City seeds: the geographical origins of European cities

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< PRELIMINARY AND INCOMPLETE >

Abstract

This paper empirically disentangles the important roles of geography in shaping the European city system. To do this we employ a, largely new, database covering all actual European cities as well as potential city locations over the period 800-1800, during which the foundations for the European city system were laid out. We relate each location's urban chances to its physical, 1st nature geography characteristics, and develop a new empirical strategy to assess the importance of the 2nd nature geography characteristics of the urban system surrounding each location as well. Instead of the, up to now, largely narrative historical accounts on the role of geography in determining the location of cities in Europe, we provide quantitative empirical evidence into the important, and changing, role of geography in creating the European city system. First nature geography is the dominant explanation from the 9th until the 16th century, but, second nature geography gains in importance from the 17th century onwards.

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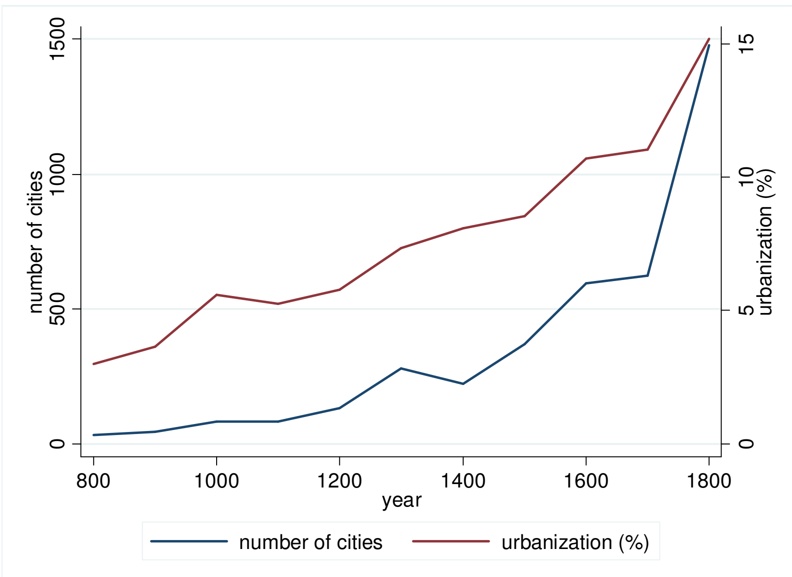
1 Introduction

"The first stylized fact about Europe is that it has, over a thousand years, become largely urban" (Hohenberg, 2004, p.3023). Indeed, today the European landscape is dotted with cities. Historically this was not always the case, in the early medieval period Europe only knew a handful of cities. Figure 1 illustrates the rise of the city in the European landscape. Europe's urbanization rate steadily increased from only 3% in 800 to 15% in 1800[1]. In 800 Europe knew only about 34 cities, but over the course of the next millenium this number increased substantially, so that in 1800 there were over 1450 cities on the continent.

