Bones, Bacteria and Break Points: The Heterogeneous Spatial Effects of the Black Death and Long-Run Growth

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Abstract: The Black Death killed approximately 40% of Europe’s population between 1347-1353. Recent studies suggest that this mortality shock played a major role in shifting Europe onto a path to sustained economic growth. Using a novel dataset that provides information on spatial variation in plague mortality, we explore the short-run and long-run impact of the Black Death on city growth. We find evidence for aggregate convergence. On average, Europe’s cities recovered their pre-Black Death population within two centuries. However, there was considerable heterogeneity in the response to the shock. The Black Death led to the creation of new cities in areas that were relatively less urbanized before it hit. Furthermore, the Black Death led to an urban reset: cities with better geographical and non-geographical endowments relatively benefited, while other cities collapsed. Our analysis thus suggests that the Black Death may have permanently affected the aggregate level and spatial distribution of economic activity, potentially contributing to long-run growth in Europe.

Key words: Black Death; Demographic Regime; Multiple Equilibria; Malthus to Solow; Urbanization; Little Divergence; Epidemics; Path Dependence; Urban Reset; Long-Run Growth

JEL classification: D5, J1, N00, O1, R1

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1. INTRODUCTION

The Black Death was the greatest demographic shock in European history: approximately 40% of the population died in just 5 years. In many recent accounts of the Great Divergence, the Black Death plays a crucial role in explaining the economic rise of western Europe (Voigtländer & Voth, 2013b,a). However, to our knowledge, no existing research makes use of actual city-level data on the demographic impact of the Black Death to study subsequent local economic development across all of western Europe. This is the objective of this paper.

We construct a novel dataset combining estimates of Black Death mortality, city populations, and numerous geographic, economic and institutional variables to study both the short-run and long-run impact of the Black Death on urban growth and hence on economic development. These data allow us to test several theories of the role the Black Death played in subsequent economic growth as well as theories about the spatial evolution of economic activity across time. First, we establish that there was aggregate convergence from the Black Death but local divergence. The effects of the Black Death were highly heterogeneous: while some cities did not recover their pre-Black Death populations until the 19th century, the Black Death stimulated city growth in areas that were previously predominantly rural. Second, we test whether locational fundamentals, increasing returns, or institutions explain long-run patterns of urban settlement. We find evidence for the importance of increasing returns and institutions. The Black Death was not just a one-off mortality shock: it changed the aggregate level and spatial distribution of economic activity in Europe.

We contribute to three literatures. First, we build on work on the origins of long-run economic growth in premodern Europe. In growth theory demographic shocks play a dual role. Population growth promotes economic growth if high population densities encourage human capital accumulation or technological progress (Kremer, 1993; Lagerlöf, 2003; Becker et al., 1999). However, population growth has a negative effect on per capita income if land or capital is inelastically supplied. In such a Malthusian environment any positive income shock is temporary; fertility increases and mortality decreases, so that any increases in the stock of capital (and income) per capital are eventually negated. Income is stable and low in the long-run (Ashraf & Galor, 2011). Countries only achieve sustained economic growth if the pace of technological development is sufficient to induce investment in human capital and if, in the long-run, a demographic transition limits population growth (Galor & Weil, 2000; Hansen & Prescott, 2002; Galor, 2011). In models of unified growth, a demographic shock like the Black Death can increase incomes sufficiently to accelerate the transition from a Malthusian to a post-Malthusian economy.

Numerous scholars have argued that the Black Death marks a watershed in European history, after
which it is possible to detect trends that would eventually led to the onset of sustained economic growth.\footnote{See Gottfried (1983); Herlihy (1997); Epstein (2000); Pamuk (2007) for historical accounts that emphasize the centrality of the Black Death to the eventual economic rise of western Europe. Epstein, for example, argues that the Black Death was the ‘exogenous event which contributed to the feudal economy’s transition from a low level ‘equilibrium trap’ to a higher growth path’ (Epstein, 2000, 54).} Acemoglu & Robinson (2012) argue that ‘the Black Death is a vivid example of a critical junction, a major event of confluence of factors disrupting the existing economic or political balance in society’; they claim that this shock helped lead the emergence of more inclusive institutions in England while cementing the existence of extractive institutions in Eastern Europe.\footnote{This argument was originally developed by Brenner (1976) and is the subject of a considerable historiography (Ashton & Philpin, 1985).} Our use of finely grained city-level data which covers all of Europe over many centuries allows us to shed light on the Black Death’s contribution to the Little Divergence that took place between northwestern Europe from southern Europe after 1400 (Allen, 2001; Acemoglu et al., 2005; van Zanden, 2009; Broadberry, 2013).

Two recent papers lay out the theoretical mechanisms that explain how the Black Death could have set north-western Europe on a different growth path. Voigtländer & Voth (2013b) construct a model in which a shock that raised per capita income like the Black Death could have moved Europe into a different, permanently higher income, equilibrium. Greater demand for manufactured goods produced in cities and an intensification in warfare further contributed to higher levels of urbanization. As cities had higher death rates, they argue that this produced a ‘horsemen effect’—an s-shaped income-death schedule—which enabled premodern Europe to attain higher per capita income in the pre-industrial period. We make a novel contribution to this literature by taking this theory to the microlevel, using a novel dataset of plague mortality. By using city-level data, we are able to better identify the effects of the Black Death on economic development, thereby providing confirmation at the micro-level for some of the main macro-level predictions of Voigtländer & Voth (2013b).

In another paper, Voigtländer & Voth (2013a) argue that the demographic shock of the Black Death had a different effect in northern Europe—where the land could now be turned over to pastoral agriculture—than in southern Europe where the land was more suited to arable farming. As pastoral farming increased the demand for female labor, this contributed to a labor and marriage market equilibrium in which individuals married late and restricted fertility (the European marriage pattern); a phenomenon that in turn raised per capita incomes.\footnote{The European marriage pattern or EMP is studied by Hajnal (1965); Macfarlane (1986); Moor & Zanden (2010). Voigtländer & Voth (2013a) build on the argument of Kussmaul (1985) that pastoral agriculture provided the economic incentives necessary to maintain the EMP.} They argue that this helped give rise to the Little Divergence in incomes that took place between northern Europe and southern and
eastern Europe in the period between 1400 and 1800.

The second literature that we contribute to is the literature on shocks and long-run persistence in economic development. A number of important recent contributions to this literature have demonstrated that demographic shocks can have long-run impacts (Young, 2005; Acemoglu & Johnson, 2007; Nunn, 2008; Bloom et al., 2014). The Black Death differs from the mortality shocks previously considered in the literature in its magnitude—an overall mortality rate of 40% dwarfs other mortality shocks that we are aware of such as the 1919 influenza pandemic which killed between 3-5% of the world's population or World War Two which killed approximately 3.7%.

We explore both the short-run and the long-run economic impact of the Black Death. Our main finding is that, while there was aggregate convergence within three centuries, at a local level the effects of the Black Death were highly heterogeneous.

The Black Death is also different to other types of shocks associated with warfare or bombings because it was a purely demographic that left man-made capital untouched. In this respect our setting has some resemblance to papers that study the impact of the Holocaust (Acemoglu et al., 2011) or large scale expulsions of population. Acemoglu et al. (2011) find that the Holocaust had negative long-term economic effects as Jews comprised a large proportion of the middle class throughout the Soviet Union. Chaney & Hornbeck (2015) find that the expulsion of the Morisco’s had a positive impact on per capita income because it made more land available. Similarly, Jebwab et al. (2015) do not find a negative effect associated with the expulsions of European and Asian settlers in Kenya. Unlike the expulsion of Jewish or Muslim populations, however, the Black Death did not target a specific group, but affected the entire economic. This aspect of our analysis has important implications for considering the potential impact of modern pandemic diseases such as Aids and malaria which have had a noticeable demographic impact in sub-Saharan Africa (Piot et al., 2001; Sachs & Malaney, 2002; Young, 2005; Weil, 2014). It thus connects with a literature on the

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4 Estimates for the total numbers killed in World War 2 (1937-1945) vary between 61 and 80 million. The larger number would represent approximately 3.7% of world population at the time which is small compared to the Black Death. Obviously, the mortality rate in selected countries was much higher: approximately 8% in the borders of prewar Germany, and as high as 13.7 % in the 1941 borders of the Soviet Union and 17% in Poland. Nevertheless, even these numbers are significantly lower than the estimates that exist for the Black Death. Other major mortality shocks include the Ukrainian and Chinese famines of the mid-twentieth century Death tolls in both famines are controversial. Recent estimates for mortality in the Ukrainian famine of 1931-1933 are around 4 million or approximately 10% of the population (see Snyder, 2010). Estimates for the Chinese Great Famine (1959-1961) range from 16.5 to 45 million or between 2.5 and 6.8% of the population (Meng et al., 2015). During the Bengal famine of 1943 about 6.6% of Bengal’s population died. The worst genocides in recent history are responsible for comparable loss of life. For example, about 11% of Rwanda’s population was killed in 1994 and 25% of Cambodia’s population during the rule of Pol Pot. These death tolls are significantly smaller as a fraction of the population than the Black Death.

5 Studies of the impact of expulsions of Jews from Nazi Germany include Akbulut-Yuksel & Yuksel (2015) on human capital; Waldinger (2010, 2012) on scientific output. These studies are less directly comparable to ours as the numbers involved were much smaller.
consequences of both recent diseases (Almond, 2006; Bleakley & Lange, 2009; Alsan, 2015) and the historical impact of pandemic diseases (Findlay & Lundahl, 2006; Bosker, Brakman, Garretson, Jogn & Schramm, 2008; Alfani, 2013).

Third, our analysis contributes to the literature on determinants of long-run urban development. This literature finds episodes where large shocks do not change the spatial distribution of economic activity and cases where shocks do lead to urban reset. Prominent theories in economic geography suggest that this depends on whether locational fundamentals (i.e. physical geography), increasing returns (i.e. economic geography) or institutions determine the location of cities. If locational fundamentals dominate then there is a unique equilibrium location for a given set of cities and economic activity will be centered around these locations irrespective of demographic shocks no matter how large they are. But in the presence of increasing returns, multiple equilibria may exist and a large enough shock can cause the spatial system to reset (e.g. Krugman, 1991a,b).

Davis & Weinstein (2002)’s seminal study of Japanese urban development in the aftermath of World War 2 provides evidence for the importance of locational fundamentals. In particular they show that after experiencing complete destruction, both Hiroshima and Nagasaki returned to the same relative positions in Japan’s distribution of cities within 20 years. Similarly, Glocker & Sturm (2014) and Miguel & Roland (2011) study the wartime destruction of German and Vietnam respectively, to test how these shocks affected the relative ranking of cities. Miguel & Roland (2011) find rapid rates of recovery and convergence suggesting a high degree of persistence in urban location. Maloney & Caicedo (2015) also find a high degree of persistence in the location of economic activity in the New World between the precolonial period and today.

Other research, however, demonstrate the importance of increasing returns in enabling local shocks to have permanent spatial effects (Bosker et al., 2007; Bosker, Brakman, Garretsen & Schramm, 2008; Redding et al., 2011; Bleakley & Lin, 2012). For example, Rauch & Michaels (2013) contrast England, where the urban network was reset after the Fall of the Roman Empire, with France, where Roman city locations remained settled throughout the early middle ages. They argue that the locations of French cities may have been shaped by path dependence and hence were inferior from the point of view of subsequent economic development. In England, however, the urban network was reset allowing English cities to relocate along coasts and rivers that were more beneficial for economic activity in subsequent centuries.

There is also evidence that institutions play a role in determining how shocks affect economic outcomes and particularly urban development. Acemoglu et al. (2005) show that the discovery of the Atlantic stimulated economic development in those countries where the power of the sovereign
was initially weak (England, the Netherlands) but not where he was initially powerful (Spain and Portugal). Campante & Glaeser (2009) argues that the contrasting developmental paths of Buenos Aires and Chicago in the twentieth centuries can be partly explained in terms of differing political institutions. Nunn & Qian (2011) examine the differential impact that the integration of the potato into European agriculture stimulated urban growth in those parts of Europe most suitable for growing potatoes. Nunn & Puga (2012) demonstrates that in the presence of an extractive institution like slavery, 'bad' geography—in this case ruggedness—could be beneficial in sub-Saharan Africa. Finally, Dincecco & Onorato (2015) studies the effects of war in stimulating urban development in preindustrial Europe.

