role in stimulating or reducing trade. For these reasons, we propose the following modified version of the gravity equation:

$$\ln SPEED_{ij} = \ln B_0 + \beta_1 \ln POP_i + \beta_2 \ln POP_j + \gamma_1 \ln \kappa_{ij} + \epsilon_{ij} \tag{3}$$

where the bilateral trade T is substituted by the speed of the Black Death spread from city i to city$j$ measured in kilometers per day ($SPEED_{ij}$). Furthermore, following De Long and Shleifer (1993) and Acemoglu, Johnson, and Robinson (2005) who show the strong positive link between income and population growth, we consider as measure of economic size for the trade pair ij the number of inhabitants of the two cities during the year 1300 (POP_i and POP_j). Finally we substitute the geographical distance with a set of unilateral and bilateral variables which can enhance or being a barrier for trade (κ_{ij}). We adopt the technique proposed by Scott and Duncan (2004), who model the bilateral transactions as a function of observable social and political variables:

$$\ln \kappa_{ij} = \alpha_0 + \alpha_1 \ln DIST_{ij} + \alpha_2 X_{ij} + \alpha_3 Z_i + \alpha_4 Z_j + \xi_{ij} \tag{4}$$

where X_{ij} are bilateral trade variables, and Z_i and Z_j are variables related to city i and j respectively. Our final gravity version to be estimated is obtained by substituting (4) into (3):

$$\ln SPEED_{ij} = \ln B_0 + \beta_1 \ln POP_i + \beta_2 \ln POP_j + \gamma_1 \alpha_1 \ln DIST_{ij} + \gamma_1 \alpha_2 X_{ij} + \gamma_1 \alpha_3 Z_i + \gamma_1 \alpha_1 Z_j + u_{ij} \tag{5}$$

The following sections analyze different estimation techniques and several robustness checks.

4 Data and Descriptive Statistics

For our econometric analysis we consider several types of data whose sources are described in Appendix A. Tables 1 and 2 display the names and brief descriptions of the variables chosen for the estimation. The motivation for the choice of the variables has been given in the previous chapter. Along this motivation we split up the table into five groups of regressors: the ones typically used in standard gravity model, geographical variables, social and political variables, religious variables and time variables which describe the environment during the period of the spread of the Black Death. We cover the period from 1346-1351. A complete list of the political regions and the number of cities taken into consideration can be found in Appendix B.

Table 3 depicts the descriptive statistics of the variables related to both the bilateral and singular characteristics of the cities. We were able to collect data from 146 different couples of cities. Similar to the results obtained by Benedictow (2004), the speed of the disease is very heterogeneous: in our dataset we can find values from about 110 meters to more than 55 km per day. The highest levels of velocity (more than 3 km per day, which represents about 46 percent of the observations in our sample) are completely related to the trade between cities along water channels (*water*). The city size in the sample (*pop*1, *pop*2) is also rather heterogeneous: the sample contains small towns with 1,000 inhabitants in Sicily to 400,000 inhabitants in Cairo (and 150,000 in Europe with Paris). The distance (*dist*) between city-pairs covers from short distances of 6 kilometers to more than 1,900 kilometers. About 37 percent of the city-pairs have a common border. About 20 percent 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 200 meters. The other variables related to geography and sociopolitical factors have heterogeneous distributions.

Table 1: Variable names and descriptions (first part)

Variable	Description
	Standard gravity model
speed	speed of the disease (in natural logarithm, km/day)
lnspeed	ln(speed)
pop1	population size in 1300 (in in thousands, first city)
lnpop1	ln(pop1)
pop2	population size in 1300 (in thousands, second city)
lndist	bilateral geographical distance (in natural logarithm, in km)
dist	bilateral geographical distance (in km)
lndist	ln(dist)
border	equals 1 if the two cities are in different regions, and 0 otherwise
	Geographical variables
noeurope	equals 1 if at least one of the two cities are not in the European continent, and 0 otherwise
waterway	equals 1 if the two cities traded along water, and 0 otherwise
water1land2	equals 1 if the the first city is by the sea and the second on land, and 0 otherwise
water2land1	equals 1 if the the first city is on the land and the second by the sea, and 0 otherwise
distsea1	distance from the next sea port (in km, first city)
lndistsea1	ln(distsea1)
distsea2	distance from the next sea port (in km, second city)
lndistsea2	ln(distsea2)
elevation1	elevation of the first city (in natural logarithm, in m)
lnelevation1	ln(elevation1)
elevation2	elevation of the second city (in natural logarithm, in m)
lnelevation2	ln(elevation2)
latitude1	latitude of the first city
latitude2	latitude of the second city
longitude1	longitude of the first city
longitude2	longitude of the second city

Table 2: Variable names and descriptions (second part)

Variable	Description
	Social and political variables
bishop1	equals 1 if the first city has a bishop, and 0 otherwise
bishop2	equals 1 if the second city has a bishop, and 0 otherwise
prince1	equals 1 if the region of the first city has a prince, and 0 otherwise
prince2	equals 1 if the region of the second city has a prince, and 0 otherwise
university1	equals 1 if the first city has a university, and 0 otherwise
university2	equals 1 if the second city has a university, and 0 otherwise
	Religious variables
lent	equals 1 if the two cities are contaminated during lent, and 0 otherwise
advent	equals 1 if the two cities are contaminated during advent, and 0 otherwise
	Time variables
winter1	equals 1 if the first city is contaminated during winter, and 0 otherwise
spring1	equals 1 if the first city is contaminated during spring, and 0 otherwise
summer1	equals 1 if the first city is contaminated during summer, and 0 otherwise
autumn1	equals 1 if the first city is contaminated during autumn, and 0 otherwise
year_1346	equals 1 if the first city is contaminated during 1346, and 0 otherwise
year_1347	equals 1 if the first city is contaminated during 1347, and 0 otherwise
year_1348	equals 1 if the first city is contaminated during 1348, and 0 otherwise
year_1349	equals 1 if the first city is contaminated during 1349, and 0 otherwise
year_1350	equals 1 if the first city is contaminated during 1350, and 0 otherwise

Table 3: Descriptive statistics

Variable	Mean	Standard deviation	Min	Max	Number of observations
Standard gravity model					
speed	4.00	6.76	0.11	58.57	146
pop1	30658.89	45890.59	3000.00	400000.00	146
pop2	21452.05	38915.47	1000.00	400000.00	146
dist	205.44	293.04	6.37	1902.49	146
border	0.37	0.48	0.00	1.00	146
Geographical variables					
noeurope	0.05	0.23	0.00	1.00	146
waterway	0.46	0.50	0.00	1.00	146
water1land2	0.16	0.37	0.00	1.00	146
water2land1	0.04	0.20	0.00	1.00	146
distsea1	126.52	125.19	1.00	649.62	146
distsea2	147.56	136.27	1.00	949.45	146
elevation1	75.74	153.26	1.00	1350.00	146
elevation2	183.30	266.86	1.00	1815.00	146
longitude1	9.48	8.16	-8.55	46.28	146
longitude2	9.00	8.48	-8.62	44.39	146
latitude1	43.84	5.37	30.05	60.38	146
latitude2	43.94	5.95	30.05	63.43	146
Social and political variables					
bishop1	0.44	0.50	0.00	1.00	146
bishop2	0.37	0.48	0.00	1.00	146
prince1	0.46	0.50	0.00	1.00	146
prince2	0.39	0.49	0.00	1.00	146
university1	0.06	0.24	0.00	1.00	146
university2	0.08	0.28	0.00	1.00	146
Religious variables					
lent	0.14	0.35	0.00	1.00	146
advent	0.23	0.42	0.00	1.00	146
Time variables					
autumn1	0.15	0.30	0.00	1.00	146
winter1	0.10	0.29	0.00	1.00	146
spring1	0.30	0.42	0.00	1.00	146
summer1	0.45	0.45	0.00	1.00	146
year_1346	0.02	0.14	0.00	1.00	146
year_1347	0.34	0.46	0.00	1.00	146
year_1348	0.51	0.48	0.00	1.00	146
year_1349	0.11	0.30	0.00	1.00	146
year_1350	0.02	0.14	0.00	1.00	146

5 Estimation Results

Tables 4 and 5 display the main results of our modified gravity estimation represented by (5) with Ordinary Least Square (OLS) following seven different types of specifications. In all columns we control for time, seasonal effects and longitude and latitude.