Figure 1. Urbanization and the number of cities in Europe, 800 - 1800

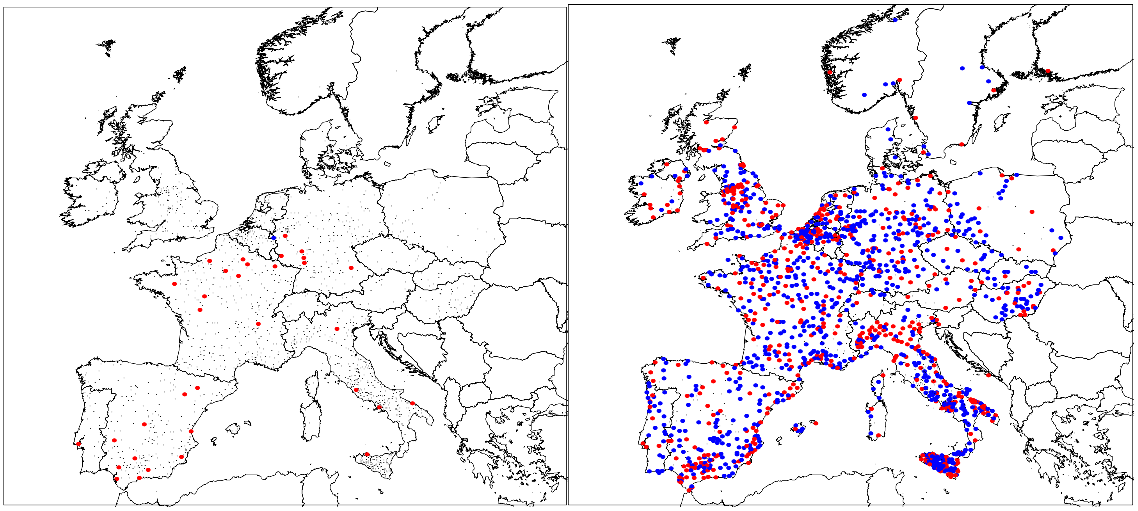


Notes: Cities are defined as agglomerations with at least 5000 inhabitants. The urbanization rate is calculated by dividing total urban population (i.e. the total number of people living in cities with at least 5000 inhabitants) by total population. Total population figures are taken from McEvedy and Jones (1979).

These cities appeared virtually everywhere on the continent. Figure 2a and 2b below[2] show that whereas in 800 we only find few scattered cities in mainly Spain, France, Germany and Italy, in 1800 cities are present throughout the continent.

[1] Urban population increased 30-fold from 0.7 to 21 million, whereas total population increased 'only' 6-fold from 23 to 137 million.
[2] For the situation in 1300 see Figure A1 in Appendix A. A full, century-by-century, visualization of the formation of the European city system can be downloaded from http://maartenbosker.googlepages.com.

Figure 2. The European city system in 800 and 1800



a) 800 b) 1800

Notes: black dots denote potential city locations [see section 3.1 for more detail], blue dots denote cities with at least 5000 inhabitants and red dots denote cities with at least 10000 inhabitants.

The rise of the city in the European landscape raises important questions. Why do cities form? And, why do they form in particular locations and not in others that are often a priori as viable as potential city location? In this paper we empirically assess the role(s) of geography, often stated as one of thè most important determinant of cities' origins, in answering this second question.

Many authors, in both the narrative urban (economic) history (e.g. Pirenne, 1922; De Vries, 1984, or Bairoch 1988) and the, more recent, urban economic literature (e.g. Krugman, 1993; Behrens, 2007; Duranton, 1999), have stressed two important, but very different, roles for geography in the origins of an urban system (Behrens, 2007; Hohenberg and Lees, 2005; Duranton, 1999).

The first role is determining a location's physical, or *1st nature geography*, characteristics. These determine a location's agricultural potential, its transportation possibilities and its defensive advantages, that all have been noted as important 'city seeds'. The second role for geography has received renewed attention in the economics literature following Krugman (1991; 1993). While not denying an important role of 1st nature geography, this line of literature stresses a location's position *relative to* the rest of the (potential) urban system, it's *2nd nature geography*. As already acknowledged by Pirenne (1922, p.145), some locations may very well be suited for urban development based on their own characteristics, but *"situated too far from the great highways of communication,* […] *they remained sterile, like seed fallen upon stony ground."*.

Surprisingly the debate on the relevance of the two different roles of geography in determining cities' origins has up to now largely taken place without using any rigorous empirical evidence. Instead relying on historical narratives, largely descriptive accounts of Europe urbanization, and detailed case studies looking at one particular city only. This is partly due to the difficulty of finding historical data for a sufficient number of cities during a period that can be classified as encompassing the origins of an urban system. This lack of historical data has, in case of Europe, been largely resolved by the work of most notably Bairoch (1988), De Vries (1984) and in case of Italy by Malanima (1998b). They have constructed comprehensive datasets providing population estimates for many cities in Europe starting as early as the year 800. Bosker et al. (2008) and Bosker et al. (2009) further complement these data with mainly geographical, but also institutional and religious, information for each of the cities documented by Bairoch (1988) and Malanima (1998b)[1], so that the observed development in the number and size of cities can now also be related to observable characteristics of these places.