Relative to this literature, a major contribution of our paper is that we exploit a shock that was exogenous at a local level (something that is not necessarily the case with wars of the discovery of the Atlantic. Furthermore, by studying a shock that killed people but did not destroy physical capital, we have an ideal framework to study the impact of a demographic shock in a Malthusian environment. Finally, our analysis allows us to speak to the ‘optimally’ of urban reset. Rauch & Michaels (2013) argue that the persistence of the Roman network in France was inefficient. One problem is that is that there are costs of switching to a new urban network and these may be high—the old network may have been inferior relative a possible new one but in the presence of positive coordination costs, it may not have changed the location of cities. The Black Death was a sufficiently large shock so that it could have led to a coordinate relocation of urban activity. And while there is no metric to characterize the optimality of an urban network, our evidence suggests that the new cities that emerged do so in better locations.

The structure of the remainder of the paper is as follows. Section 2 describes our data and provides necessary background information concerning the Black Death. In Section 3 we report our baseline results: Section 4 demonstrates that at the city-level recovery was highly heterogeneous. It explores what factors drove city growth in the aftermath of the Black Death and provides evidence that there was a partial ‘urban reset’. Section 5 concludes.

2. DATA AND BACKGROUND

2.1 Data

Data on Black Death mortality come from Christakos et al. (2005) who compile information from a wide array of historical sources.\(^6\) This data yields estimates of mortality for 185 locations. Of

\(^6\)We verify this data by consulting Ziegler (1969), Russell (1972), Pounds (1973), Gottfried (1983), and Benedictow (2005).
these, we can match 139 of these locations to cities in our city database. Therefore we have 139 cities for which we have an estimate of plague mortality and an estimate of their population size in 1300. We have a percentage estimate of the mortality rate for 89 of these 139 cities. For example, Florence had an estimated mortality rate of 60%. In other cases the sources report more qualitative estimates i.e. that ‘about half’ or ‘at least half’ of the population died in which case we code our estimate as 50% or that the city was ‘desolated’ or ‘abandoned’ in which case we attribute a mortality rate of 80%.

Our main source of urban population data is the Bairoch (1988) dataset of city populations. The Bairoch dataset reports estimates for 1,797 cities between 800 and 1850. It provides estimates for every century up to 1700 and then estimates for each fifty year interval up to 1850. We use 1,792 of these cities as 5 cities, in northern Norway, Finland, and in the remote West Atlantic, cannot be matched to the GIS data that we employ to create our geographical controls. The criterion for inclusion in the Bairoch dataset is a city population greater than 1,000 inhabitants at any point between 800 and 1850. This dataset has been widely used by a range of scholars studying premodern urbanization and economic development.

We follow Bosker et al. (2013) and Voigtländer & Voth (2013b) in updating the Bairoch dataset where a consensus of historians have provided revised estimates of the population of a particular city, including Bruges, Paris, and London. Specifically, we supplement the Bairoch (1988) dataset using several sources for pre-plague population including Chandler (1974, 1987), Nicholas (1997), and Campbell (2008). In our regressions we will use both the corrected dataset and the original Bairoch dataset.

For control variables we group our data into three categories: (1) measures of locational fundamentals, (2) factors that might generate increasing returns, and (3) institutional variables. To control for differences in physical geography that could affect the success of a city we collect the following geographic variables for each city. We create a dummy variable for whether a city is within 10 km of the coast or a major river. We record every city’s elevation in meters, the cereal and grazing suitability of the surrounding 25 km. We use a distance of 25km because we are interested in the potential agricultural productivity of each city’s hinterland as this was a major determinant of city size in a world of high trade costs. We also control for a city’s longitude, latitude and its average temperature between 1500-1600 (the earliest data for which estimates of the level of temperature exist).

7The historical populations of Paris and London in 1300 are now considered higher than they were by Bairoch. We use the figure of 228,000 for Paris and 60,000 for London. On the other hand, the population of Brugge is now thought to be smaller than the number given by Bairoch. We assign them a population of 12,000 in 1000, 15,000 in 1100, 25,000 in 1200 and 35,000 in 1700. Further details are confined to the Web Appendix.
Increasing returns can stem from a variety of sources. First, there are preexisting trade routes. To capture the importance of trade routes we include a dummy variable if a city belonged to the Hanseatic league (Dollinger, 1970) or was within 10 km of a medieval (land) trade route or the intersection of a trade route Shepherd (1923). Second, prior investments in physical capital provide a source of agglomeration effects. Previous research has shown that the Roman road network remained the major road network throughout medieval Europe (Bosker et al., 2013). We include a dummy if a city was within 10 km of a major Roman road or an intersection of a Roman road (McCormick et al., 2013). Thirdly, human capital may be another source of agglomeration effects as demonstrated by Dittmar’s (2011) study of the effect of the printing press on city growth rates. Therefore we include a dummy variable for whether a city had a medieval university (Shepherd, 1923).

We control for log city population in 1300 as this may effect subsequent city growth. If there are agglomeration effects and these dominate congestion effects, then we would expect larger city cities to growth faster than smaller cities. If, on the contrary, urban growth is limited by a fixed factor of production as Dittmar (2015) suggests was the case then we would expect the coefficient on log population in 1300 to be negative.

Following De Long & Shleifer (1993) and Acemoglu et al. (2005) and others we also expect institutional factors to affect city growth in preindustrial Europe. To measure institutional differences between European cities we assign each city to its political jurisdiction in 1300 based on Nussli (2011). We also use modern political boundary fixed effects in our analysis as a robustness check. We distinguish between cities that were located in monarchies such as such as England and France and autonomous cities, that is city republics either city republics such as Florence or Venice or cities which had de facto self-governance such as Lübeck. This was the major distinction in types of polities in the medieval period. We rely on Stasavage (2014) and Bosker et al. (2013) to code cities as autonomous. The historical literature suggests one might expect autonomous cities to follow policies that were more conducive to trade and commerce within the city (Stasavage, 2014). However, there is also evidence that city states like Venice and Florence imposed high taxes and extractive policies on the surrounding countryside (Epstein, 2000).

Since cities that were administrative centers may have followed different development paths, we code whether or not a city was a capital city in 1300 using Bosker et al. (2013). Finally, the fourteenth century saw an intensification in warfare which may have affected economic growth as suggested by Voigtländer & Voth (2013b). As it is impossible to obtain precise numbers on excess mortality due to warfare for the medieval period, we follow a recent scholarship in collecting data on the location of conflicts (e.g. Dincecco & Onorato, 2015; Iyigun et al., 2015). Our main source
is Wikipedia’s list of all battles that took place between 1300 and 1600. For each battle we assign a geo-coordinate based on either the location of the battle or the location of the nearest town or city mentioned in the entry. We exclude naval battles and conflicts which cannot be located (such battles were typically extremely minor). We create a dummy variable that measures the distance to major battles between 1300-1350 and 1350-1600. This provides a proxy for the both disruption caused by warfare to nearby areas and for the ‘safe-harbor’ effect identified by Dincecco & Onorato (2015) that might led to urban growth as rural citizens move to cities for greater security.

2.2 Epidemiological Background

Until recently the etiology of the Black Death was a matter of scholarly dispute (e.g. Twigg (1984); Cohn (2003)). Epidemiologists have identified the DNA of skeletons from mass graves associated with the Black Death as *Yersinia pestis* (Haensch et al., 2010; Bos et al., 2011; Schuenemann et al., 2011). This decisive evidence means that we are be confident in inferring the characteristics of the Black Death on the basis of what we know about outbreaks of bubonic plague in the modern period.

Modern bubonic plague was spread by the fleas that live on black rats *Rattus Rattus*. The bacteria *Yersinia pestis* normally lives in the digestive tracts of fleas. If the bacteria multiple sufficiently in the stomach of the flea then this causes a blockage. Fleas that are thus blocked regurgitate this bacteria into the skin of whatever animals they bite as they fed (Gottfried, 1983, 6-7). Rats are the primarily host for the bacteria. Rat fleas only spread to humans (and other secondary hosts) when the rat population has become exhausted. Bubonic plague has a mortality rate of around 70-75%.

Identification of the causal impact of the Black Death requires Black Death mortality to be uncorrected with factors that could influence subsequent city growth. Importantly, population density is not a determinant of the spread of bubonic plague. Benedictow notes that ‘it is a unique feature of the Bubonic plague ‘that the densities of rats and rat fleas overrule the effects of the density of the susceptible human population that is the decisive factor for the dynamics of epidemic spread in the case of all diseases that spread directly between human beings by cross infection’ (Benedictow, 2005, 284). Rat density is not necessarily correlated with population density as rates are territorial animals. In rural areas a single rate colony may cohabit with a single household. However, in urban areas people live closer together and the ratio between rats and humans will tend to be lower. As Benedictow (2005) argues: the ‘severity of impact on human population does not increase with mounting density of human settlement’ (Benedictow, 2005, 33). These feature of the plague

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8We discuss alternative explanations of the Black Death proposed by historians and the modern scientific evidence in our Web Appendix where we also provide more details and citations concerning our data sources.

9Similarly Gottfried notes that *R. rattus* was well-suited to both the thatched roofs of peasant dwellings and the
distinguish it from almost all other epidemic diseases such as influenza and smallpox and help to account for why mortality was unrelated to factors such as population density.

The high mortality rates and contemporary descriptions also suggest that pneumonic plague was present in some cases. Bubonic plague is spread solely from fleas to humans. Pneumonic plague can be transmitted person to person via airborne transmission. It has a mortality rate of 95-100% following a two to three day incubation period. Many individuals die in the first 24 hours, before their develop the infectious cough (Benedictow, 2005, 28). This extremely high level of mortality means that the spread of pneumonic plague is typically much more restricted than that of bubonic plague. It is worthy of note, therefore, that while bubonic plague is uncorrelated with population density, pneumonic plague may be correlated with the density of human settlement. We not able to distinguish between the two forms of plague due to a lack of evidence. This is unlikely to be a major of source of bias in our analysis as the historians and scientists agree that the rapid spread of the plague is consistent with the outbreak being largely one of bubonic plague (see Benedictow (2005, 62-76) and Scott & Duncan (2001, 30)).

In more formal analysis below we show that plague mortality was uncorrelated with population density and other geographic and economic variables.

2.3 Historical Background

The Black Death arrived in Europe in 1347. Over the next five years it spread across the continent killing approximately 40% of the population. Conventional the death rate is estimated at 1/3 of Europe’s population. More recent studies suggest that the overall death rate was considerably higher than this (Benedictow, 2005).

Death rates were comparable in the cities and in rural areas, and in general, historical accounts are unable to explain variation in morality rates (Ziegler, 1969; Gottfried, 1983; Theilmann & Cate, 2007; Jr. & Alfani, 2007). Black Death mortality was not correlated with city size or population density. To illustrate, Venice had extremely high mortality (60%) while Milan escaped comparatively unscathed (15% mortality). Highly urbanized Sicily suffered heavily from the plague. However, equally urbanized Flanders (modern-day Belgium) had relatively low death rates, while the more rural northern Netherlands was devastated. Southern Europe and the high roof beams and dark corners of urban houses’ (Gottfried, 1983, 7).

Benedictow observes that ‘it is clear primary pneumonic plague cannot play a major independent epidemic role and that the Black Death cannot have been wholley or mainly an epidemic of this kind’ (Benedictow, 2005, 30).

Prior to the Black Death there had been no major outbreak of epidemic disease for several centuries and as a result neither the medical profession or political authorities were able to respond effectively.

There is no indication that variation in sanitation or hygiene explanations this pattern. Gottfried notes ‘it would be a mistake to attribute too much to sanitation. The failure of Venice’s excellent sanitation to stem the deadly effect of the plague has been discussed’ (Gottfried, 1983, 69).
Mediterranean was hit especially hard, but so were the British Isles and Scandinavia. Figure 4 suggests that there is no relationship between Black Death mortality and city population in 1300.