Columns (1) and (2) consider the standard model of (5) assuming that the entire effects of resistance and/or positive adjustment to trade can be explained by the geographical distance or by a political border: the first column studies the effect on population size and distance on the speed of propagation; in the second one the model is extended to a presence of a political border and a dummy which is equal to 1 if one of the two cities involved in trade is situated in an extra European territory and if the two cities are connected by a waterway. We find for the population size of the city a negative significant coefficient for the sending and a positive significant coefficient for the receiving city. These results are different from the ones provided by the standard gravity model using international trade data. However the outcome is in line with the theoretical and empirical evidence on urban studies. The coefficient for the distance is significantly positive. Thus, the coefficients suggest that the longer is the distance the higher is the intensity of trade. This supports the conclusion by medieval economic historians that long distance trade plays a crucial role in medieval trade, but is different from what international trade empiricists find when they measure trade flows between countries based on GDP of imports and exports. the sign of the variable *border* is negatively significant and very similar to the one showed by McCallum (1995) Thus, political borders represent barriers to medieval trade. This is consistent with the empirical insights by trade economists and confirms the findings by medieval historians who argued that political fragmentation confined trade. The coefficient for reagions outside Europe (*noneurope*) is negative as predicted by historians who support the thesis that Late Medieval Europe economically outperforms the non European Mediterranean. However the sign is not significant. The estimator for *waterway* connections is positively significant. Hence, this suggests that the trade on a water channel or a seaway is much more intense than on the land. This confirms the studies by medieval historians. Next, column (3) reports the coefficients of the basic model extended by additional geographical variables. However we cannot find any significant effects.

Furthermore, column (4) displays the previous specification enhanced with the religious periods *lent* and *advent* and these period variables interacting with the dummy *border*. We can observe that, even if sometimes not always significant, the dispersion of the disease during lent and advent decelerates in comparison with to the other periods of the year. In addition, the results suggest that trade during the Lent is higher if it takes place across a political border.

Column (5) introduces the social and political variables *bishop*, *prince*, and *university*. The coefficients for the receiving residential cities *bishop*2 and *prince*2 are positive and for *bishop*2 significant. Incorporating the results from columns (6) and (7) we also find a negative sign for transmitting residential cities *bishop*1 and *prince*1. This confirms our hypothesis weakly that consuming cities receive the plague faster and transmit the disease more slowly. The signs for university cities are all negative and only in one case weakly significant. Hence, lines of argument along human capital or autocratic rulers discussed in the previous sections cannot be confirmed.

Finally, columns (6) and (7) display results refining the religious period variables and keeping all the other variables unchanged. The variable *lent* and *advent* is tested with all kinds of interaction terms. In general, the results suggest that trade during the Lent is higher if it happens across a political border or if the first city is located in the proximity of a coast. These results are in line with some historical studies (Bridbury (1955), Newman (1962) and Ciappelli (1997)): which show that during Advent and Lent, meat from four-legged animals or fowl and any other derivates from them were prohibited. Usually, the only flesh allowed was fish, suggesting a more intense long-distance trade from the sea.

Table 4: Determinants of Trade: OLS Regressions (first part)

Dep. Variable:				$\ln Speed_{ij}$			
lnspeed	(1)	(2)	(3)	(4)	(5)	(6)	(7)
				Standard gravity model			
lnpop1	-0.22**	-0.17***	-0.16**	-0.16**	-0.18**	-0.06	-0.15*
	(0.08)	(0.06)	(0.07)	(0.07)	(0.07)	(0.05)	(0.07)
lnpop2	0.14*	0.13**	0.11**	0.07	0.01	0.01	0.05
	(0.07)	(0.06)	(0.05)	(0.05)	(0.06)	(0.04)	(0.06)
lndist	0.73***	0.41***	0.45***	0.50***	0.55***	0.33***	0.56***
	(0.06)	(0.08)	(0.08)	(0.08)	(0.07)	(0.06)	(0.09)
border		-0.32**	-0.32**	-0.54***	-0.54***	-0.39***	-0.40**
		(0.15)	(0.15)	(0.18)	(0.16)	(0.11)	(0.15)
noeurope		-0.34	-0.30	-0.52	-0.26	-0.35	-0.72
		(0.42)	(0.40)	(0.41)	(0.42)	(0.35)	(0.56)
				Geographical variables			
waterway		1.28***	1.27***	1.19***	1.16***	0.80***	1.18***
		(0.15)	(0.16)	(0.15)	(0.15)	(0.10)	(0.15)
lndistsea1			0.10	0.14	0.13	0.13*	0.26
			(0.15)	(0.15)	(0.12)	(0.07)	(0.14)
lndistsea2			-0.04	-0.09	-0.08	-0.14**	-0.22
			(0.15)	(0.14)	(0.11)	(0.07)	(0.13)
lnelevation1			0.02	0.06	0.02	0.02	0.03
			(0.05)	(0.05)	(0.05)	(0.03)	(0.05)
lnelevation2			-0.04	-0.03	-0.02	0.01	-0.02
			(0.03)	(0.03)	(0.03)	(0.02)	(0.03)
water1land2			0.29	0.44	0.37	0.32	0.92
			(0.71)	(0.68)	(0.56)	(0.33)	(0.63)
water2land1			-0.84	-1.07	-1.20	-1.03**	-1.92*
			(0.92)	(0.96)	(0.78)	(0.42)	(0.73)
longitude1	-0.05	-0.01	-0.00	-0.00	-0.01	-0.01	0.13
	(0.04)	(0.03)	(0.02)	(0.02)	(0.02)	(0.02)	(0.15)
longitude2	0.03	0.01	-0.01	-0.00	0.00	-0.00	-0.05
	(0.03)	(0.02)	(0.02)	(0.02)	(0.02)	(0.02)	(0.12)
latitude1	-0.04	-0.05	-0.05	-0.04	-0.02	0.01	0.05
	(0.04)	(0.04)	(0.04)	(0.03)	(0.03)	(0.03)	(0.06)
latitude2	-0.05	-0.02	-0.01	-0.02	-0.04	-0.05**	-0.08*
	(0.04)	(0.03)	(0.03)	(0.03)	(0.03)	(0.02)	(0.05)
longitude1*latitude1							0.00
							(0.84)
longitude2*latitude2							0.00
							(0.33)
				Religious variables			
lent				-0.33	-0.38*	-1.05**	-0.10
				(0.21)	(0.23)	(0.51)	(0.43)
lent*border				0.81***	0.76	0.84**	
				(0.29)	(0.30)	(0.39)	
advent				-0.73***	-0.75***	-0.56	-0.90**
				(0.20)	(0.20)	(0.50)	(0.31)
advent*border				0.38	0.38	-0.62	
				(0.39)	(0.35)	(0.47)	
lent*logremote1						-0.14	-0.73*
						(0.22)	(0.38)
lent*logremote2						0.29	0.73*
						(0.24)	(0.39)
advent*logremote1						-0.31**	-0.34
						(0.12)	(0.23)
advent*logremote2						0.25**	0.40*
						(0.12)	(0.23)
lent*water1land2							-2.97**
							(1.45)
advent*water1land2							-1.12
							(1.01)

Table 5: Determinants of Trade: OLS Regressions (second part)