This data has up to now been used either to provide largely descriptive accounts of urban expansion (Bairoch, 1988; De Vries, 1984; Kim, 2000[2]), or to uncover the major drivers of a city's size *once a city is established* (Acemoglu, Johnson and Robinson, 2005; De Long and Shleifer, 1993; Bosker et al., 2008 or Bosker et al, 2009). By looking at city size *conditional* on a city's existence, although very interesting in itself, these papers take cities' location as given and refrain from shedding any empirical light on the question why these cities were formed at their particular location in the first place. They do not answer the question why other, often equally viable, locations never became a city or only did so at a much later stage[3].

This paper fills this gap. Using a large, and for a substantial part newly collected, data set on potential city locations in Europe over the period 800 – 1800 A.D., we empirically

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[1] They also extend the geographical coverage of the dataset to include cities in the Arab World.

[2] Kim (2000) focuses on data for the US, describing in detail the evolution of the US urban system from 1690 – 1990. His account of the early period of the US city system is largely descriptive. Only from 1880 onwards does he present empirical evidence on the drivers behind urban expansion (focussing on city size instead of city creation).

[3] As put by Bairoch (1988, p.144): "one must never confuse the factor determining the location of a city with those factors favoring its subsequent growth".

uncover the (relative) importance of so-called 1st and 2nd nature geography in determining the location of cities.

The European case provides an ideal 'testing ground' for the following two reasons. First, historical data availability on the size and characteristics of individual cities in Europe is the best in terms of both spatial and temporal coverage. Our dataset, which will be discussed in more detail in section 3.1, covers both locations that eventually turn into a city, as well as potential locations that in principle could have become a city but never did. It comprises detailed information for 1784 (potential) city locations in each century from 800 until 1800. Besides documenting the (non)existence of a city in a particular location in a particular century, it contains information on, most importantly for the purposes of this paper, a location's 1st and 2nd nature geography. But it also provides information on several religious, educational and institutional characteristics of each (potential) city location.

Second, all this data is available for the period, 800 – 1800 A.D.[1], in which one can forcefully argue that the seeds for the eventual European city system were sown. Following the eclipse of the Roman empire, cities (and trade) in Europe withered (Pirenne, 1922). But over the next millennium Europe witnessed an unprecedented revival of urban activity and the establishment of cities on a scale not seen before (see Figures 1 and 2). As put by Davis (1955, p.432; text between square brackets has been added): "*The eclipse of cities in Europe* [following the demise of the Roman Empire] *was striking. Commerce declined to its bare minimum; each locale became isolated and virtually self-sufficient… Yet it was precisely in western Europe where cities and urbanization had reached a nadir during the Dark Ages, that the limitations that had characterized the ancient world were finally to be overcome.* […] *the development of cities* […] *kept going on the basis of improvements in agriculture and transport, the opening of new lands and new trade routes*".

Using our information on 1784 potential city locations in Europe, we quantify the role of 1st and 2nd nature geography in conditioning the spread of cities across the European continent. More specifically, we provide an answer to the following three questions. Do 1st

[1] Actually, Bairoch (1988) provides data up until 1850. We do not consider this 1850 data for two reasons. The first is that it would add the Industrial Revolution to our sample. Given the rapid and substantial change during that period, in terms of transportation, production, and importance of different resources, we find that including the Industrial Revolution would require a detailed account of its effects. Something that we feel lies beyond the scope of our paper. Second the rest of the data is avaible on a centennial basis. Including the 1850 would constitute a substantial shortening (halving) of the sampling period, with possibly unwanted consequences for the statistical analysis.

and 2nd nature geography play a role in determining why some locations become a city whereas others never do so, or do so at a much earlier or later stage? If we find that they do, the immediate follow up questions are, of course, to what extent? And, what about their relative importance?