The spread of the plague was rapid and largely determined by chance. For example, it was largely chance that determined that the plague would spread first from Kaffa in the Black Sea to Messina in Sicily as the ships carrying the plague could have stopped at other ports in the Mediterranean. Similarly, it was partly coincidental that the plague spread directly from Messina to Marseilles. When it arrived in a country it spread rapidly. For instance, it arrived in southern England in June 1348 in Dorset in the southwest of the country. It reached London by November. It hit the north of England by early 1349 peaking in that part of the country in the summer of 1349 (Theilmann & Cate, 2007).

The Black Death affected all segments of the population.\textsuperscript{14} Medical knowledge was rudimentary and ineffective: Boccaccio, for instance, wrote that ‘[a]ll the advice of physicians and all the power of medicine were profitless and unavailing’ (Boccaccio, 2005, 1371). Individuals fews ways to protect themselves from the disease. Institutional measures of prevention were nonexistent: the practice of quarantine was not employed until later in the fourteenth century.\textsuperscript{15}

Figure 1a presents estimates of total population and urbanization for the 17 (modern) countries which contain the cities we use in our main analysis. Europe only regained its pre-plague population by around 1600. Urbanization, in contrast, rose in the aftermath of the Black Death from around 7\% to 10\% by 1400, and 12\% in 1600. The source of the increase in urbanization is evident in Figure 1b which depicts the evolution of Europe’s urban population between 1100 and 1600. Approximately 50\% of the acceleration in urban growth after 1353 is largely attributable to the growth of cities that either did not exist or were below the threshold of 1,000 inhabitants in 1300. These aggregate statistics suggest it was the emergence of new urban centers that was important in explaining the growth in urban population relative to total population between 1353 and 1600. These data also imply that the effect of the Black Death on Europe’s economic structure was highly heterogeneous: many cities had not recovered their 1300 populations by 1600 while other cities rapidly expanded in these centuries.

To see this more clearly we examine the 139 cities for which we have explicit Black Death mortality data. For these 139 cities we can tentatively construct an estimate of their population in 1353—

\textsuperscript{14}It is commonly asserted that the Black Death killed indiscriminately. Recent research examining the skeletons from plague pits in London suggests that on average plague victims were likely to be older, frailer, or less well-nourished (DeWitte & Wood, 2008). They interpret this as evidence that mortality is rarely if ever non-selective.

\textsuperscript{15}The term quarantine was first used in the city of Ragusa, part of the Venetian empire in 1377. It was adopted as a standard policy by Venice in 1423 (Gensini et al., 2004, 257).
immediately after the Black Death—by multiplying population estimates for 1300 by Black Death mortality rates. Figure 2 studies how the distribution of these city sizes changed over time relative to the base of 1300. The mortality shock of the Black Death is evident in the rightward shift of the line for 1353. What is most interesting is that while the peak of the distribution remained below 100 for both 1400 and 1500, many cities not only recovered their 1300 population but grew far larger, while some cities did not recover at all. Among the 139 cities in 1600, 52 had a population below their 1300 population; 30 have a population below 2/3’s of their 1300 level and 18 cities had a population below 1/2 of their 1300 level. In the next section we conduct a more formal regression analysis to investigate these findings further.

3. AGGREGATE CONVERGENCE AND LOCAL DIVERGENCE

To study the effects of the Black Death on city growth we estimate:

$$\% \Delta \text{Pop}_{i,t} = \alpha + \beta_t D_{1347-1353} + X_i' \delta + \gamma_c + \epsilon_{i,t}$$

where $\% \Delta \text{Pop}_{i,t}$ is the percentage population growth in city $i$ over period $t - 1$ to $t$: $\text{Pop}_t - \text{Pop}_{t-1} / \text{Pop}_{t-1}$, $D_{1348}$ is a measure of the mortality rate of the Black Death between 1347 and 1353, $\gamma_c$ represent either historical or modern country fixed effects, and $X_i$ is a vector of city specific controls which we employ in some of our regressions.

3.1 Short-Run Effects: 1300-1400

First, we focus on the impact of the Black Death on city population between 1300 and 1400. Column (1) measures the short-run impact of the plague. The coefficient on the OLS regression is -0.85. This should be examine in relation to an immediate effect for the period 1347-1353 which is 1 by construction. A value greater than -1 in magnitude might occur if in additional people left cities struck by hard the plague in subsequent years. The coefficient that we obtain suggests that a 10% higher mortality rate during the Black Death was associated with an 8.5% smaller population growth rate. There was little recovery in population in the decades following the onset of the plague. This finding is consistent with the observations of historians like Nicholas (1999, 99) and Hohenberg (2004, 14) who write of an ‘urban crisis’ in the wake of the Black Death.

3.2 Long-Run Effects: 1300-1600

What was the effect of the Black Death on long-run urban development? To answer this question we focus on the period between 1300 and 1600 to minimize contamination from potentially
confounding events such as the discovery of the Americas as studied by Acemoglu et al. (2005), the adoption of the printing press Dittmar (2011) or the introduction of the potato (Nunn & Qian, 2011). Columns (4)–(8) of Table 1 examine the long-run impact of the Black Death. There was recovery in those cities hit hardest by the Black Death in 1400-1500 and 1500-1600. The coefficient we obtain in Column (7): of -0.15 is not significantly different from zero and demonstrates that by 1600 there was convergence in the aggregate.

In their analysis of Japanese city growth Davis & Weinstein (2002) find full convergence from the shock of World War 2 by 1960. Their coefficient of interest is precisely estimated and the standard errors associated with their estimates are small suggesting that convergence occurred at the city level. This is best illustrated by the fates of Hiroshima and Nagasaki. Ranked, 7 and 11 respectively in the distribution of Japanese cities in 1940, they fell to 26 and 25 in 1945 in the wake of the atomic bombs. However, by 1960 their relative ranking was again 6 and 11. In contrast, we find long-run convergence in the aggregate but we do not obtain city by city convergence. In fact at a local level there was consider variation in population recovery. The coefficient we obtain in Column (7) is not precisely estimated. (We report the relevant confidence intervals in square brackets below each estimate.) It is not just that the coefficient we that we obtain is small, but that the confidence intervals for Column (7) and associated standard errors are very wide. This is inline with the high amount of dispersal we observe in Figure 10 which plots the percentage change in city population between 1300 and 1600 against Black Death mortality rates. The experience of European cities after the Black Death was highly heterogenous.

3.3 Identification Strategy

The immediate question is whether these results are casual? We employ a series of identification strategies. First we drawn on he historical and epidemiological literature which suggest that mortality rates during the Black Death may have been plausibly exogenous to factors that might influence subsequent city growth. Second, we test this argument by making sure that there is no ‘placebo’ effect of Black Death mortality in the thirteenth century. Columns (2)-(3) of Table 1 shows that prior to 1300, there is no difference in growth between cities most affected and those comparatively unaffected by the Black Death. The cities in our sample that were hit hard by the Black Death and those that escaped comparatively unscathed were following similar trends prior to the demographic shock that they experienced in the 14th century.

Third, we show that Black Death mortality is uncorrelated with observable city-level characteristics (Table 2). Variation in mortality rates cannot be explained in terms of locational fundamentals (see Column (1)), nor are they accounted for by our measures of increasing returns (Column (2)), or by different institutional factors (Column 3). The only significant factor is latitude which has a
significant negative relationship with mortality rates. This reflects the fact that the Black Death hit southern Europe first, and was in general more severe there than in northern Europe. The only institutional variable we include that has statistical significance is the bishopric dummy. However, this is no longer significantly different from zero when we include all of our variables in a single regression (see column (4)). Fourth, we employ two instrumental variable (IV) strategies which we now turn to.

3.4 IV Analysis

We now conduct an instrumental variable (IV) analysis to provide further evidence for the causal impact of the Black Death. Our analysis utilizes two IV strategies. The first exploits the timing of the Black Death. Timing provides exogenous variation in Black Death morality as there is evidence that the plague became less virulent over time. Cities that were affected earlier, all else equal, tended to experience higher death rates. Figure 6 provides support for our instrumental strategy. It plots Black Death Mortality against the data that the city was first infected. In general cities infected later had lower mortality estimates.

Our second IV makes use of variation generated by the month of first infection within a single year. The Black Death was at its most virulent during the summer months (Benedictow, 2005, 233-235). Rat fleas can survived for between 6 months and year without a host. But they become most active when it is fairly warm and humid—their optimal temperature is between 15°C − 20°C and high humidity while the cold limits their activity (Gottfried, 1983, 9).

The average duration of the Black Death was 7 months (Figure 7). Therefore, cities that became infected close to the winter escaped relatively unscathed compared to cities that were infected during the spring or earlier summer. Support for this is provided by detailed month by month estimates of mortality from a number of cities. Figure 13 plots data from the two proxies for Black Death mortality: the number of testaments during 1348 from fives Italian cities alongside data on the number of vacant benefices in Barcelona. Both sources of data reveal that mortality peaked in the summer months. Christakos et al. (2005), similarly, analysis data from the city of Piacenza. They find that mortality rates peaked in September, three months after the first infection was recorded in July. By November and December mortality rates from the plague fell towards zero. The analysis we present in Figure 8 suggests that this IV has some explanatory power.

Table 3 reports our IV estimates alongside our baseline analysis. Using the date of first infection as an IV we obtain a coefficient of -1.67 (Column (2)). This is negative and precisely estimated. However, it is significantly larger than our OLS coefficient and the F-statistic is on the low side suggesting that the exclusion restriction may be violated. Our preferred specification, therefore,
includes our control variables and a fourth order polynomial in longitude and latitude. We obtain a coefficient is that close to -1 and a considerably high F-statistic. As in our baseline analysis, our first IV analysis (IV1) conforms that the fact that there were pre-trends in urban development and that the long-run aggregate effect of the Black Death was close to zero.

Column (3) reports the results of our analysis using our second IV: month of first infection (IV2). We obtain qualitatively similar results, although their is some concern about the validity of the IV as the F-statistic is low and the coefficient around twice the size of the OLS coefficient. It is nonetheless reassuring that the results of both our IV analyses are consistent with our baseline findings. Together, they provide further confidence that we have identified the causal impact of the Black Death on urban development. Next we explore the robustness of our main results to a variety of specifications, choices of data and controls.

3.5 The Robustness of our Main Results

Table 3 explores the robustness of our results. The first column shows our results remain more or less unchanged when we vary the way that we construct our data for mortality rates and urban population. Column (1) reports our baseline estimates. Columns (2)-(6) show that our general result holds when we use alternative measures of Black Death mortality. Specifically in Columns (2) and (3) we use our extrapolated mortality data to obtain mortality estimates for all 467 cities in the Bairoch dataset in 1300 Column (2) uses data extrapolated from the 139 cities for which we have both mortality estimates and population numbers. Column (3) employs data from 185 mortality estimates provided by Christakos et al. (2005). As a further robustness exercise we show that our results remain stable when exclude estimates that record a mortality rate of 25% or 50% due to concerns about heaping in the historical accounts that provide our underlying data. (Column (4)), and when we drop all mortality estimates that do not provide specific numeric estimate (Column (5)). Column (6) shows that we obtain similar results when we use extrapolated mortality estimates for 467 cities based on the sample of 89 precise mortality rates. Columns (7) and (8) show that our findings are robust whether we use the uncorrected Bairoch dataset or the Chandler dataset for our estimates of urban population.

The second panel of Table 3 demonstrates that our results remain unchanged once we employ our controls locational fundamentals, increasing returns, and institutional controls (Columns 9-16). Specifically in Columns (9)-(11) we introduce these controls sequentially while Column (12) utilizes all our controls at once. The coefficient we obtain for the short-run impact of the Black Death is somewhat smaller than in the baseline specification. In Column (14) we conduct the same exercise using our extrapolated mortality rates. To capture the possibility that the effect of some of geography may vary over time we interact latitude and longitude with a quartic polynomial in location.
Column (13). In Column (15) we control for proximity to a major battle between 1300–1350 and 1350-1600. Column (16) includes all our controls in addition to two dummies if a city is within 10 km of either the Atlantic or North Sea coasts.

The third row introduces our fixed effects and explores a variety of different specifications for modeling city growth. Using fixed effects for 1300 boundaries hardly changes our coefficient relative to the baseline (Column 17). We include modern country fixed effects in Column (18) as an additional robustness check although we view them as less informative.