Dep. Variable:				$\ln Speed_{ij}$			
lnspeed	(1)	(2)	(3)	(4)	(5)	(6)	(7)
				Time variables			
				Social and political variables			
bishop1					0.03	-0.03	-0.06
					(0.14)	(0.10)	(0.16)
bishop2					0.47***	0.37***	0.49***
					(0.14)	(0.09)	(0.14)
prince1					-0.40	-0.18	-0.40
					(0.27)	(0.19)	(0.29)
prince2					0.26	0.25*	0.25
					(0.22)	(0.14)	(0.21)
university1					-0.27*	-0.18	-0.24
					(0.16)	(0.16)	(0.23)
university2					-0.08	-0.15	-0.08
					(0.22)	(0.15)	(0.22)
				Time variables			
spring1	-0.81	-1.29	-1.25	-1.23*	-0.84	0.06	0.19
	(1.35)	(0.83)	(0.86)	(0.74)	(0.77)	(0.33)	(0.23)
summer1	-0.91	-1.31	-1.31	-1.26*	-0.84	-0.11	0.05
	(1.36)	(0.82)	(0.86)	(0.75)	(0.77)	(0.31)	(0.24)
autumn1	-1.17	-1.27	-1.35	-1.00*	-0.74	6.65***	0.19
	(1.39)	(0.87)	(0.90)	(0.80)	(0.80)	(1.77)	(0.35)
year_1346	-1.71	0.94	1.03	1.13	-1.05	11.93**	-0.35
	(1.12)	(1.04)	(1.33)	(1.10)	(1.37)	(4.19)	(2.77)
year_1347	-4.16*	1.51	1.60	1.61	-2.36	12.37**	-0.42
	(2.22)	(2.19)	(2.99)	(2.63)	(2.98)	(4.34)	(6.35)
year_1348	-3.40	2.39	2.31	1.99	-2.23	12.58**	-0.34
	(2.37)	(2.27)	(3.10)	(2.65)	(3.01)	(4.41)	(6.38)
year_1349	-2.99	2.80	2.66	2.41	-1.56	14.14**	0.31
	(2.48)	(2.37)	(3.18)	(2.70)	(3.01)	(4.42)	(6.37)
year_1350	-0.87	4.18*	4.54	4.08	0.44	-0.73**	2.33
	(2.41)	(2.26)	(3.13)	(2.70)	(3.11)	(0.31)	(6.35)
constant	6.91**	1.06	0.60	0.43	5.06*	0.01	0.52
	(2.95)	(2.37)	(2.97)	(2.67)	(3.04)	(0.21)	(6.86)
R^2	0.62	0.77	0.78	0.81	0.85	0.78	0.79
N. of observations	146	146	146	146	146	146	146
RESET test (p-value)	0.95	0.86	0.88	0.89	0.90	0.85	0.86
White test (p-value)	0.14	0.14	0.46	0.46	0.46	0.46	0.46

*; **; *** indicate significance at 10, 5 and 1% respectively.
All estimates with robust standard error clustered by the first city

6 Robustness Checks

As remarked by Silva and Tenreyro (2006), the traditional estimates of the OLS estimation techniques can be affected by several biases once the dependent variable consists of the logarithm of the positive values of T_{ij} and excludes the observations equal to zero. In the first instance, this procedure could violate the Jensen inequality biasing the estimation results. Secondly, the exclusion of the observations $T_{ij} = 0$ can raise problems related to truncation. Thirdly, the choice of different sets of explanatory variables could be not completely specified. Furthermore, the presence of heteroskedasticity can worsen those biases once the logarithmic specification is chosen. 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 start the robustness checks with controlling whether our gravity equation could be affected by nonlinearities in some regressors. In order to test for that, we perform a heteroskedasticity robust RESET test.[8] The *p*-values of this test (with values between 0.85 and 0.95 shown in the last part of Table 5) reject such misspecifications for all the models proposed and estimated with an OLS. However we find that the specifications are affected by heteroskedasticity. The last line of Table 5 reports the *p*-values of a White (1980)'s information test (Cameron and Trivedi (1992) and Wooldridge (2010)). With values between 0.14 and 0.46, we reject the hypothesis that errors obtained by the OLS regressions are not homoskedastic, suggesting that the OLS could provide some biases in our specification. Thus another type of estimation in particular considering also the "zero" observations could be more appropriate.

For these reasons we take into account also observations of city-pairs. We do not directly observe any transmission bewteen them. Beside the 146 observations already in the OLS specification, we incorporate all the possible land-trade contacts which are less than or equal to the maximum distance observed in the first cities of 146 city-pairs, all the connections of cities on waterways at a distance less or equal than 700 kilometers, and all the possible land-trade contacts which are less or equal to the maximum distance observed in the first cities. In this way we obtain a new set based on 270 observations.

We test our specifications in the following way:[9] First, we consider whether different distances used for the threshold can imply different types of potential geographical clustering due to several externality effects: we compare the White standard errors obtained by the OLS regression with the ones obtained by spatial correlation following the approach suggested by Conley (1999). Figure 6 in Appendix C shows the difference of the two measures for the coefficient related to population size (the variables *lnpop*1 and *lnpop*2) and the distance (*lndist*). We can observe that the changes in the Conley standard errors decrease monotonically over the distance considered. This confirms that our results are not affected by geographical externalities effects.[10] Finally, we consider different types of water distance between cities: if we restrict the distance on waterways between 0 and 1,100 km we get the same results in terms of sign, size and significance and the RESET test always rejects the hypothesis that the model is not specified completely. If we consider a distance higher than 1,200 km, the RESET test does not accept the hypothesis that the model is fully specified.

[8] This test, introduced by Ramsey (1969), consists in adding the square of the fitted value of the model to the original specification and in testing whether this extra regressor is significant.

[9] A different approach considering the matches between the first "infector"' city with the second "infectee"' city is often used in epidemiology (Eggo and Ferguson (2011)).

[10] Similar results are obtained for all the other variables on our specification.

In Tables 6 and 7 we compare the most complete OLS regression illustrated in the previous section (column (1)) with the other estimation techniques which allow us to consider the 270 observations. The regression in column (2) transforms the dependent variable $\ln Speed_{ij}$ (used in column (1)) into $\ln(1 + Speed_{ij})$ and provides the estimation results with an OLS. Column (3) reestimates the same regression using a Tobit technique. Furthermore, column (4) displays the estimates following the method proposed by Eaton and Tamura (1994), which differs from the standard Tobit model in the construction of the dependent variable. In this type of estimation, we consider as measure of trade intensity $\ln(a + Speed_{ij})$, where the additional estimated parameter a is assumed a sort of iceberg costs such that we obtain some bilateral activities if and only if trade is higher than this value. Finally, columns (5) and (6) show the technique introduced by Silva and Tenreyro (2006) which is based on a Pseudo Poisson Maximum Likelihood (PPML) (Gourieroux, Monfort, and Trognon (1984)) both for the 146 pairs of cities with positive dependent variable and for the entire sample. This methodology is considered to be particularly versatile in dealing with measurement errors and sample selections.

The RESET tests reported at the end of Table 7 reject in all the cases the hypothesis of any misspecification of the model. In all the cases, we can observe that all results in terms of sign and significance are almost all the time confirmed by the different types of specification-even if the distance, geographical and political variables are more significant and bigger in terms of size-suggesting the robustness of the results. First, we can observe that the coefficient obtained by the Poisson estimation are just slightly different once both the sub-sample with positive value at the dependent variable and the entire sample are taken into consideration. This suggests that the truncation of the observations with zero values has a limited impact on the estimation results. Furthermore, the geographical coordinates also turn out to be significant indicating greater intensity from East to West and from North to South. In addition, the similar results displayed by columns (5) and (6) suggest that truncation is not a relevant problem for our regression. The very last hypothesis to test is the one related to heteroskedasticity: if we increase the number of observations, another serious bias related to the estimation of the log-linearized form of the basic gravity equation can appear: when zero values on the dependent variables are added, the error term ϵ_{ijt} of (3) can depend on the other regressors. For those reasons, assuming that our best specification is the one obtained by column (6), we consider the Gauss-Newton regression (GNR) test (Davidson and MacKinnon (1994)) the Park-type test introduced by Manning and Mullahy (2001).[11] All the tests reported in Table 8 reject the hypothesis of heteroskedasticity.

[11] Those tests are based on a robust covariance matrix estimator of the equation $\frac{(T_i - \hat{T}_i)^2}{\sqrt{\hat{T}_i}} = \delta_0 \sqrt{\hat{T}_i} + \delta_0 (\delta_1 - 1)(\ln T_i)\sqrt{\hat{T}_i} + \epsilon_i$ where $\hat{T}_i$ is the estimated value of the level of speed.