In the next section, we will spell out in more detail the main theoretical insights regarding the role of 1st and 2nd nature geography in sowing the seeds of cities. These follow from both the (largely narrative) economic and geographical urban history literature, and the, more recent, new economic geography literature. They will serve as the theoretical underpinnings of our empirical analysis in the rest of the paper, guiding the selection of both the potential city locations to consider, as well as the 1st and 2nd nature geography variables to include in our empirical analysis. In case of 2nd nature geography this results in developing a novel way to quantify the nonlinear effect, following from theory, that an already established city exerts on another location's urban chances.

As a prelude to our results, we find that, indeed, both 1st and 2nd nature geography have played an important role in the origins of European cities. A natural advantage for water-based transport turns out to be the most important 1st nature geography characteristic. And, the effect of 2nd nature geography turns out to correspond very closely to the predictions made by economic geography theory. Also, the (relative) importance of 1st and 2nd nature geography shows substantial changes over time. 1st nature is the dominant geographical force in the early stages of the formation of the European city system. But, as trade costs fall and the overall European population increases, 2nd nature geography gains in importance and starts to be an equally important determinant of city formation from the 17th century onwards.

2 Theory

2.1 Economic and urban history

Traditionally, the debate on cities' origins was conducted within the realm of the, largely narrative, economic history and geography literature (Pirenne, 1925; Weber, 1922; Bairoch, 1988; De Vries, 1984). This literature stresses defensive, religious and sometimes administrative motives as the main drivers of city formation. Bairoch (1988, p.121) for example notes that *"Throughout Christian Europe episcopal and archiepiscopal seats conditioned the progress of urbanization."* And Pirenne (1922, p.72/74) clearly states that *"The first need that was manifest was that of defence.* […] *the burgs were, above all, military* *establishments."* Economic motives such as facilitation of exchange or specialization are often only viewed of secondary importance. As put by Duby (1959) writing about urban life in South Eastern France in medieval times: *"the market and the port never had at that time as much importance for the city as the wall and the towers"*.

Economic motives may not be seen as the most important explanation of why cities were formed in the first place, they do feature prominently in this literature when turning to the main question that we are concernced with in this paper: *where do cities form*? Here the historical literature mostly turns to a priori differences between locations as the main reason for some locations to be more likely to become a city than others. Such spatial inhomogeneities, what we will call *1st nature geography*, between locations arise on the one hand from the earlier-mentioned defensive and religious motives. Cities were established near places with an important religious function (an abbey, monastery or local shrine) or at a strategic location, e.g. a river crossing, the foot of a mountain pass or a hill overlooking the countryside (see e.g. Hohenberg, 2004; Hohenberg and Lees, 1995, p.30). However, economic motives now also play a prominent role. Attractive city locations were those close to natural resources (fertile plains, mineral deposits, or thermal springs, etc). But mostly stressed (see e.g. Bairoch, 1988, p.143) is the role of transport in determining the location of a city. Location on a navigable river, an overland transport route or at sea offers substantial advantages in terms of transportation possibilities. Cities therefore tended to form along the main trade routes, or (even better) at the junction of several trade routes.

2.2 Economic geography

These spatial inhomogeneities, or 1st nature geography, also feature prominently in the, more recent, economic literature on city creation (Duranton, 1999; Anas, Arnott, Small, 1998; Fujita and Mori, 1996; Krugman, 1993, Behrens, 2007). Although this literature does not deny the importance of endowments of minerals, soil or climate as important determinants of city formation (see Anas, Arnott and Small, 1998), the 1st nature geography characteristic that receives most attention in this literature is the effect of a preferential location on transport routes (Fujita and Mori, 1996; Behrens, 2007; Konishi, 2000). Transportation or, more generally, trade costs[1], together with scale economies, are viewed as the crucial elements in the process of city formation.

[1] All costs associated with moving goods from one location to another, including not only transportation costs, but also tolls or tariffs, and less tangible costs associated with language, institutional or legal differences between locations.