In Column 19 we control for population growth in the prior century: 1200-1300. This yields a coefficient greater in magnitude than -1 implying that once we control for previous population growth cities hit hard by the Black Death grew disproportionately. Column 20 reports the results of regressions where we do not employ 1300 population weights; our results are similar to our baseline estimates. We employ a panel model in which we use city and century fixed effects in Column 22. This also yields a coefficient that is larger in magnitude than in our baseline.

In Column 23 we use a Log-Log specification. We employ a Solow-style regression model in Column 24 in which we allow the percentage change in period between 1300-1400 and 1300-1600 to be a function of initial population as well as the Black Death shock. This resulting coefficients are quantitatively similar to that obtain in our baseline regression.

The fourth row of Table 3 explores different ways of clustering our standard errors and sequently excludes observations from the countries with the greatest number of cities in our sample in order to ensure that they are not driving our results. Columns 25 to 27 show that our results are robust when we cluster our standard error either at the 1300 country level, at the modern country level or if we employ Conley (2008) standard errors with a radius of 100 km in order to account for spatial correlation in the error term. Finally, in Columns (28)-(32) we show that the results are robust when we omit the modern countries with the largest numbers of observations in our dataset: France, Germany, Italy, and the UK. These results imply our findings can be interpreted as applying to Europe as whole.

4. HETEROGENEOUS EFFECTS

Historical evidence suggests the heterogeneity of the response to the Black Death shock was important. To illustrate, we examine the fate of two cities: Hamburg and Montpellier. Hamburg had a population of about 8,000 individuals in 1300. It was struck hard by Black Death, experiencing a
mortality rate of approximately 58%. However, it recovered and indeed boomed in the subsequent half-century, growing so rapidly that it had a population of 22,000 by 1400. Like the rapid recovery of Hiroshima and Nagasaki after World War 2, such impressive growth in the wake of a major demographic shock is in line with theories that emphasize the role locational fundamentals play in determining urban location and development (Davis & Weinstein, 2002). By the seventeenth century, Hamburg was a major center of international trade (Lindberg, 2008).

In contrast, for other cities the demographic shock of the Black Death appears to lead to a period of prolonged decline. Montpellier, for instance, had a population of 35,000 in 1300. Like Hamburg it was struck hard by the plague, experiencing a 50% mortality rate. However, unlike Hamburg, it did not recover: its population in 1400 was 17,000, a 45% decline. It fell from being the 4th largest French city to being the 20th. Moreover, the decline of Montpellier continued for centuries; the city did not exceed its 1300 population until 1850. Relative to Hamburg, the fate of Montpellier is more in keeping with models of multiple equilibria in urban location in which a large enough shock can cause the urban system to reset (e.g. Krugman, 1991b); it calls into question theories that emphasize locational fundamentals as the most important factors in driving its growth up to 1300 as these same fundamentals evidently could not ensure economic success in the post-Black Death period. We ask which experience—that of Hamburg’s or that of Montpellier's—was more representative of Europe as a whole?

4.1 Locational Fundamentals v. Increasing Returns v. Institutions

Table 4 studies the heterogeneous effects of the Black Death on city growth. As in Table 2, we divide our variables as pertaining to locational fundamentals, increasing returns, or institutional factors. We report the interaction effects for each factor with Black Death mortality for our sample of 139 cities for which we have mortality data and using our extrapolated mortality data.

The set of results demonstrate that the only measure of locational fundamentals that is robust in explaining convergence is proximity to the Mediterranean coast. Cities that were hit by a one standard deviation higher mortality rate during the Black Death experienced between 30% (≈ 1.90 × 0.16) and 50% (≈ 3.27 × 0.16) faster city growth between 1300 and 1600 if they were close to the Mediterranean.

Among our measures of increasing returns, we find two robust results. First, threshold effects matter. Cities with low initial populations in 1300 grew more slowly if they suffered from high Black Death mortality relative to cities which had comparatively large populations in 1300. Cities like Paris, London and Venice were large in 1300 and bounced back from the Black Death shock

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16 Ziegler (1969, 86) estimates the death toll in Hamburg as between a half and two-thirds.
relatively quickly but for many small cities the Black Death represented a permanent shock to their populations.

Second, cities within the Hanseatic League in northern Germany recovered rapidly from the plague. The coefficient reported in Table 5 suggests that a one standard deviation increase in Black Death morality was associated with approximately 64 % \( \approx 4 \times 0.16 \) faster growth than in a non-Hanseatic city. This unsurprising as the Hanseatic league was at its peak as commercial trading network during the fourteenth and fifteenth centuries.\(^{17}\)

Finally, we study the effects of institutions on recovery from the Black Death. We find no effect for our measures of whether a city was a capital, a republic, or the seat of bishopric or archbishopric. We also find no effect for the presence of nearby battles or for parliamentary activity at the country level. The only institutional variable that matters for city recovery is whether or not a city belong to a major territorial state like England, France, Castile, Aragon, Portugal, or Scotland.

To explore the argument that the Black Death may have had an heterogeneous impact on location of economic activity we now turn to a cell-level analysis.

4.2 Malthusian Dynamics and Horsemen Effects: Cell-Level Analysis

Voigtländer & Voth (2013\(^{\text{b}}\)) argue that the Black Death generated ‘horsemen effects’ that lead to higher urbanization in western Europe after 1350. The Black Death exogenously raised death rates, and, as the economy was Malthusian, this raised wages and per capita incomes. Higher wages meant higher demand for products manufactured in cities and thus led to greater urbanization. They contrast this outcome to China where warfare and disease did not sufficiently raise the death rate and no increase in urbanization occurred. We build on Voigtländer & Voth (2013\(^{\text{b}}\))’s analysis here as we can directly test the mechanisms they propose.\(^{18}\)

Table 5 explores whether or not the effects of the Black Death varied spatially by conducting an analysis at the cell level. We can test whether the Horsemen Effects theorized by Voigtländer & Voth (2013\(^{\text{b}}\)) were different in different parts of Europe.

There are 565 cells for which we know the Black Death mortality rate. Among these 565 cells, 344

\(^{17}\)See Dollinger (1970). The political decline of the Hanseatic league occurred in the fifteenth century (see Rotz, 1977). However, they remained economically successful until the end of the sixteenth century when 'Amsterdam emerged as northern Europe's economic center, and Dutch control of the Baltic spice trade at this time marked the end of the dominant role of the Hanseatic cities within northern European trade' (Lindberg, 2008, 647).

\(^{18}\)Voigtländer & Voth (2013\(^{\text{b}}\)) do not exploit heterogeneity within western Europe which is the focus of our analysis. In fact that note that '[w]hile we do not explore this aspect in detail, the differential impact of the plague also appears to be a good predictor of changes in urbanization . . . Where the plague shock was largest, subsequent gains in urbanization were strongest' (Voigtländer & Voth, 2013\(^{\text{b}}\), 805).
had a city in our dataset at at least one point between 1300-1600, and 243 had a city in 1300. In Column (1) we estimate the effects of Black Death mortality on subsequent city growth at the cell level focusing on the growth of those 243 cities that existed in 1300. We confirm our city level results, obtaining coefficient of -0.90*** for the period 1300-1400, and a coefficient of 0.56 for the period between 1300-1600. The comparatively high standard errors associated with this coefficient (0.78) suggest that the Black Death had positive long-effect effect for some cities, but not all cities.

We further explore how the effects of the Black Death varied spatially by differentiating between cells which had a high level of urban activity in 1300 and those that did not. In a standard Malthusian-style model in which individuals have Stone-Geary preferences, we expect richer cells to have higher demand for manufactured goods and hence greater urban activity. We examine the effect of Black Death death on the growth of cities that are not in our dataset for 1300 but which passed the threshold of 2,000 inhabitants (and hence enter the dataset) at some point between 1400-1600. We call these cities ‘new cities’.

This analysis can therefore distinguish between the effect of the Black Death on areas which were more or less economically developed in the period before the Black Death. We find Black Death mortality has a larger effect on subsequent urban growth in cells which did not have sizable urban activity in 1300. Specifically, Column (2) focuses on the growth of new cities in the 243 cells which already had at least one city in 1300. We obtain a much smaller negative coefficient of -0.06**. There is also no long-run effect of Black Death morality on city growth rate. This suggests that the Black Death did not lead to the rise of new urban centers in areas which were already highly developed in 1300.

In Column (3), we study the 101 cells that did not contain a city in 1300 but in which a city passed the threshold of 2,000 inhabitants (and hence entered the dataset) at some point between 1300-1600. In contrast to Column (2), we find no effects on mortality rates on growth in the short-run, but strong positive effects in the long-run. The coefficient we obtain of 0.24*** implies that a morality rate of 50% during the Black Death in a particular cell was associated with 12,000 additional inhabitants by 1600.

Finally, in Column (4) we look at the combined effect of Black Death mortality on cells with and without cities in 1300. We find a negative effect in the short-run as expected. The coefficient we obtain for the long-run effect suggests that this effect is positive, although not precisely estimated because there is a lot of heterogeneity. This finding is consistent with the results of Table 3. To summarize, we find that the Black Death prompted urban growth in those cells which were previously rural but had no effect on average in those cells where there were already large cities in
1300. Hence in addition to a tale of two cities there was also a tale of two cells. The effects of the Black Death on city growth were greatest in areas which were comparatively undeveloped before the plague thereby providing some evidence for an urban reset.

5. CONCLUSION

Numerous scholars have argued that the Black Death marks a watershed in European history, after which it is possible to detect trends that would eventually led to the onset of sustained economic growth (Gottfried, 1983; Herlihy, 1997; Epstein, 2000; Pamuk, 2007; Acemoglu & Robinson, 2012). Existing accounts have focused on the fertility response to the Black Death (Moor & Zanden, 2010; Voigtländer & Voth, 2013a), its effect on real wages and GDP (Allen, 2001; Broadberry, 2013), or its impact on political institutions (Epstein, 2000; Acemoglu & Robinson, 2012). Recent work has focused on the effect of the Black Death on urbanization in Europe in comparison to China (Voigtländer & Voth, 2013b).

Our unique dataset of urban mortality explore the spatial dimension of the impact of the Black Death on urban development in late preindustrial. Using a range of identification strategies involve two IV strategies we find that the Black Death had a large impact on urban population in the short-run. On average cities recovered on from the Black Death within three centuries. However, this aggregate convergence masks divergence at a local level. Some cities recovered rapidly while others declined. We find that cities recovered fastest from the Black Death if they had reached a threshold size by 1300. This is consistent with an account where increasing returns play a role in determining the location of urban activity. Cities that belonged to the Hanseatic league or to more centralized monarchies also recovered more strongly. We conduct a cell-level analysis which suggests that the Black Death shock led to the reallocation of urban activities to areas which previous lacked large urban settlements.
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FIGURE 1: Evolution of Europe’s Total Population and Urbanization Rate, 1100-1600

Panel A shows the respective evolutions of the total population (millions) and urbanization rate (%) of the 17 European countries of our main analysis. Panel B presents the evolution of the total urban population (millions). The modern countries in our sample are Austria, Belgium, Czech Republic, Denmark, France, Germany, Italy, Luxembourg, Norway, Poland, Portugal, Spain, Sweden, Switzerland, the Netherlands, and the United Kingdom. The main sources for total population are Malanima (2009) and Malanima (2010). The urbanization rate is defined as the share of all the localities above 1,000 in the total population. Total (urban) population in 1353 is proxied by the total (urban) population in 1300 times the average (urban) mortality rate in 1347-1353, which we estimate as 40% (37.5%). City population data is from Chandler (1974, 1987) and Bairoch (1988).

FIGURE 2: Distribution of City Sizes for the Existing Cities in 1300, 1300-1600

This figure shows the Kernel distribution of city sizes (base 100 in 1300) for the 139 existing cities in 1300 for which we also know their Black Death mortality rate, for the years 1353, 1400, 1500 and 1600. These cities belong to the 17 European countries of our main analysis (see the notes below Figure 1 for a list). Their population in 1353 is proxied by their population in 1300 times their Black Death mortality rate in 1347-1353. The sources for the city population data are Chandler (1974, 1987) and Bairoch (1988). For ease of readability we exclude 21 outlying observations whose population is more than 3 times their population in 1300.
FIGURE 3: Black Death Mortality Rates in 1347-1353

This map plots the location of all 139 cities for which we have mortality estimates for the Black Death in 1347-1353.
FIGURE 4: Mortality Rates and 1300 Population

This figure plots mortality rates for 139 existing cities in 1300 for which we have mortality data. It shows that mortality rates are uncorrelated with population in 1300. Sources: see web appendix.