Table 6: Determinants of trade: Robustness check (first part)

	(1)	(2)	(3)	(4)	(5)	(6)
Dep. Variable	$\ln Speed_{ij}$	$\ln(1 + Speed_{ij})$	$(1 + Speed_{ij})$	$(a + Speed_{ij})$	$Speed_{ij}$	$Speed_{ij}$
Estimator	OLS	OLS	TOBIT	TOBIT	PPML	PPML
			Standard gravity equation model			
lnpop1	-0.07	0.02	0.10	-0.26***	-0.05	0.06
	(0.05)	(0.04)	(0.06)	(0.06)	(0.08)	(0.08)
lnpop2	0.02	-0.04	-0.04	0.03	0.17*	0.07
	(0.04)	(0.04)	(0.06)	(0.06)	(0.07)	(0.07)
lndist	0.32***	0.15**	0.15	0.53***	0.52***	0.47***
	(0.06)	(0.05)	(0.09)	(0.08)	(0.11)	(0.12)
border	-0.29**	-0.16*	-0.50***	0.17	-0.60***	-0.69***
	(0.10)	(0.07)	(0.12)	(0.11)	(0.16)	(0.16)
noeurope	-0.31	0.67	1.05	-1.15*	-1.41*	-1.08
	(0.38)	(0.48)	(0.55)	(0.52)	(0.61)	(0.61)
			Geographical variables			
waterway	0.81***	1.09***	1.33***	0.91***	1.21***	1.82***
	(0.11)	(0.11)	(0.16)	(0.15)	(0.19)	(0.19)
lndistsea1	0.22*	0.11	0.30*	0.11	0.21	0.39***
	(0.09)	(0.14)	(0.14)	(0.12)	(0.12)	(0.12)
lndistsea2	-0.20*	0.07	-0.07	-0.09	-0.26*	-0.24*
	(0.09)	(0.13)	(0.13)	(0.11)	(0.11)	(0.11)
lnelevation1	0.02	0.02	0.06	0.00	0.05	0.19**
	(0.04)	(0.02)	(0.05)	(0.04)	(0.06)	(0.06)
lnelevation2	0.00	-0.02	-0.03	-0.01	-0.01	-0.02
	(0.02)	(0.02)	(0.03)	(0.03)	(0.04)	(0.04)
water1land2	0.78	0.43	1.30*	0.30	0.58	1.65**
	(0.43)	(0.60)	(0.64)	(0.54)	(0.61)	(0.59)
water2land1	-1.33**	0.56	-0.39	-1.08	-2.08**	-1.84**
	(0.50)	(0.70)	(0.78)	(0.64)	(0.70)	(0.71)
longitude1	0.08	0.33**	0.52***	-0.05	0.01	0.58***
	(0.11)	(0.10)	(0.14)	(0.14)	(0.17)	(0.16)
longitude2	-0.06	-0.36***	-0.51***	0.08	0.12	-0.34**
	(0.08)	(0.09)	(0.11)	(0.12)	(0.13)	(0.11)
latitude1	0.02	0.03	0.06	-0.03	0.03	0.05
	(0.03)	(0.03)	(0.04)	(0.04)	(0.04)	(0.04)
latitude2	-0.05*	-0.04	-0.05	-0.06	-0.08*	-0.08*
	(0.02)	(0.03)	(0.03)	(0.03)	(0.03)	(0.03)
longitude1*latitude1	-0.00	-0.01***	-0.01***	0.00	0.00	-0.01***
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
longitude2*latitude2	0.00	0.01***	0.01***	-0.00	-0.00	0.01*
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
			Religious variables			
lent	-0.19	-0.47	-0.95**	0.69	0.01	-0.65
	(0.29)	(0.24)	(0.35)	(0.39)	(0.47)	(0.46)
advent	-0.53*	-0.47*	-0.63*	-0.82**	-0.84**	-1.01***
	(0.22)	(0.21)	(0.25)	(0.28)	(0.31)	(0.27)
lent*logremote1	-0.58*	-0.22	-1.10**	0.01	-0.66	-1.16*
	(0.26)	(0.16)	(0.34)	(0.21)	(0.44)	(0.47)
lent*logremote2	0.61*	0.31	1.28***	-0.16	0.67	1.28**
	(0.27)	(0.16)	(0.35)	(0.20)	(0.44)	(0.46)
advent*logremote1	-0.25	-0.17	-0.41	-0.06	-0.20	-0.01
	(0.16)	(0.19)	(0.23)	(0.21)	(0.26)	(0.28)
advent*logremote2	0.29	0.20	0.43	0.16	0.22	-0.02
	(0.16)	(0.19)	(0.23)	(0.20)	(0.27)	(0.28)
lent*water1land2	-2.10*	-0.65	-3.95**	-0.15	-16.10	-16.75
	(0.99)	(0.64)	(1.33)	(0.86)	(847.58)	(515.21)
advent*water1land2	-0.77	-0.28	-1.03	-0.10	-0.16	1.50
	(0.69)	(0.78)	(1.00)	(0.87)	(1.40)	(1.46)

Table 7: Determinants of trade: Robustness check (second part)

	(1)	(2)	(3)	(4)	(5)	(6)
Dep. Variable	$\ln Speed_{ij}$	$\ln(1+Speed_{ij})$	$(1+Speed_{ij})$	$(a+Speed_{ij})$	$Speed_{ij}$	$Speed_{ij}$
Estimator	OLS	OLS	TOBIT	TOBIT	PPML	PPML
			Social and political variables			
bishop1	-0.03	0.03	-0.05	0.20	-0.26	-0.04
	(0.10)	(0.11)	(0.14)	(0.13)	(0.17)	(0.16)
bishop2	0.37***	0.27**	0.40***	0.30**	0.59***	0.55***
	(0.09)	(0.10)	(0.13)	(0.12)	(0.15)	(0.15)
prince1	-0.18	0.77***	1.29***	-0.82***	-0.33	1.24***
	(0.19)	(0.18)	(0.24)	(0.25)	(0.33)	(0.25)
prince2	0.25*	-0.27**	-0.61***	0.49**	0.45**	-0.51**
	(0.14)	(0.12)	(0.18)	(0.19)	(0.22)	(0.20)
university1	-0.18	-0.19**	-0.36	-0.01	-0.38	-0.73**
	(0.16)	(0.09)	(0.22)	(0.19)	(0.32)	(0.31)
university2	-0.15	-0.05	-0.01	-0.29	-0.22	0.01
	(0.15)	(0.13)	(0.19)	(0.18)	(0.22)	(0.21)
			Time variables			
autumn1	0.10	0.25	0.46	-0.12	0.16	0.26
	(0.23)	(0.22)	(0.34)	(0.28)	(0.49)	(0.50)
spring1	0.12	0.18	0.19	0.23	0.05	0.06
	(0.16)	(0.18)	(0.82)	(0.20)	(0.33)	(0.33)
summer1	0.04	0.08	-0.01	0.20	-0.06	-0.11
	(0.16)	(0.17)	(0.23)	(0.20)	(0.33)	(0.31)
year1 1346	-0.28	3.21***	5.50***	-2.95	0.14	6.65***
	(1.49)	(1.20)	(2.25)	(2.10)	(1.93)	(1.77)
year1 1347	-1.09	6.50**	11.15***	-6.64	-1.17	11.93**
	(3.53)	(2.70)	(5.90)	(4.99)	(4.44)	(4.19)
year1 1348	-1.05	6.79**	11.61**	-6.85	-1.11	12.37**
	(3.59)	(2.75)	(5.96)	(5.06)	(4.62)	(4.34)
year1 1349	-0.53	7.07**	11.97**	-6.34	-0.45	12.58**
	(3.61)	(2.80)	(6.00)	(5.09)	(4.65)	(4.41)
year1 1350	0.81	8.50**	13.44***	-4.55	0.44	14.14**
	(3.64)	(2.72)	(6.03)	(5.12)	(4.71)	(4.42)
Constant	2.56	-6.40**	4.00	10.39*	-1.95	-17.57***
	(3.57)	(3.03)	(4.36)	(4.96)	(4.61)	(4.24)
R^2	0.78	0.67	0.38	0.41	0.62	0.65
RESET test (p-value)	0.78	0.79	0.79	0.91	0.02	0.22
N. of observations	146	270	270	270	146	270

*; **; *** indicate significance at 10, 5 and 1% respectively.
All estimates with robust standard error clustered by the first city

Table 8: GNR and Park test for heteroskedasticity

Test	146 obs.	270 obs.
GNR ($V\left[T_{ij}\|x\right] \alpha\mu\left(x\beta\right)$)	0.02	0.02
Park	0.00	0.00

7 Geographical Effect on Trade

In this section we study trade effects determined by the geographical coordinates of longitude and latitude in more detail. So far we could disentangle many different factors, which drive medieval trade. A specific emphasis in historical studies has been put on the different economic developments of different regions in Europe and the Mediterranean area. As pointed out earlier, the Late Middle Ages were a period of catching up (or even overtaking) of Western Europe compared to the African and Eastern Mediterranean area. This brings us to the question if we can identify different speeds of inflows, outflows, and net flows in different parts of Europe and the Mediterranean area for the period of investigation. Furthermore, we have found that marginal effects of distance are crucial in determining the speed of transmission. Thus, we need to check if this "far distance trade effect" plays a different role in different regions.