Transportation costs are vital to a city given that it relies entirely on exchange with its hinterland to meet its own demand for agricultural produce. When the cost of transporting these agricultural goods (or the goods the city produces in exchange for these) are extremely high, this results in the so-called tyranny of distance. Cities will only form in locations offering good 1st nature conditions, so that sufficient food can be imported from closeby[1]. *"With the tyranny of distance, it is no real surprise that more prosperous cities tended to be found in fertile areas and in locations with specific advantages to shipping costs such as at a confluence of rivers, on a port, and so on."* (Duranton, 1999, p.2173).

However, when the tyranny of distance is alleviated by developments in transportation technology, the importance of *1st nature geography* diminishes. Given that agricultural products can now be shipped over longer distances it becomes possible to establish cities at locations that, given their lack of 1st nature advantages, were previously unviable to host a city. In that case , spatial inhomogeneities can not explain why two a priori similar locations sometimes show very different development paths – the one becoming a city and the other not –, or why cities, after having lost their initial 1st nature geography advantage, tend to remain instead of disappear as would be suggested by a theory relying solely on 1st nature geography explanations.

This is where scale economies come in. In the presence of such scale economies in the production of certain goods (public or private), there is a strong tendency for the production of these goods to become clustered in agglomerations. Cities, by virtue of their density, are more attractive places for both producers and consumers. They offer knowledge spillovers, thicker labor markets (allowing specialization), more consumption diversity, local public goods unviable in rural areas (defensive walls, opera houses, theatres, etc), and, often, higher wages. Cities' density, however, also has its downsides (diseconomies of scale). Increased congestion, pollution, crime, a higher price of nontradables such as housing (see e.g. Helpman, 1997), fiercer competition among firms on product or factor markets (Krugman, 1991; Fujita and Mori, 1997, Puga, 1999), or having to import agricultural products from ever farther away are some of the examples.

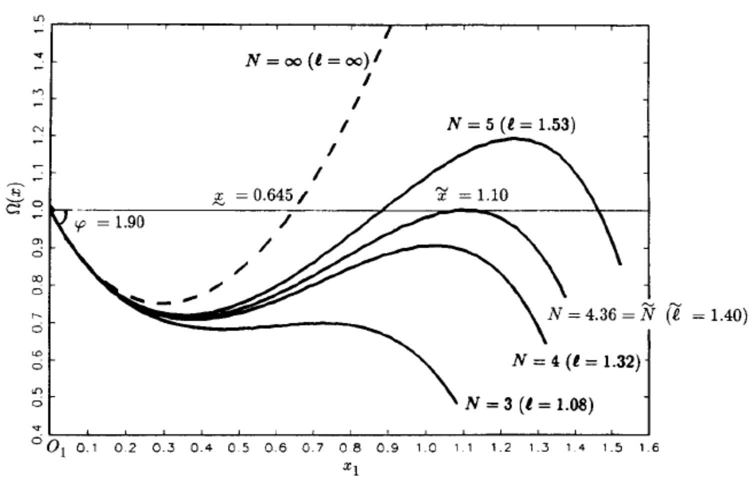
Whether a city forms or not (and how large it will become) thus depends on the balance between the advantages and disadvantages of agglomeration (see Duranton and Puga, 2004 for an overview). If the advantages outweigh the disadvantages, a city is viable and will be formed in a certain location. Also, once established the city creates its own lock-in effect,

[1] In an extreme case, with prohibitively high trade costs, it can happen that no city will be formed at all: it is simply to costly to provide its inhabitants with any food.

i.e. it is there to stay, while at the same time exerting an influence on nearby locations' chances of ever becoming a city.