FIGURE 5: The Heterogenous Response of Urban Growth to the Black Death

The figure plots the percentage change in city population for the 139 cities for which we have mortality data between 1300-1600. It shows that the response of urban growth to the Black Death shock was highly heterogenous. To improve visibility we excluded the top and bottom 5% of observations. Source: see web appendix.
FIGURE 6: Timing of the Onset of the Black Death and Black Death Mortality: IV(1)

This figure depicts the relationship between Black Death mortality and the timing of the onset of the Black Death. It demonstrates the validity of our first IV. Cities which were affected by the Black Death earlier had higher mortality rates. Source Christakos et al. (2005).

FIGURE 7: Duration of the Black Death

This figure shows that the average duration of the Black Death was 7 months. We use this relationship to construct our second IV which relies on the month of Black Death onset as a source of exogenous variation. Source Christakos et al. (2005).
FIGURE 8: Month of Black Death Onset and Black Death Mortality: IV (2)

This figure shows the relationship between Black Death mortality and the month of onset (within year). The Black Death was more virulent during the summer months. Given the duration of the Black Death, month of onset, therefore, provides exogenous variation in the mortality rate. Source Christakos et al. (2005)

FIGURE 9: Cell Level Analysis: Testing for ‘Horsemen Effects’

This figure illustrates our cell level analysis. We use 1 by 1 degree grids. We distinguish between cells that had a city in 1300 from those cells which acquired a city between 1300 and 1600 or did not have a city throughout the period of analysis.
FIGURE 10: Heterogeneous Effects:
### TABLE 1: BLACK DEATH MORTALITY RATES AND CITY GROWTH, 1100-1700

**Dependent Variable:** Percentage Change in City Population (%) in Period $t$

<table>
<thead>
<tr>
<th>$t$:</th>
<th>1300-1400</th>
<th>1100-1200</th>
<th>1200-1300</th>
<th>1400-1500</th>
<th>1500-1600</th>
<th>1300-1500</th>
<th>1300-1600</th>
<th>1300-1700</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta_t$</td>
<td>-0.85***</td>
<td>-0.15</td>
<td>0.05</td>
<td>0.46**</td>
<td>0.39</td>
<td>-0.43</td>
<td>-0.15</td>
<td>0.07</td>
</tr>
<tr>
<td>(0.31)</td>
<td>[-1.5;-0.2]</td>
<td>[-0.9;0.6]</td>
<td>[-1.2;1.3]</td>
<td>[0.1;0.9]</td>
<td>[-0.2;1.0]</td>
<td>[-1.1;0.2]</td>
<td>[-1.2;0.9]</td>
<td>[-1.6;1.8]</td>
</tr>
<tr>
<td>Obs.</td>
<td>139</td>
<td>59</td>
<td>87</td>
<td>138</td>
<td>138</td>
<td>138</td>
<td>138</td>
<td>139</td>
</tr>
<tr>
<td>$R^2$</td>
<td>0.12</td>
<td>0.00</td>
<td>0.00</td>
<td>0.02</td>
<td>0.01</td>
<td>0.01</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

**Notes:** This table shows the effect $\beta_t$ of the Black Death mortality rate (%) in 1347-1352 on the percentage change in city population (%) for various periods $t$. The main sample consists of 139 cities (i.e. localities $\geq 1,000$ inh.) that already existed in 1300 and for which the mortality rate is available. We use the population of each city in the initial year as regression weights. Robust SE's: * $p<0.10$, ** $p<0.05$, *** $p<0.01$. The 95% confidence level intervals are shown into brackets. See Web Data Appendix for data sources.

### TABLE 2: CITY CHARACTERISTICS AND BLACK DEATH MORTALITY RATES

**Dependent Variable:** Black Death Mortality Rate (%), 1347-1352

<table>
<thead>
<tr>
<th>Location Fundamentals:</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
<th>(4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Temperature 1500-1600 (d)</td>
<td>-1.01 (1.28)</td>
<td>-0.79 (1.51)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elevation (m)</td>
<td>-0.01 (0.01)</td>
<td>-0.02 (0.01)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cereal Suitability 25 Km</td>
<td>3.20 (2.04)</td>
<td>2.69 (1.90)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grazing Suitability 25 Km</td>
<td>-2.13 (2.28)</td>
<td>-2.51 (2.67)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coast 10 Km Dummy</td>
<td>4.75 (3.18)</td>
<td>5.16 (3.89)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rivers 10 Km Dummy</td>
<td>-0.96 (3.02)</td>
<td>0.98 (3.63)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Longitude (d)</td>
<td>-0.10 (0.24)</td>
<td>0.22 (0.42)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Latitude (d)</td>
<td>-1.50* (0.78)</td>
<td>-1.59* (0.89)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Increasing Returns:**

| Log City Population in 1300 | -0.06 (1.64) | -2.96 (2.06) |
| Maj. Roman Rd (MRR) 10 Km Dummy | 3.35 (7.32) | -2.99 (6.34) |
| MRR Intersection 10 Km Dummy | 2.43 (4.84) | -1.92 (5.70) |
| Any Roman Rd (ARR) 10 Km Dummy | 0.82 (7.02) | 0.93 (6.86) |
| ARR Intersection 10 Km Dummy | -0.65 (5.46) | 6.05 (5.89) |
| Medieval Route (MR) 10 Km Dummy | 1.46 (3.22) | 3.16 (3.36) |
| MR Intersection 10 Km Dummy | -3.98 (5.15) | -1.01 (5.58) |
| Market & Fair Dummy | -6.33 (3.89) | -2.92 (4.13) |
| Hanseatic League Dummy | 3.77 (5.89) | 10.78 (6.85) |
| University Dummy | 3.29 (4.40) | 1.15 (4.97) |

**Institutions:**

| Monarchy in 1300 Dummy | 4.94 (4.44) | 5.58 (5.75) |
| State Capital in 1300 Dummy | -0.72 (4.15) | 3.24 (5.54) |
| Autonomous City in 1300 Dummy | -3.75 (3.78) | -0.95 (4.28) |
| Parliamentary Activity in 1300-1400 | 0.51 (3.83) | 1.67 (4.90) |
| Bishopric before 1350 Dummy | 7.83** (3.01) | 3.86 (3.53) |
| Archbishopric before 1350 Dummy | 5.71 (3.58) | 2.39 (4.35) |
| Battle w/i 100 Km in 1300-50 Dummy | -3.91 (3.04) | -1.19 (3.38) |

| Obs.; $R^2$ | 139; 0.15 | 139; 0.06 | 139; 0.12 | 139; 0.24 |

**Notes:** This table shows the effects of various city characteristics proxying for locational fundamentals, increasing returns and institutions on the Black Death mortality rates (%) in 1347-1352. We use the main sample of 139 cities. Columns (1)-(4) represent four different regressions. Robust SE's: * $p<0.10$, ** $p<0.05$, *** $p<0.01$. See Web Data Appendix for data sources.
<table>
<thead>
<tr>
<th>Dependent Variable: Percentage Change in City Population (%) in Period $t$</th>
<th>Baseline OLS</th>
<th>IV1: Number of Months between First Infection and Oct 1347</th>
<th>IV2: 12 “Month of First Infection” Dummies (Control for Year of Infection)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
</tr>
<tr>
<td>$\beta_{1300-1400}$</td>
<td>-0.85***</td>
<td>-1.67**</td>
<td>-1.98***</td>
</tr>
<tr>
<td></td>
<td>(0.31)</td>
<td>(0.72)</td>
<td>(0.55)</td>
</tr>
<tr>
<td>IVF-Stat.</td>
<td></td>
<td>18.2</td>
<td>9.2</td>
</tr>
<tr>
<td>$\beta_{1300-1400}$</td>
<td>-0.82***</td>
<td>-1.13***</td>
<td>-1.40***</td>
</tr>
<tr>
<td>Controls + Quartic</td>
<td>(0.24)</td>
<td>(0.42)</td>
<td>(0.43)</td>
</tr>
<tr>
<td>IVF-Stat.</td>
<td></td>
<td>33.6</td>
<td>1.9</td>
</tr>
<tr>
<td>$\beta_{1200-1300}$</td>
<td>0.05</td>
<td>-0.21</td>
<td>0.70</td>
</tr>
<tr>
<td></td>
<td>(0.62)</td>
<td>(2.16)</td>
<td>(1.84)</td>
</tr>
<tr>
<td>IVF-Stat.</td>
<td></td>
<td>18.4</td>
<td>11.4</td>
</tr>
<tr>
<td>$\beta_{1300-1600}$</td>
<td>-0.15</td>
<td>-1.16</td>
<td>-1.30</td>
</tr>
<tr>
<td></td>
<td>(0.51)</td>
<td>(1.24)</td>
<td>(0.92)</td>
</tr>
<tr>
<td>IVF-Stat.</td>
<td></td>
<td>18.2</td>
<td>9.2</td>
</tr>
<tr>
<td>$\beta_{1300-1700}$</td>
<td>0.07</td>
<td>0.21</td>
<td>-1.34</td>
</tr>
<tr>
<td></td>
<td>(0.85)</td>
<td>(1.77)</td>
<td>(1.51)</td>
</tr>
<tr>
<td>IVF-Stat.</td>
<td></td>
<td>18.2</td>
<td>9.2</td>
</tr>
</tbody>
</table>

Notes: This table shows the effect $\beta_t$ of the Black Death mortality rate (%) in 1347-1352 on the percentage change in city population (%) for various periods $t$. We use the main sample of 139 cities. Columns (1) reproduce some results from Table 1. In the second panel, we include the controls listed in Table 2 as well as a fourth order polynomial in longitude and latitude. In Column (2), we instrument the mortality rate by the number of months between the city-specific date (month-year) of first infection and October 1347, the month Messina was first infected. In Column (3), we instrument the mortality rate by twelve dummies for the month at the peak of the infection (approx. 3.5 months after the month of first infection), while simultaneously controlling for the year of infection. Except in the second panel, we use the unconditional IV Robust SE’s: * $p<0.10$, ** $p<0.05$, *** $p<0.01$. See Web Data Appendix for data sources.
### TABLE 4: BLACK DEATH AND CITY GROWTH, ROBUSTNESS CHECKS

<table>
<thead>
<tr>
<th>Dependent Variable: Percentage Change in City Population in Period $t$ (%)</th>
<th>Baseline (1)</th>
<th>(2)-(6): Black Death Mortality Data</th>
<th>(7)-(8): Pop. Data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Extrapol139</td>
<td>Extrapol185</td>
</tr>
<tr>
<td>$\beta_{1300-1400}$</td>
<td>-0.85***</td>
<td>-0.72***</td>
<td>-0.70***</td>
</tr>
<tr>
<td></td>
<td>(0.31)</td>
<td>(0.22)</td>
<td>(0.22)</td>
</tr>
<tr>
<td>$\beta_{1300-1600}$</td>
<td>-0.15</td>
<td>0.31</td>
<td>0.34</td>
</tr>
<tr>
<td></td>
<td>(0.51)</td>
<td>(0.50)</td>
<td>(0.48)</td>
</tr>
<tr>
<td>Observations</td>
<td>139</td>
<td>467</td>
<td>467</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Locational Fundamentals (9)</th>
<th>Increasing Returns (10)</th>
<th>Institutions (11)</th>
<th>All Controls (12)</th>
<th>All Quartic (13)</th>
<th>All Extrapol89 (14)</th>
<th>All Battles (15)</th>
<th>All Trade (16)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta_{1300-1400}$</td>
<td>-0.55*</td>
<td>-0.73***</td>
<td>-0.91***</td>
<td>-0.65***</td>
<td>-0.82***</td>
<td>-0.49*</td>
<td>-0.69***</td>
</tr>
<tr>
<td></td>
<td>(0.31)</td>
<td>(0.27)</td>
<td>(0.31)</td>
<td>(0.24)</td>
<td>(0.24)</td>
<td>(0.26)</td>
<td>(0.24)</td>
</tr>
<tr>
<td>$\beta_{1300-1600}$</td>
<td>0.68</td>
<td>-0.28</td>
<td>-0.15</td>
<td>-0.06</td>
<td>-0.27</td>
<td>0.30</td>
<td>0.21</td>
</tr>
<tr>
<td></td>
<td>(0.56)</td>
<td>(0.45)</td>
<td>(0.49)</td>
<td>(0.62)</td>
<td>(0.68)</td>
<td>(0.52)</td>
<td>(0.63)</td>
</tr>
<tr>
<td>Observations</td>
<td>139</td>
<td>139</td>
<td>139</td>
<td>139</td>
<td>139</td>
<td>467</td>
<td>139</td>
</tr>
</tbody>
</table>

| State Country Control No Pop. Level Panel Log-Log Solow |
|---|---|---|---|---|---|---|---|
| $\beta_{1300-1400}$ | -0.81** | -0.60** | -1.10*** | -0.84*** | -0.86* | -1.09* | -0.35*** | -0.33*** |
| | (0.39) | (0.27) | (0.38) | (0.24) | (0.46) | (0.56) | (0.11) | (0.10) |
| $\beta_{1300-1600}$ | 0.58 | -0.36 | -0.14 | -0.00 | 0.00 | -0.03 | -0.13 | -0.15 |
| | (1.09) | (0.53) | (0.61) | (0.50) | (0.64) | (0.52) | (0.16) | (0.16) |
| Observations | 91 | 134 | 87 | 138 | 139 | 133 | 133 | 133 |