The Mediterranean area and especially the Italian trading area have been recognized as central to trade activities (Lopez (1976) and Epstein (2000b)). In comparison, the East Mediterranean was found to have entered a phase of economic decline (Lewis (2002) and Kuran (2003)). Egypt and the Byzantine empire were rich, but started to become politically backwards and less technology-friendly (Runciman (1952)). For example, the area was swamped by textile products from Northwest Europe, in particular from Flanders. Their own textile production was in decline. Only spices and silk were still traded to the West. North Africa and Tunisia were strongly linked to Italy and imported many goods from there. Tunisia and neighboring African areas could rely on easy accessible gold streams from the South. This access supported strong consumption and has been identified as a source of economic stagnation (Abulafia (1952)). In contrast, Northwest Europe, especially Flanders, neighboring French areas and England were enjoying an economic upswing (Postan (1952)). The same is true, even somewhat slower and timely shifted back for South and Western Germany (Kellenbenz (1980)), Bohemia, and Selesia (Malowist (1952)). Romania and Moldavia as connections between the Black Sea and land trade routes to Central/ West Europe started to play a vital economic role (Stefanescu (1980)). France played an important role as a link between Italy and Flanders (Favier (1980)). Spain was partly backward, however along the Mediterranean coast was economically well developed. Catalonia was a critical factor in Mediterranean trade (Suarez Fernandez (1980)).

In order to create geographical predictions for trade flows we consider the last specification estimation of Table 7. The upper part of Figures 2, 3 show the predictions of the speed of the disease for the infector and the infectee, which we use as proxy for inflows and outflows. The lower part shows instead the marginal fixed effects of distance on the speed of the speed along the range of the different coordinates, i.e. how much the speed of dispersion can increase or decrease once the value of $lndist$ is increased by one unit. In addition, Figures 4 and 5 display the net effect, i.e. the difference of inflows and outflows, of Figures 2 and 3. The colors follows a rainbow scale, while the color white cover non significant areas. Furthermore, those predictions are measured on a scale of 10 meters in order to make the graphs clearer.

These figures depict the following results. We find fast outflows for water and land trade in England, North of France, the Netherlands, and neighboring areas in west Germany. Significant geographical effects can be measured for all over Western Europe inclusive Italy, and parts of the Iberian Peninsula (except the very South West of Spain and Portugal). Significant effects can also be measured in Eastern Europe up to the north until Silesia, Bohemia and big parts of Germany, to the South until Serbia and Romania. In addition we find marginal effects in the Mediterranean parts of Algeria and Tunisia. For inflows we find significant effects in Italy and all the Eastern Mediterranean area. In particular strong are the geographical effects along the North African coast line area around Tunisia and neighboring areas. Analogue to these findings, we find distance effects for land and water trade in those geographical areas. The marginal distance effects for outgoing flows are strong in Northwest Europe, and for the incoming flows strong in the Eastern Mediterranean area. Finally if we net all these effects we find faster outflows from North West Europe. This positive net outflow results still hold up to the very north of Italy, although the results are much weaker. Italy has in general close to balanced trade flows (measured as the speed of outflows minus inflows) but with a tendency towards faster inflows. Finally for the Eastern Mediterranean areas we can measure stronger inflows, again with particular fast inflows in the areas around Tunisia. The long distance effects again confirm the picture. Thus, although these results rely on simulated estimators, and we have to be careful not to over interpret these findings, they confirm the thesis by medieval historians: Uprising economic areas like the North West of Europe have faster trade outflows than incoming streams. Conversely, stagnating areas with high consumption, like the Eastern Mediterranean areas have faster incoming than outgoing trade streams. Areas with recognized both streams of production and consumption can be characterized by close to even net flows such as Italy.

Figure 2: Trade along waterways: Outflows and inflows of predictions (upper part) and marginal fixed effect with respect to distance (lower part)

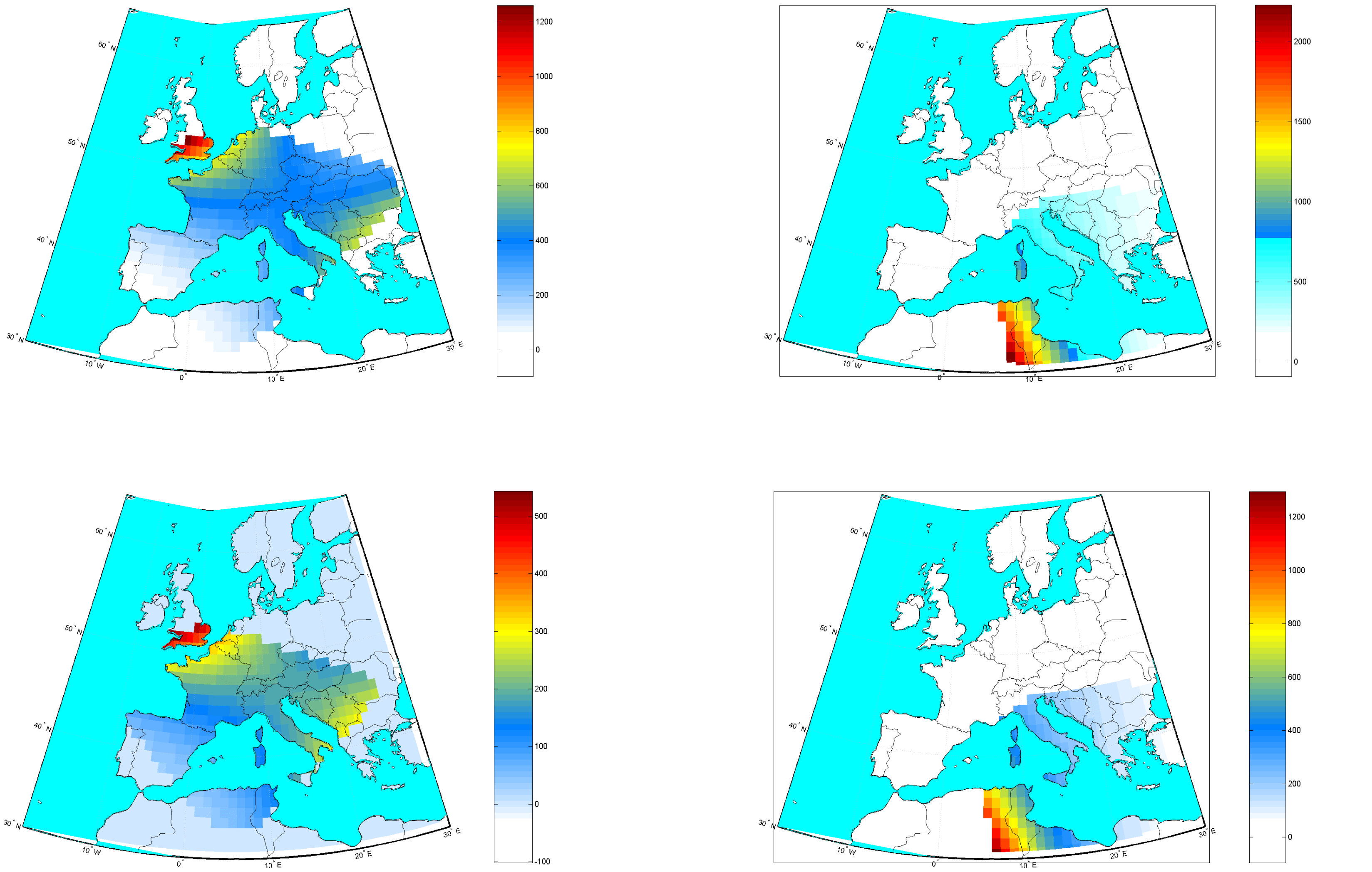


Figure 3: Trade along land: Outflows and inflows of predictions (upper part) and marginal fixed effect with respect to distance (lower part)