But, where, will this city appear? Here many of the urban economic theories relying on scale economies and transport costs remain silent: a city's location is either completely disregarded (see e.g. Henderson, 1974 or Black and Henderson, 1999) or the structure of the city system, i.e. the number of possible city locations, is a priori assumed (see e.g. von Thünen, 1826, Krugman, 1991 or Konishi, 2000). Several papers, building heavily on insights from the new economic geography literature (Krugman, 1991), do however explicitly focus on the *where-do-cities-form* question. Started with contributions by Krugman (1993a, 1993b), Fujita (1993), and Fujita and Krugman (1995), these papers (Fujita and Mori, 1996 and 1997; Fujita, Krugman and Mori, 1999 and Behrens, 2007) not only establish theoretically, using fully specified general equilibrium models, under what conditions a city (or subsequent cities) will form, they also make clear predictions about *which locations are more likely to become a city and which locations are not.*

Figure 3. The 2nd nature geography effect of an existing city



Notes: This figure is taken from Fujita and Mori (1996, p.108). The x-axis (x_1) indicates the distance from the already established city, which is located at the origin. The y-axis depicts the value of the so-called market potential function shown in the figure. Locations where the value of the market potential curve exceeds 1 (the solid straight line in the figures), are locations where a new city is viable. *N* denotes overall population.

These papers stress the importance of *2nd nature geography*[1], that is the current distribution of people and economic activity across space, in the process of city formation. A location's chances of becoming a city depend not only on its own characteristics but also on that of the

[1] This is not to say that these papers do not consider 1st nature geography. Fujita and Mori (1997) and Behrens (2007) explicitly consider the effect of spatial inhomogeneities, and their interaction with 2nd nature geography, on the process of city formation.

urban system, already in place, that it is part of. Figure 3 (taken from Fujita and Mori, 1996) illustrates how an already existing city affects other locations' urban chances. It depicts so-called market potential curves that can be interpreted as indicating the chances of a location, located at a distance x from an already existing city at the origin, to become a city too. Whenever a location's market potential exceeds 1[1], it becomes a viable new city location. When total population (N in Figure 3) is small, it will only be viable to have one city (that at the origin). This changes as total population increases, at a certain point it becomes viable for a second city to form. However, not at all locations. A new city will never form too close, or too far from an already existing city (see also Fujita, Krugman and Mori, 1999 and Fujita and Mori, 1996). Only locations at medium range are viable city locations. Being too close to an already existing city induces too strong competition (both for agricultural produce and for inhabitants) with that city (or, not uncommon in medieval times, the existing city uses force to prevent any competitor city forming in its immediate backyard). Being too far away from an already existing city on the other hand, prohibits a potential location to take advantage of (cheap) trade with the already established urban centre, making it a less likely location for a new city. This leaves locations at medium range from existing cities as preferred new city locations: they offer relatively cheap trading possibilities to the already existing cities compared to locations too far off, as well as only limited competition with these same existing cities compared to location at too close range.

Figure 3 totally abstracts from any 1st nature geography advantages (i.e. each potential city location is a priori the same). Fujita and Mori (1996) and Behrens (2007) improve on this and show that locations with a 1st nature transportation advantage produce sharp positive kinks in the market potential function (see Figure A2 in the Appendix), making them more likely future city candidates than other locations without such an advantage. However, 1st nature geography advantages are not the whole story: a location may have a 1st nature geography advantage, but , if located too far from or too close to existing cities, it will still fail to become a city[2].

By introducing an important role for the current state of the urban system in determining its future development, 2nd nature geography offers a substantially different and

[1] See Appendix B and D in Fujita and Mori (1997), for the analytical details of these market potential functions. Also, see section 4.2 in their paper for a more thorough discussion of the market potential curve.
[2] In market potential curve terms: the positive kink is simply not high enough to give that location an overall market potential advantage over other locations at medium range for the existing city.

more dynamic answer to the *where-do-cities-form* question than the much more static[1] explanation offered by 1st nature geography hinging on a priori spatial differences between locations. This makes establishing their (relative) importance the more interesting. In the remainder of this paper we do just that. We construct a dataset on the basis of which we can empirically identify the role of both 1st and 2nd nature in 'sowing the seeds' of the European city system. In doing so we also develop a new empirical strategy to uncover the effects of 2nd nature geography that is closely aligned to the predictions made by economic geography theory.