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1300-1400</td>
<td>-0.85***</td>
<td>-0.85**</td>
<td>-0.85**</td>
</tr>
<tr>
<td></td>
<td>(0.29)</td>
<td>(0.37)</td>
<td>(0.33)</td>
</tr>
<tr>
<td>1300-1600</td>
<td>-0.15</td>
<td>-0.15</td>
<td>-0.15</td>
</tr>
<tr>
<td></td>
<td>(0.57)</td>
<td>(0.39)</td>
<td>(0.51)</td>
</tr>
<tr>
<td>Observations</td>
<td>139</td>
<td>139</td>
<td>139</td>
</tr>
</tbody>
</table>

---

Notes: (2)-(3) and (6): Using extrapolated mortality rates based on 139 cities ((2)), 185 cities ((3)), and 89 cities ((6)) respectively. (4): Dropping the observations with mortality rates equal to 25% or 50%. (5): Using the raw mortality data. (7)-(8): Using the raw Bairoch and Chandler population data. (9)-(12): Controlling for locational fundamentals (9), increasing returns (10), institutions (11), or all of them together (12), ditto. (13): All controls + a fourth order polynomial in longitude and latitude. (14): All controls, but using the extrapolated rates based on 89 cities. (15) All controls + one dummy for whether a battle occurred within 100 km from the city in 1350-1350 or 1350-1600. (16) All controls + two dummies if within 10 km from the Atlantic Coast or the North-Baltic sea. (17) Adding 13 state in 1300 FE (excl. the states with ≤ 3 obs.). (18) Adding 8 country FE (excl. the countries with ≤ 3 obs.). (19) Controlling for the percentage change in city pop. in 1200-1300. (21) We regress city pop. on the number of dead and the initial city pop. (22) We run a panel model with city and year FE in 1200-1600. (23)-(24) We regress the log difference in city pop. on log mortality (23), and then add also control for log initial city pop. (24). Robust SE’s: * $p<0.10$, ** $p<0.05$, *** $p<0.01$. See Web Appendix for data sources.
TABLE 5: BLACK DEATH AND CITY GROWTH, CELL-LEVEL ANALYSIS, 1300-1600

<table>
<thead>
<tr>
<th>Dep.Var.</th>
<th>Percentage Change for Existing Cities in 1300</th>
<th>Absolute Change for Non-Existing Cities in 1300</th>
<th>Absolute Change for Non-Existing Cities in 1300</th>
<th>Absolute Change for All Cities</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>with a City in 1300</td>
<td>with a City in 1300</td>
<td>with a City in 13-1600 but no City in 1300</td>
<td>with a City in 13-1600</td>
</tr>
<tr>
<td></td>
<td>(1)</td>
<td>(2)</td>
<td>(3)</td>
<td>(4)</td>
</tr>
<tr>
<td>1300-1400</td>
<td>-0.90***</td>
<td>-0.06**</td>
<td>-0.00</td>
<td>-0.24***</td>
</tr>
<tr>
<td></td>
<td>(0.30)</td>
<td>(0.03)</td>
<td>(0.03)</td>
<td>(0.08)</td>
</tr>
<tr>
<td>1300-1600</td>
<td>0.56</td>
<td>0.13</td>
<td>0.24**</td>
<td>0.28</td>
</tr>
<tr>
<td></td>
<td>(0.78)</td>
<td>(0.15)</td>
<td>(0.11)</td>
<td>(0.25)</td>
</tr>
<tr>
<td>Observations</td>
<td>243</td>
<td>243</td>
<td>101</td>
<td>344</td>
</tr>
</tbody>
</table>

Notes: This table shows the effects for various periods (1300-1400; 1300-1600) of the average Black Death mortality rate (%) of each 1x1 degree cell (using the spatially extrapolated mortality rates based on 139 cities) in 1347-1351 on: (1) the percentage change in city population (%) for the existing cities in 1300 for the 243 cells with a city in 1300; (2) the absolute change in city population (inh.) for the non-existing cities in 1300 for the 243 cells with a city in 1300; (3) the absolute change in city population (inh.) for the non-existing cities in 1300 for the 101 cells with a city at one point in 1300-1600 but with no city in 1300; and (4) the absolute change in city population (inh.) for all (existing and non-existing) cities in 1300 for the 343 cells with a city at one point in 1300-1600. Robust SE’s: * p<0.10, ** p<0.05, *** p<0.01. See Web Appendix for data sources.
TABLE 6: BLACK DEATH AND CITY GROWTH, HETEROGENEOUS EFFECTS, 1300-1600

<table>
<thead>
<tr>
<th>Dependent Variable</th>
<th>Percentage Change in City Pop. (%) in 1300-1600</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Sample of Cities: 138</td>
</tr>
<tr>
<td></td>
<td>Mortality Rates:</td>
</tr>
<tr>
<td></td>
<td>(1)</td>
</tr>
</tbody>
</table>

Each row represents a separate regression: Effect of Black Death Mortality Rate ( % ) x Dummy:

Locational Fundamentals:

<table>
<thead>
<tr>
<th>Dummy</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coast 10 Km Dummy</td>
<td>1.49</td>
<td>-0.16</td>
<td>0.11</td>
</tr>
<tr>
<td>Mediterranean Coast 10 Km Dummy</td>
<td>1.90**</td>
<td>3.20***</td>
<td>3.27***</td>
</tr>
<tr>
<td>Atlantic Coast 10 Km Dummy</td>
<td>9.88</td>
<td>-0.96</td>
<td>0.12</td>
</tr>
<tr>
<td>North-Baltic Coast 10 Km Dummy</td>
<td>5.44</td>
<td>-2.09</td>
<td>0.29</td>
</tr>
<tr>
<td>Rivers 10 Km Dummy</td>
<td>-0.44</td>
<td>-0.61</td>
<td>0.59</td>
</tr>
<tr>
<td>High Elevation ( m ) Dummy</td>
<td>-1.12</td>
<td>-1.20</td>
<td>1.06</td>
</tr>
<tr>
<td>High Av. Temperature 1500-1600 ( d ) Dummy</td>
<td>-0.63</td>
<td>1.27</td>
<td>1.06</td>
</tr>
<tr>
<td>Low Cereal Suitability 25 Km Dummy</td>
<td>0.23</td>
<td>0.58</td>
<td>0.55</td>
</tr>
<tr>
<td>Low Grazing Suitability 25 Km Dummy</td>
<td>2.03*</td>
<td>1.03</td>
<td>0.97</td>
</tr>
<tr>
<td>Western Europe ( Low Longitude ) Dummy</td>
<td>1.05</td>
<td>-0.57</td>
<td>0.58</td>
</tr>
<tr>
<td>Southern Europe ( Low Latitude ) Dummy</td>
<td>-0.92</td>
<td>0.59</td>
<td>0.38</td>
</tr>
</tbody>
</table>

Increasing Returns:

<table>
<thead>
<tr>
<th>Dummy</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Log City Population in 1300 Dummy</td>
<td>-4.43</td>
<td>-2.76*</td>
<td>-2.67*</td>
</tr>
<tr>
<td>Hanseatic League Dummy</td>
<td>4.97**</td>
<td>4.05*</td>
<td>3.78*</td>
</tr>
<tr>
<td>Market &amp; Fair Dummy</td>
<td>0.63</td>
<td>0.10</td>
<td>0.00</td>
</tr>
<tr>
<td>University Dummy</td>
<td>0.11</td>
<td>2.32</td>
<td>2.24</td>
</tr>
<tr>
<td>Major Roman Road ( MRR ) 10 Km Dummy</td>
<td>-1.99</td>
<td>-1.99</td>
<td>-2.04</td>
</tr>
<tr>
<td>MRR Intersection 10 Km Dummy</td>
<td>0.41</td>
<td>-0.14</td>
<td>-0.16</td>
</tr>
<tr>
<td>Any Roman Road ( ARR ) 10 Km Dummy</td>
<td>0.04</td>
<td>-2.70</td>
<td>-2.81</td>
</tr>
<tr>
<td>ARR Intersection 10 Km Dummy</td>
<td>1.30</td>
<td>4.97*</td>
<td>5.13*</td>
</tr>
<tr>
<td>Medieval Land Route ( MLR ) 10 Km Dummy</td>
<td>0.83</td>
<td>-0.43</td>
<td>-0.42</td>
</tr>
<tr>
<td>MLR Intersection 10 Km Dummy</td>
<td>-1.75</td>
<td>-1.36</td>
<td>-1.53</td>
</tr>
</tbody>
</table>

Institutions:

<table>
<thead>
<tr>
<th>Dummy</th>
<th>(1)</th>
<th>(2)</th>
<th>(3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monarchy in 1300 Dummy</td>
<td>0.98</td>
<td>2.60***</td>
<td>2.47***</td>
</tr>
<tr>
<td>State Capital in 1300 Dummy</td>
<td>0.26</td>
<td>1.69</td>
<td>1.51</td>
</tr>
<tr>
<td>Autonomous City in 1300 Dummy</td>
<td>1.94**</td>
<td>0.38</td>
<td>0.39</td>
</tr>
<tr>
<td>Battle within 100 Km in 1300-50 Dummy</td>
<td>0.57</td>
<td>-0.42</td>
<td>-0.29</td>
</tr>
<tr>
<td>Bishopric before 1350 Dummy</td>
<td>-1.73*</td>
<td>-0.80</td>
<td>-0.89</td>
</tr>
<tr>
<td>Archbishopric before 1350 Dummy</td>
<td>0.36</td>
<td>2.57</td>
<td>2.43</td>
</tr>
<tr>
<td>Parliamentary Activity in 1300-1400</td>
<td>0.08</td>
<td>0.90</td>
<td>0.77</td>
</tr>
</tbody>
</table>

Number of observations: 138 460 460

Notes: This table shows the interacted effects of the Black Death mortality rates in 1347-1351 and various city characteristic dummies proxying for locational fundamentals, increasing returns and institutions. Each row represents a separate regression for each city characteristic dummy. Column (1): The sample consists of 138 cities that existed in 1300 and 1600 and for which the Black Death mortality rate is available. Columns (2) and (3): The sample consists of 460 cities that existed in 1300 and 1600 and for which the Black Death mortality rate is spatially extrapolated using the 139 cities or 185 places in 1300 for which the true mortality rate is available. Robust SE’s: * p<0.10, ** p<0.05, *** p<0.01. See Web Appendix for data sources.
Web Appendix (not for publication)

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6. MAIN DATA SOURCES

6.1 City Population Estimates

Our main source of urban population data is the Bairoch (1988) dataset of city populations. The Bairoch
dataset reports estimates for 1797 cities between 800 and 1850. We use 1792 of these cities and 5 cities in
northern Norway and Finland cannot be matched to the map that we employ to create our geographical
controls. The criterion for inclusion in the Bairoch dataset is a city population greater than 1,000 inhabitants.