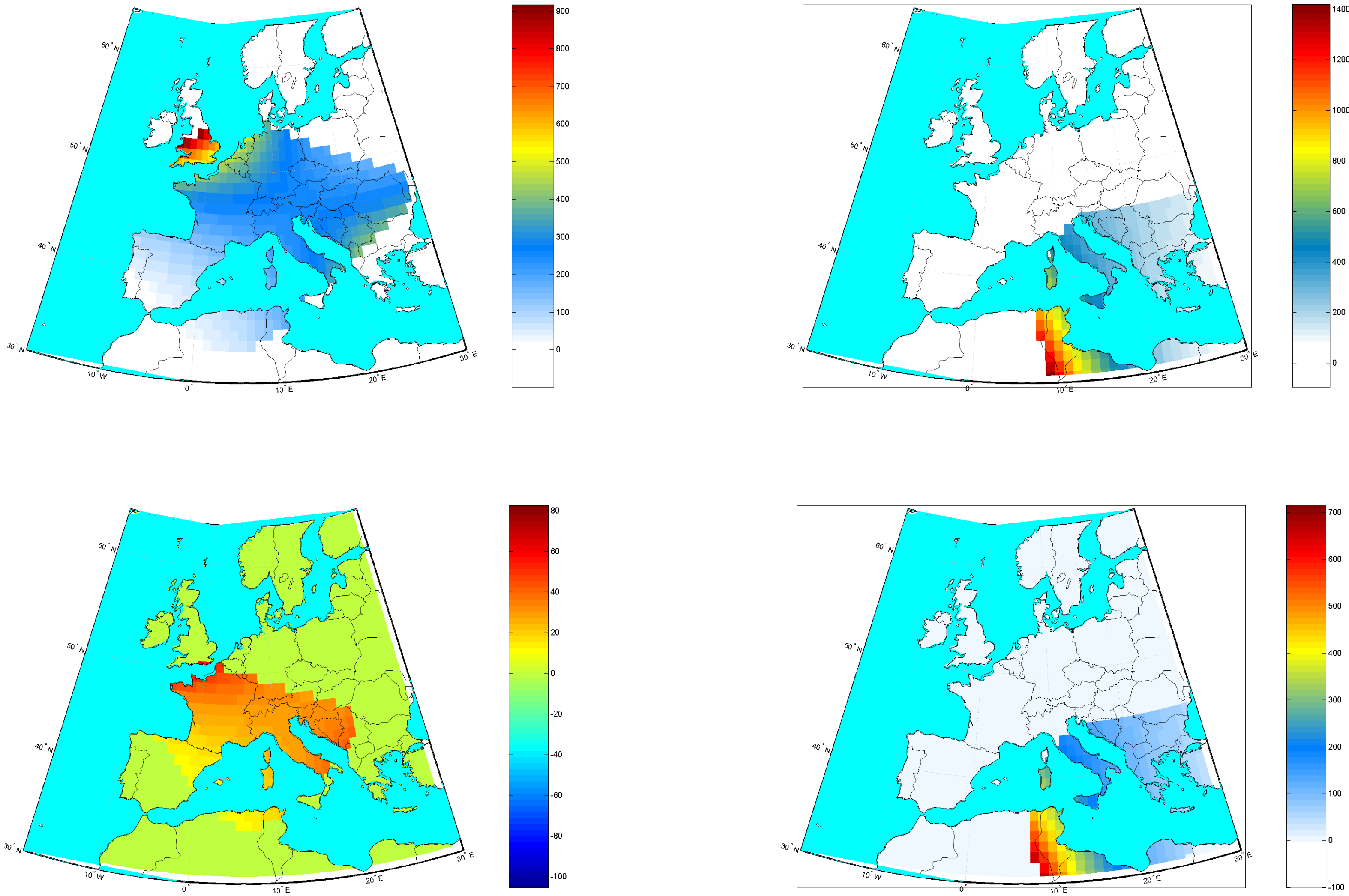
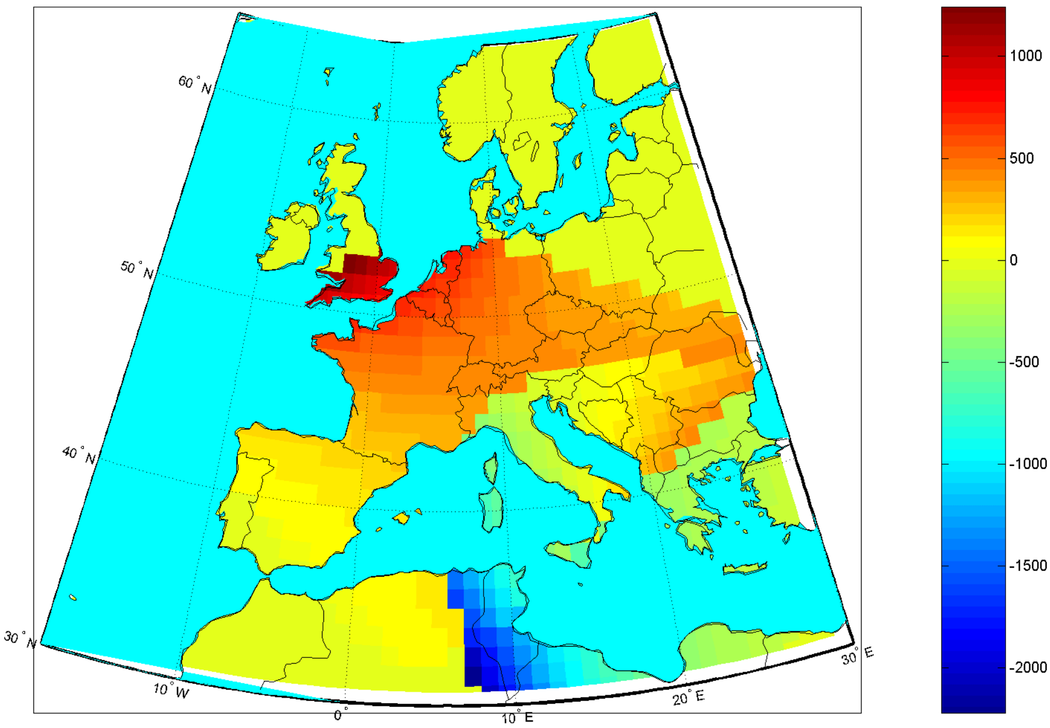


Figure 4: Trade along waterways: Net values of predictions (upper part) and marginal fixed effect with respect to distance (lower part)