This dataset has been widely used by a range of scholars studying premodern urbanization and economic
development. We follow Bosker et al. (2013) and Voigtländer & Voth (2013b) in updating the Bairoch
dataset where a consensus of historians have provided revised estimates of the population of a particular city,
including Bruges, Paris, and London. Indeed, while the Bairoch data set is our main source of information,
Chandler (1974, 1987) is more specific in the sources used to measure city population. This way, we can
better assess the “true” population of each city in each year. For example we prefer Chandler’s population
estimates for a range of cities including Granada, Paris, Venice, Genoa, and Milan. In our analysis we use
this corrected dataset as our benchmark. We also employ the original Bairoch dataset and the Chandler dataset in our robustness exercises.

The Baiorch dataset contains cities from the following countries that existed in 1988: Germany, Austria, Belgium, Bulgaria, Denmark, Spain, Finland, France, United Kingdom, Greece, Hungary, Ireland, Italy, Luxembourg, Malta, Norway, The Netherlands, Poland, Portugal, Romania, Russia, Sweden, Switzerland, Czechoslovakia, Albania, and Yugoslavia. We drop all cities in the following Eastern European countries as we do not possess any Black Death mortality data for them: Albania, Bulgaria, Finland, Greece, Hungary, Romania, Russia, Malta, and Yugoslavia. We assign cities in “Czechoslovakia” to either the Czech Republic or Slovakia based on their modern borders.

The Bairoch dataset reports city populations every century. Therefore we have population estimates for our entire sample both for 1300 and for 1400. This provides an important benchmark for our analysis but is far from ideal as population growth or shrinkage may have taken place between 1300 and 1348 and population recovery may have occurred between 1350 and 1400. We employ several approaches to overcome this problem.

We collected data on estimates of pre-plague population from a range of historical sources. Chandler (1974, 1987) provides alternative estimates on city population growth including estimates for city sizes in 1320 and 1360. Christakos et al. (2005) summarizes a wide range of historical estimates of pre-plague populations and mortality rates. We used his data and returned to a several of the sources in the secondary literature to provide checks on his estimates of pre-plague population including Ziegler (1969), Russell (1972), Pounds (1973), Gottfried (1983), Nicholas (1997) and Benedictow (2005).

### 6.2 Plague Mortality Estimates

We base our urban mortality data on the estimates collected by Christakos et al. (2005) which come from a wide range of historical sources. We supplement these where possible with data from other sources including Ziegler (1969), Gottfried (1983), and Benedictow (2005). These sources provide an estimated mortality rate for either a city such as Florence which had an estimated mortality rate of 60% or for a region such as Navarre which had mortality rate of between 60-65% (Benedictow, 2005, 275). In some cases, these sources yield an percentage estimate; in other instances they report that the city was ‘desolated’ or ‘abandoned’.

This data yields estimates of mortality for 185 cities. However, not all of these cities are in the Bairoch database in the year 1300. Therefore we have 139 cities for which we have an estimate of plague mortality and an estimate of their population size in 1300. We have a percentage estimate of the mortality rate for 89 of these 139 cities.

There is considerable variation in mortality rates. In Milan the morality rate was just 15%. It was also estimated to be only 10% in Alsace, Lorraine, and Bohemia (Gottfried, 1983). However, Cambridgeshire had an estimated mortality rate of between 53-70%.
There are several sources of potential bias in our data. The first source of potential basis is reliance on medieval chroniclers who form the basis of many (but not all) of the estimates in the Christakos et al. (2005) data. Chroniclers were notoriously innumerate. The numbers they reported for medieval battles are known to exaggerate, sometimes by an order of magnitude. We know that some of the figures recorded by chroniclers are also exaggerations. For example, Agnolo di Tura thought that 52,000 individuals died in Siena but historians regard this as implausible as the population of Siena was no higher than 60,000 (Gottfried, 1983, 45). Indeed historians of the late nineteenth and early twentieth century were inclined regard the estimates of death tolls during the Black Death as uniformly exaggerated. Modern research, however, has largely confirmed the estimates of medieval chroniclers. Therefore, modern historians tend to regard chroniclers estimates as highly informative. They are no doubt subject to error but this is classical measurement error and there is no reason to suspect any source of systematic bias.

A second source of potential bias is heaping. It is well known that in societies with low numeracy individuals tend to report their age to the nearest five or ten digits (Baten et al., 2013, e.g.). Similarly, there is a tendency of contemporary observes to choose round numbers such as one-half or one-quarter when reporting Black Death mortality. We control for this source of bias in our regression analysis.

A third source of possible bias is that many of our estimates are based on tax data. Tax records are used in additional to and in instead of chroniclers estimates because there was much greater incentive to be accurate. However, tax records only record households wealthy enough to be assed for taxation. The poor were not counted or assessed. Furthermore, as Benedictow notes ‘[a]nother problem arises from the fact that the proportion of the poor and destitute that were unable to pay taxes or rents was dramatically reduced in the wake of the Black Death. In the small city of Albi in southern France, the recorded population of the population that was too poor to pay taxes diminished from 43 per cent in 1343 to 28 per cent in 1357’ (Benedictow, 2005, 263). This places a source of downwards bias on estimates of plague death especially as there is evidence for supermortality of the poor during the Black Death.

A fourth source of potential bias occurs when the underlying estimates of plague mortality come from data on the death of the clergy. It is not clear what the direction of this bias is. On the one hand, the clergy may have been somewhat better educated and better fed than the rest of the population, leading to a lower mortality rate. On the other hand, the duty of the clergy lay in looking award the sick and this exposed them to infection and may having given rise to a higher than average mortality rate.

Rural morality rates were at least as high as urban mortality rates. Benedictow (2005) provides a range of estimates for some but not all parts of Europe. Christakos et al. (2005) also report scattered estimates of rural mortality. Table 7 reports our estimate of overall mortality during the plague. It demonstrates that this number is fairly robust to different plausible estimates about mortality rates in specific countries or regions.
### TABLE 7: OVERALL MORTALITY BY COUNTRY

<table>
<thead>
<tr>
<th>Country</th>
<th>1300 Pop (m)</th>
<th>Mortality Estimate</th>
<th>High Estimate</th>
<th>Low Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria, Czech Republic &amp; Hungary</td>
<td>10</td>
<td>20%</td>
<td>15% (Gottfried*)</td>
<td>15% (Gottfried*)</td>
</tr>
<tr>
<td>Belgium</td>
<td>1.4</td>
<td>22.5%</td>
<td>25% (Gottfried)</td>
<td>20% (Gottfried)</td>
</tr>
<tr>
<td>England &amp; Scotland</td>
<td>6</td>
<td>55%</td>
<td>62.5% (Benedictow)</td>
<td>45% (Gottfried)</td>
</tr>
<tr>
<td>France</td>
<td>16</td>
<td>50%</td>
<td>60% (Benedictow)</td>
<td>30% (Gottfried)</td>
</tr>
<tr>
<td>Germany</td>
<td>13</td>
<td>22.5%</td>
<td>25% (Gottfried)</td>
<td>20% (Gottfried)</td>
</tr>
<tr>
<td>Italy</td>
<td>12.5</td>
<td>50%</td>
<td>55% (Benedictow)</td>
<td>40% (Ziegler)</td>
</tr>
<tr>
<td>Netherlands</td>
<td>0.8</td>
<td>32.5%</td>
<td>35% (Gottfried)</td>
<td>30% (Gottfried)</td>
</tr>
<tr>
<td>Poland</td>
<td>2</td>
<td>25%</td>
<td>25% (Gottfried)</td>
<td></td>
</tr>
<tr>
<td>Portugal</td>
<td>1.3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scandinavia</td>
<td>1.9</td>
<td>55%</td>
<td>60% (Benedictow)</td>
<td>50% (Gottfried)</td>
</tr>
<tr>
<td>Spain</td>
<td>5.5</td>
<td>50%</td>
<td>62.5% (Benedictow)</td>
<td>30% (Gottfried)</td>
</tr>
<tr>
<td>Switzerland</td>
<td>0.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Overall</strong></td>
<td><strong>72.8</strong></td>
<td><strong>38.75%</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* estimate is for Czech lands. For Portugal and Switzerland we have assumed a mortality rate of 40%. Sources: Ziegler (1969); Gottfried (1983); Benedictow (2005).

### 6.3 Composition of Black Death Mortality

### 6.4 Extrapolated Mortality Data

In order to extend our analysis to cities for which we don’t have explicit mortality rates, we use spatial analysis to impute the missing values. Our assumptions in doing this are that (1) there exist some underlying causes of mortality rates which are unobserved, (2) these causes have a large random component (i.e. are external to our model of subsequent city growth), (3) these causes are also spatially correlated. For example, it is widely acknowledged that fleas living off of rat populations were a primary vector for the plague. It is highly plausible that a latent variable measuring the suitability of a city’s surrounding region for sustaining large rat populations satisfies the three criteria laid out above.

In order to impute the missing mortality rates we create a two-dimensional surface of predicted plague mortality using an inverse distance weighted function of known mortality rates. For every point on the surface a predicted mortality rate is generated using the closest 15 cities within an approximately 1,000 km radius circle around the point. For a point on the surface, \( x \), with unknown mortality the influence of city, \( i \), with known mortality diminishes with its distance from \( x \) according to the weights used. These weights are determined by a parameter, \( p \geq 0 \), referred to as power. As the power decreases, the influence of more distant points increases. If \( p = 0 \), then all points receive equal weight in determining all other points on the map. The influence of more distant points decreases exponentially as \( p \) increases.

\[ 19 \text{If there are fewer than 15 cities in this radius, the a minimum of 10 are used. Our predictions are robust to experimenting with different values of the maximum and minimum number of cities allowed.} \]
To create our mortality estimates we choose an optimal $p$ using cross-validation techniques. The procedure begins by choosing some power, $\bar{p}$. Then, using the sample of $n$ cities with known mortality rates, we create a predicted mortality rate surface using all of the cities except for city $j$. We then predict the mortality rate for city $j$ as $\hat{m}_j$ using our mortality surface and create it’s residual as $(\hat{m}_j - m_j)$ where $m_j$ is the known mortality rate for city $j$. This procedure is then repeated to create predicted mortality rates and residuals for all the remaining cities. We then calculate the Root Mean Square Error (RMSE) of the residuals created as $\text{RMSE}(\bar{p}) = \sqrt{\frac{\sum_{i=1}^{n}(\hat{m}_i - m_i)^2}{n}}$, where $i$ indexes the cities with known mortality rates. This procedure is repeated for a large number of choices of $p$ and then the optimal power is chosen as the one which minimizes the RMSE.

We generate optimal mortality surfaces using several different city samples. Our baseline sample consists of cities that existed in 1300 for which mortality rates are reported in the historical literature. There are 139 of these cities and the cross-validation exercise chooses an optimal power for creating the mortality surface as 1.02 (RMSE=14.25). Panel A of Figure 11 shows the relationship between the measured and predicted mortality rates for this 139 city sample. Figure 3 shows the mortality surface generated using the 139 city sample along with the location of all cities (not just those with mortality rates) for which we have population data in 1300.

We also generate an optimal mortality surface using the sample of 185 cities for which we have an estimate of Black Death mortality. The most likely reason the extra 46 cities included in this sample may not have been recorded in Bairoch for 1300 is because their populations were too small (less than 5,000) in the 13th century. Nonetheless, they provide valuable information on mortality rates. The cross-validation analysis
suggests an optimal power of 1 for these cities, which yields a RMSE of 14.10. Panel B of Figure 11 shows the measured versus predicted values using the optimal power.

Some of the mortality rates for the 139 and 185 city samples are reported with greater accuracy than others. For example, often, the rate is given as ‘about half’ or ‘at least half’ of the population, which we then code as 50%. This can be seen in the Figure 11 as the heaping around 0.50. In other cases, the mortality rates are reported as for ‘clergy’ as opposed to the general population. As a robustness check on our mortality predictions, we generate subsamples of the 139 and 185 city samples in which we drop any vague or ambiguous mortality reports. This generates a sample of 89 cities that existed in 1300 for which we have mortality rates and another sample of 111 cities consisting of all unambiguously reported death rates. For the 89 city sample, the optimal power used is 1.13 and this yields a RMSE of 13.89. For the 111 city sample, the optimal power is 1.35 and this yields a RMSE of 13.51. It is reassuring that largest sample consisting of precisely reported death rates also yields the most accurate predictions from its mortality surface.

7. CONTROL VARIABLES

We employ a wide range of geographic, economic and institutional city-level controls variables. We categorize our controls into three categories: physical geography controls; economic geography controls’ and institutional controls.

7.1 Physical Geographical Controls

Distance to the Coast and Major Rivers

We create a variable to measure distance to the coast and major rivers in meters using ArcGIS. We base these distances on the 1300 shape file downloaded from Nussli (2011). All maps are projected into World Mercator WGS 1984.

Soil Suitability

Our soil suitability data are from the FAO Global Agro-Ecological Zones (GAEZ) dataset as described in Fischer et al. (2002). We use these in preference to the Ramankutty et al. (2002) as the latter does not have full coverage for all of western Europe (it omits Sicily for example). We use the GAEZ’s overall cereal suitability data assuming low inputs and rain-fed irrigation. We extract the average soil suitability within 25, 50, and 100 kilometer radius circles around each city. Overall cereal suitability is scaled from 1-9 where 1 is best, 8 is unsuitable and 9 is water (seas and oceans are treated as missing values).
Elevation

City elevation data come from Jarvis et al. (2008) which is available at http://srtm.csi.cgiar.org

This data reports elevation in meters. The spatial resolution between 1 and 3 arc-seconds. Where there is missing data we have supplemented it using wikipedia.

Grazing Suitability

In the literature on long-run economic growth in Europe emphasizes the importance of pastoral farming. Broadberry (2013) emphasizes that regions that adopted pastoral farming engaged in higher value-added production that was also more capital intensive. Voigtländer & Voth (2013a) argue that there was an interaction between the Black Death and pastoral farming which led to lower fertility rates and increased human capital accumulation. We control for the potential suitability of a region surrounding a city for pastoral farming with a variable measuring grazing suitability. This variable come from Erb et al. (2007) who create land use measures at a resolution of 5 arc minute cells, or approximately 10 km X 10 km at the equator. The record how land is used in each cell in 2000. The five categories they code for are: cropland, grazing, forestry, urban, and areas without land use. Their grazing category is calculated as a residual after accounting for the percentage of area taken up by the other four uses. As part of this analysis they also generate a variable measuring the suitability of each cell for grazing (as opposed to actual present-day use). The suitability measure is created by first separating grazing land into three categories based on cover: 'high suitability of cultivated and managed areas, medium suitability of grazing land found under tree cover, and low suitability if shrub cover or sparse vegetation is detected in remote sensing' (Erb et al., 2007, 199). The then further subdivide the first two of these categories into areas with a net primary productivity of Carbon per meter squared is greater than 200 grams and those in which it is less than 200 grams. This results in five categories which they regroup into four categories with 1 = most suitable and 4 = least suitable. There is a fifth category which is ‘no grazing’ which we re-code as 5. We then extract the average suitability of the region around a city for grazing using circles of 25, 50, and 100 km’s.

Temperature

We use temperature data from Luterbacher et al. (2004). They reconstruct seasonal European temperatures since 1500 using proxy data from ice cores, tree rings, and written records. The data cover 0.5°X 0.5° grids which is approximately 50km X 50 km at European latitudes. The data extend from 25°W to 40°E and 35°N to 70°N which includes all of the cities in our extended Bairoch sample. We extract the growing season (summer) temperature for each of our cities during the 16th century as this is the closest century to the Black Death period for which we have data.
7.2  **Economic Geographical Controls**

*Roman Romans*

Data on Roman roads is provided by the *Digital Atlas of Roman and Medieval Civilizations*. It is available from:

http://darmc.harvard.edu/icb/icb.do?keyword=k40248&pageid=icb.page601659

We use this shape file to create two distances: (1) distance to all Roman roads and (2) distance to ‘major’ Roman roads. Since major settlements often formed along the intersection of the road network, we also create a variable for distance to Roman road intersection using ArcGIS.

*Medieval Universities*

Bosker et al. (2013) provides data on the presence of medieval universities for European cities with populations greater than 10,000 (at some point between 800 and 1800). We consulted Wikipedia and other sources to find evidence of medieval universities in European cities with smaller populations. There are five medieval universities missing from the list in Bosker et al. (2013): Angers, Greifswald, Ingolstadt, Tuebingen, and Uppsala. However, as none of these universities were established prior to the Black Death, do not include them in our analysis.

*Medieval Fairs*

Medieval fairs were important locations of economic activity in the medieval period. Fairs provided central meeting points for trade to take place—enabling a greater degree of economic specialization than would otherwise have been possible (Spufford, 2002). The major fairs were consequently economic centers, particularly in the period before the Black Death. Proximity to a major fair might therefore give a city an economic advantage. As such we control for whether or not a city contained an important fair or its proximity to a fair.

We obtain data on the location of important medieval fairs from two sources. The first source is Shepherd (1923). The second source we use is the *Digital Atlas of Roman and Medieval Civilizations*:

http://darmc.harvard.edu/icb/icb.do?keyword=k40248&pageid=icb.page188865


We drop the following fairs as they cannot be matched with cities in the Bairoch dataset: Stamford, St Ives, 20

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20Fairs have been studied by North et al. (2009) and Edwards & Ogilvie (2012).
Bergen op Zoom, Mesen, Bar-sur-Eabue and Lagny.

Trade Routes

We use Shepherd (1923) to obtain the path of major medieval land trade routes. We use ArcGIS to create a shape file that allows us to measure distance to major medieval land trade route or the intersection of two major trade routes. Figure ?? depicts this data. We create a dummy variable that takes the value of 1 if a city is within 10 kilometers of trade route or intersection.

7.3 Institutional Controls

Bosker et al. (2013) provides data on the presence of bishoprics, parliaments and participatory urban governments for European cities with populations greater than 10,000 (at some point between 800 and 1800. This gives us a rich set of geographic and institutional control variables for 677 of the 1797 cities in our sample. Full details on these controls are provided in the appendix to Bosker et al. (2013). We briefly summarize some of the most important controls here.

Bosker et al. (2013) collect data on capital cities from McEvedy & Jones (1978); information on universities from the ninth edition of the Encyclopedia Britannica; data on communes from Lexikon des Mittelalters in
addition to other historical sources; data on parliamentary activity from Zanden et al. (2012).

Archbishoprics and Bishoprics

Bishoprics were important religious, political, and administrative centers in medieval Europe. Additionally, the presence of a bishopric (in southern Europe at least) indicates that a city has a history of being an important local center that went back to the late Roman period at least. For these reasons we control for the presence of a bishopric in our baseline analysis.

Bosker et al. (2013) provide information on the locations of bishoprics and archbishoprics for all cities in the Bosker et al. (2013) dataset. However, since the Bairoch dataset is a superset of the Bosker et al. (2013) we collected additional data on the location of bishoprics and archbishoprics in cities which are too small to appear in the Bosker et al. (2013) dataset.

For additional bishoprics and archbishoprics we used information from Shepherd (1923). In order to ascertain that all the bishoprics in our dataset were in existence in 1300 we consulted the following website:

http://www.catholic-hierarchy.org/country/

Hanseatic League

We document whether or not a city was a member of the Hanseatic League. We do this by matching where possible the Bairoch city data with available lists of cities which belonged to the League. We include only cities which were members of the League and do not included cities with Hansa trading posts or Hansa communities. Our main source is Dollinger (1970).


For an alternative list of cities with Hanse affiliations, we also consult the list in:

https://en.wikipedia.org/wiki/Hanseatic_League
We are able to match the majority of these Hansa cities. The exceptions are as follows. We do not match Demmin, Darlowo, Falsterbo Muster, Pasewalk as they not in our dataset as it they were presumably too small during the middle ages to make it into the Bairoch dataset. As the Bairoch dataset did not include cities in the then Soviet Union, we do not include the following cities which are in modern Latvia, Estonia, Belorussia, or Russia: Riga, Reval, Doporat, Kanunaas, Köingsberg, Novgorod, Pleskau, and Polotsk.

**Political Boundaries in 1300**

The shape files provided by Nussli (2011) report political boundaries in Europe for every century. We use the shapefile in Nussli (2011) to obtain political boundaries for Europe in 1300. We then assign each city in the Bairoch dataset to its political boundary in 1300.

**Monarchy and Republic Variables**

We further code whether or not a city had a Republican government. Our definition of a republic is a narrow one. It does not encompass cities that had some measure of self-government but owed ultimate fealty to a higher sovereign (such as London or many of the free imperial cities of the Holy Roman Empire). It includes the Republic of Florence, the Republic of Lucca, the Republic of Siena, the Republic of Pisa, the Republic of Venice.

Finally, we a city as belonging to a monarchy in 1300 if it it belonged to the Kingdom of Bohemia, the Kingdom of Denmark, the Crown of Castile, the Kingdom of France, the Kingdom of Norway, the Kingdom of England, the Kingdom of Sicily in Naples, the Kingdom of Granada, the Kingdom of Scotland, the Kingdom of Hungary, the Kingdom of Sicily, the Kingdom of Galicia-Volhynia, the Crown of Aragon, the Kingdom of Portugal, the Kingdom of Majorca, the Kingdom of Sweden.

Nussli (2011) does not provide separate political boundaries for all of the small states that comprised the Holy Roman Empire coding themselves instead as ‘small states of the Holy Roman Empire’. We code these as a small states in our main analysis. For robustness we also code all cities within the borders of the Holy Roman Empire as belonging to a large state.

**Commune and Autonomous Cites**

Bosker et al. (2013) provide information on the existence of communes for a subset of the cities in the Bairoch dataset. Bosker et al. (2013) create a variable “commune” that takes a value of 1 if there is indication of the presence of a local urban participative organization that decided on local urban affairs.

Stasavage (2014) provided us with data on 169 cities that where autonomous at some point between 1000 and 1800. We utilize the variable for 1300-1400. There are xx autonomous cities in our dataset. Stasavage (2014) defines autonomous cities in the following terms:
‘I have defined an “autonomous city” as being one in which there is clear evidence that such institutions of self-governance existed, and in addition there is also clear evidence of exercise of prerogatives in at least one of the policy areas referred to above. In the absence of such evidence the default is to code a city as non-autonomous (6).

As Stasavage (2014) notes, his definition of city autonomy is stricter than the definition of commune used by Bosker et al. (2013).

**Warfare data**

Warfare was a leading contributor to the fourteenth century crisis and therefore affected population trends during the period of analysis (Voigtländer & Voth, 2013b, see). As it is impossible to obtain precise numbers on excess mortality due to warfare for the medieval period, we follow a recent scholarship in collecting data on the location of conflicts. This allows to create a control variable which reflects variation in the intensity of warfare over time and space.

As our main source we use Wikipedia’s list of all battles that took place between 1300 and 1600.


This is a highly reliable source for the most important battles of the period. We are not concerned about sample selection here as Wikipedia’s coverage of European history is extensive; battles not listed on Wikipedia are likely to have been extremely small.

For each battle we assign a geo-coordinate based on either the location of the battle or the location of the nearest town or city mentioned in the entry. We exclude naval battles and conflicts which cannot be located (such battles were typically extremely minor).

Since not all battles were the same, we also collect data on the intensive margin of conflict by recording information on the total number of participants in each battle. We use this metric for several reasons. The most important is it captures the size of forces involved in a battle which is a good proxy for the amount of devastation in terms of disruption of food supplies and disease that warfare imposed on the nearby population. Additionally, the size of the armies involved in battle is more widely available and recorded with less noise than are estimates of battlefield casualties.

These estimates are not ideal. The location of a battle may not account for the all of the devastation that armies might wreck on the countryside of a city. Nevertheless, given data limitations it is the best way to account for the affects of major conflicts on city populations in the middle ages.
FIGURE 13: The Severity of the Black Death by Month: Testaments and Vacant Benefices

This figure plots data for testaments from Siena, Perugia, Rome, Areezzo and Florence for the year 1348 and vacant benefices in Barcelona. Both measures are proxies for overall mortality. They indicate that mortality peaked in the summer months during the outbreak of 1348 in Italy. Source Cohn03}.
FIGURE 14: The Timing of the Black Death

This figure depicts the timing of the Black Death. It is reproduced directly from Christakos et al. (2005, 185).

FIGURE 15: Maximum, Mean, and Median City Size 1300-1600

This figure shows the maximum, mean and median city size for the period 1300-1600. These were stable suggesting that there were no major changes in urban technology during this period.