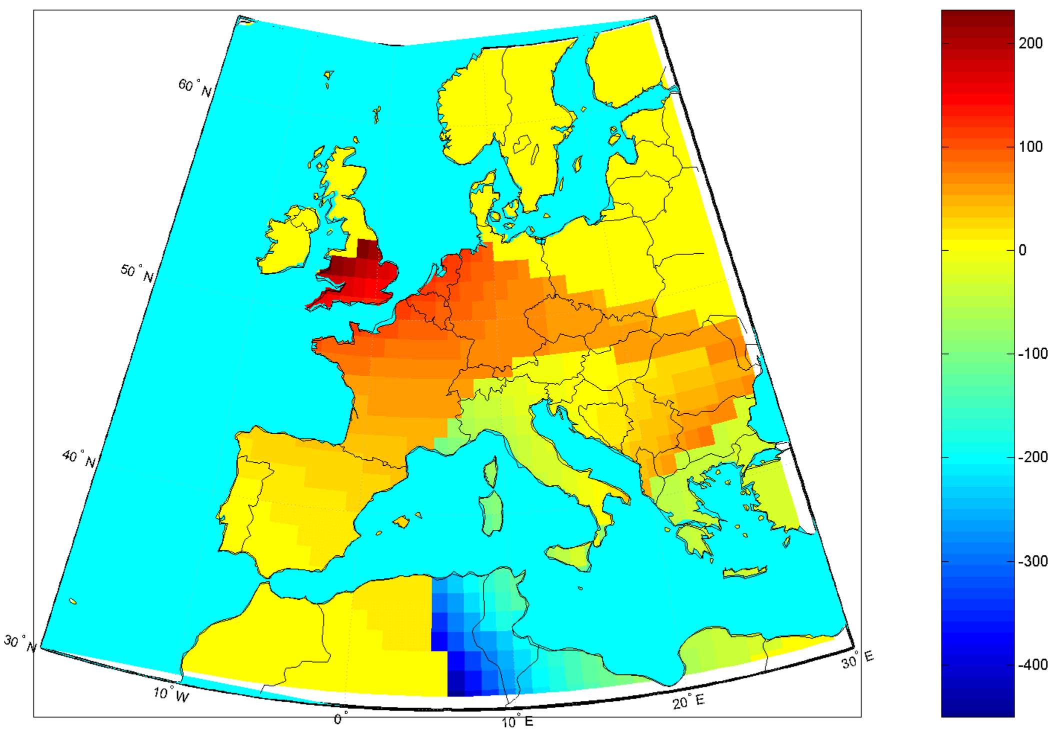
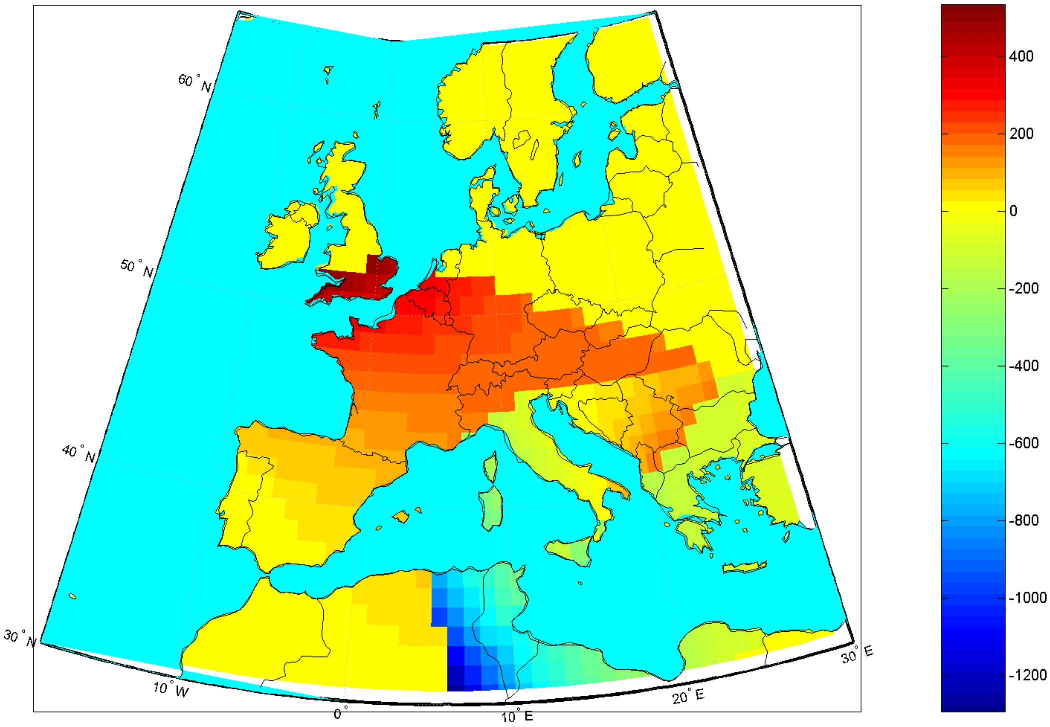
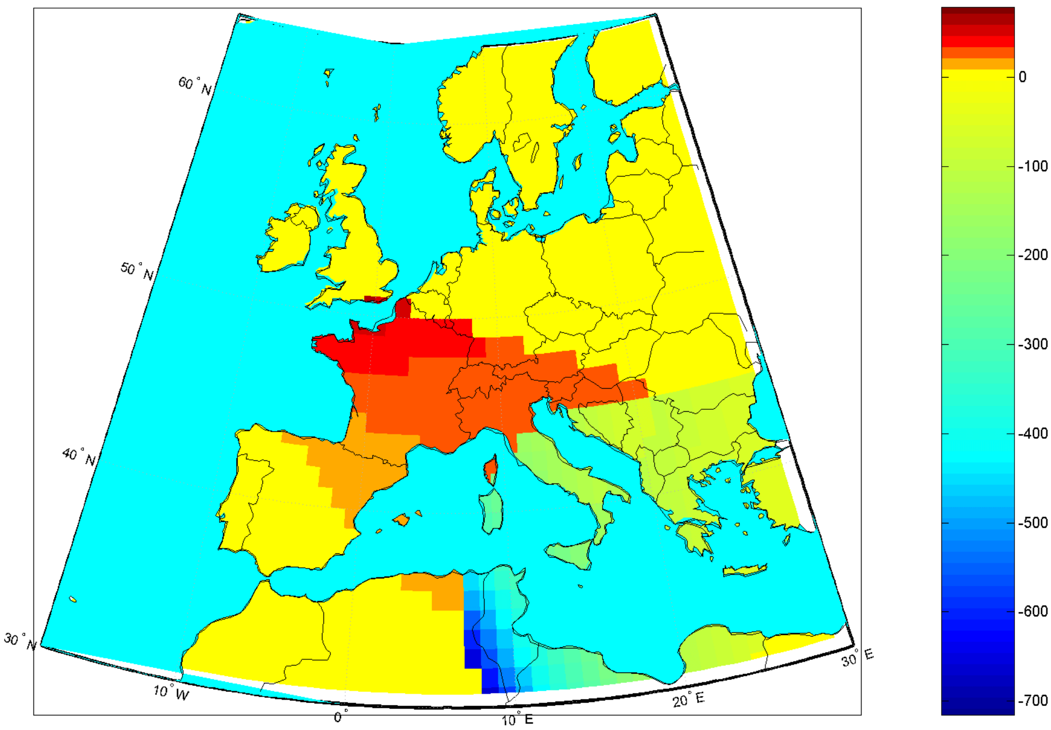


Figure 5: Trade along land: Net values of predictions (upper part) and net and sum of marginal fixed effect with respect to distance (lower part)





8 Conclusion

This paper studied medieval trade flows based on the spread of the Black Death from 1347-1351 in Europe. We used the speed of the transmission of the plague from one city to the next as a proxy to identify the intensity of trade between these two cities. This way we created a set of approximately 146 city-pairs from Europe and the Mediterranean area to identify the intensity of trade. Our main findings are that the speed of trade depends on the means of transportation, the distance, the political borders, religious holidays, and the institutional function of a city.

To arrive at these conclusions, we introduced a modified gravity model where the speed (in kilometers per day) is the dependent variable. We identified a set of dependent variables which are based on the findings of medieval economic historians, who used qualitative observations of what determined trade and on the insights of empirical trade economists who estimated significant variables which influence trade flows. We run several variations of this modified gravity equation and made several robustness checks: we started with a simple OLS-regression and corrected for the standard error by the robustness methodology by White (1980) and by Conley (1999). Next we introduced several types of Tobit estimation techniques to control for unobservable data sets. This way we enlarged the data set to more than 270 observations. Beside the standard Tobit technique we also used the methods by Eaton and Tamura (1994) and Silva and Tenreyro (2006).

Based on these estimation techniques, we showed that water transportation on rivers and seas was faster than along land trade routes. Political borderlines slowed the speed. Furthermore, we found that distance had a positive impact of the speed of transmission. In addition we showed that the religious holidays of Advent and Lent slowed down trade and concluded that political residential cities, in particular bishop cities had a significantly faster inflow. City size (used as a medieval proxy for economic size) played a negative or non significant role in determining the speed of transmission. Finally, we showed that the speed of inflow, outflow, and net speed (inflow minus outflow) depend on the geographical location of a place. We found high speeds in the Mediterranean area and in Northwest Europe. We detected strong outflows from North West Europe and strong inflows into the Eastern Mediterranean area and North Africa. Similar geographical effects we also found for the distance effects between two cities. Regions with fast receiving and transmitting rates had strong positive distance effects.

These results allow us for the first time to quantify medieval trade flows on an aggregate level. We can confirm findings by medieval economic historians that trade on water transport routes was much faster and more intensive (Postan (1952)), and that political borderlines were a major impediment to medieval trade. North and Thomas (1973) We can back up the argument that long distance trade was the critical factor in medieval trade (Braudel (1949), Lopez (1952 and 1976), Cipolla (1993)). We can identify religious holidays and political functionality as determinant for late medieval trade flows, which both have not been taken into consideration to explain trade flows in the literature. Furthermore, the geographical effects confirm the thesis that the Late Middle Age was the crucial period for the rise of North Western Europe and the beginning decline of North Africa and the Eastern Mediterranean area. This way our findings contribute to early triggers of the Great Divergence of Western Europe from other parts of the world.Pomeranz (2001) Finally, the results of the negative impact of city size and positive impact on distance also confirm insights by urban economists (Von Thunen (1826), Krugman (1991) and Ades and Glaeser (1995)).

Furthermore, with the application of the gravity model to data in epidemics we contribute to a small but growing literature which study channels of communication and economic activities in the context of or in relation to epidemics (Bettencourt, Lobo, Strumsky, and West (2007) Oster (2007) and Bettencourt and West (2010) Viboud and al. (2006)). Such a link can be useful when quantitative data are missing or can be used as a complementary approach to study trade flows and other social interaction effects.

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Appendix A: Data Sources

Geographical Transmission of the Black Death

We collect and elaborate the geographical transmission and the timing of the Black Death in Europe from different sources: the data are mainly constructed following the information contained in Biraben (1975) and Benedictow (2004). Data on dispersion on non European countries are collected from Dols (1977) and Borsch (2005). Additional observations for Italy and Germany are obtained by Corradi (1865), Hoeniger (1881), Del Panta (1980) and Fössel (1987).

Standard Gravity Model and Geographical Variables

Data of urban population during 1300 are taken by Bairoch, Batou, and Chévre (1992), Chandler (1987) and Malanima (1998). We also collect data on geographical location (i.e., longitude and latitude) and on altitude from Nunn and Puga (2011). The variables *lndist*, *lndistsea*1 and *lndistsea*2 are computed as geodesic distances between a pair of coordinated on the surface of the Earth assuming no elevation. We define that trade across a border if the pair of cities belongs to different areas. Table 9 displays the list of regions. Definitions on political regions, rivers and water ports are mainly obtained by McEvedy and Woodrofe (1992).

Social and Political Variables

We consider data on the presence of a bishop before the Black Death from Jedin, Latourette, and Martin (1970) and Magosci (1993) and integrated by Wikipedia (`www.wikipedia.org`). The different classifications of Western European Régimes is derived from De Long and Shleifer (1993) at 1330. Finally, pieces of information on university sites are taken from Sheperd (1911) and Darby (1970).

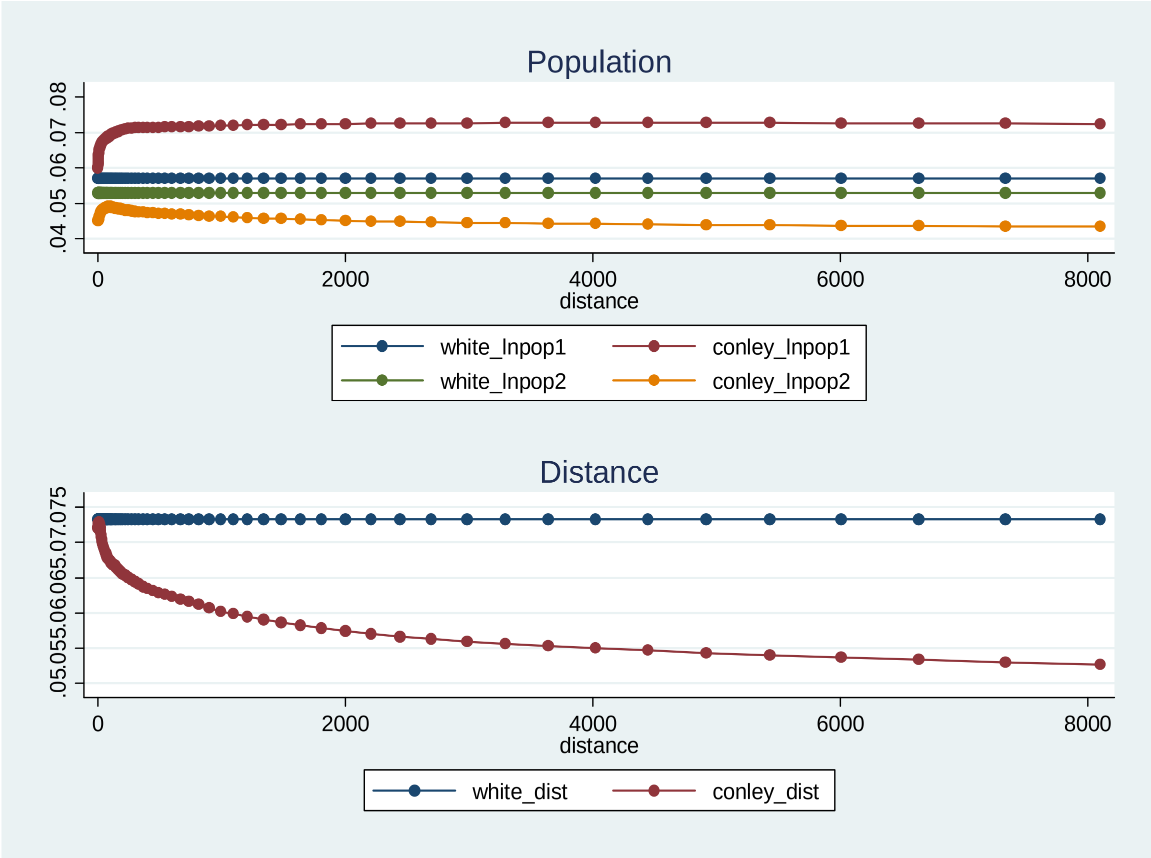
Appendix B: Regions considered

Table 9: List of regions

Region	N. of Obs.	Region	N. of Obs.	Region	N. of Obs.
Europe		*Ancona*	3	*Castilla*	1
Denmark	2	*Este*	5	*Crown of Aragon*	15
Kingdom of Denmark	2	*Florence*	6	*Kingdom of Granada*	1
England	6	*Giudicato di Arborea*	3	**Switzerland**	4
Kingdom of England	6	*Milan*	15	*Basel*	1
France	24	*Padoa*	1	*Bern*	1
Bordeaux	1	*Papal State*	2	*Geneva*	1
County of Provence	3	*Perugia*	1	*Luzern*	1
Holy Empire	2	*Kingdom of Sicily*	27	**Turkey**	2
Kingdom of France	18	*Kingdom of Sicily in Naples*	2	*Ottoman Empire*	2
Lordship of House of Burgundy	1	*Republic of Genoa*	2	**Ukraina**	1
Germany	16	*Romagna*	2	*Republic of Genoa*	1
Cologne	1	**the Netherlands**	3	**Non Europe**	
Hausburg Dominion	2	*Friesland*	1	**Egypt**	4
Holy Empire	9	*Holland-Hainaut*	2	*Egypt*	4
Lower Bavaria	2	**Norway**	3	**Iran**	1
Mainz	1	*Kingdom of Norway*	3	*Persia*	1
Trier	1	**Poland**	1	**Iraq**	1
Ireland	2	*Wolgast*	1	*Persia*	1
Mouth	1	**Portugal**	1	**Morocco**	1
Ormonde	1	*Coimbra*	1	*Northern Africa*	1
Italy	69	**Spain**	17		

Appendix C

Figure 6: White and Conley standard errors for population size and distance



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