3 Data and descriptives

Before immediately turning to our estimation results we first discuss the data we use in detail. We focus in turn on our choice of potential city locations, the city-definition we employ, the 1st and 2nd nature geography variables we are considering, and, briefly, some additional non-geography related control variables that we include in several robustness checks. We discuss in particular detail how we incorporate 2nd nature geography into the analysis. We propose a novel way to construct our 2nd nature geography variables that, by corresponding closely to the main theoretical insights presented in section 2.2, improves on earlier work.

3.1 Potential city locations

In order to empirically study the rise of cities in Europe, the first important choice to make is what locations to consider as potential city locations[2]. In principle one could argue that we should consider each possible pair of coordinates as constituting a potential city location. Next, obtain information on each coordinate pair's 1st nature and 2nd nature geography characteristics and establish whether or not it ever was a city during our sample period. This

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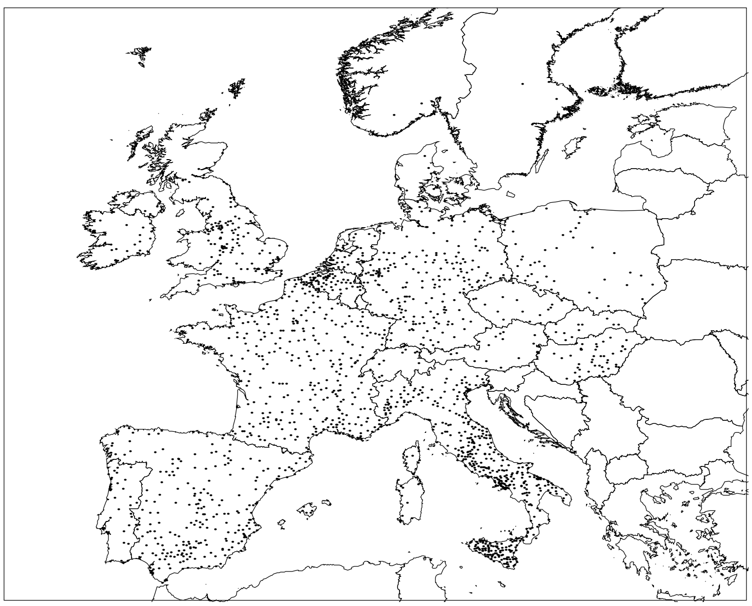
[1] Not completely static however, as the importance of particular spatial inhomogeneities may change over time. A good example is cities formed for defensive purposes only. Often located at impregnable locations, these offer limited possibilities for expansion in more peaceful times. Another poignant example is location near coal reserves. Before the industrial revolution this bore no particular advantage. This changed substantially because of the industrial revolution and we subsequently saw new cities emerge near the vast coal reserves of e.g. the Ruhr area in Germany, north-east England or the Limburg provinces of Belgium and the Netherlands. However with the role of coal increasingly diminishing as oil became the dominant energy source, cities established in these coal-rich areas began (and continue) to wither.

[2] Another prominent choice is the spatial scope of our study. We define Europe as roughly everything west of the line between Trieste and St. Petersburg. This line is well known from the literature on the European Marriage Pattern (see Hajnal, 1965) and is arguably the best approximation of the historical border of the Latin West; it coincides with the border of the Catholic Church during the Middle Ages. Europe thus defined comprises current-day Norway, Sweden, Finland, Poland, Germany, Czech Republic, Slovakia, Austria, Hungary, Belgium, Luxembourg, the Netherlands, France, Great Britain, Ireland, Switzerland, Italy, Spain and Portugal. See also De Vries (1984), Findlay and O'Rourke (2007), or Bosker, Buringh and van Zanden (2009).

however is an almost impossible task. Besides that, most coordinate pairs would turn out never to become a city. As a result these locations do not provide any time-varying information, so that, in any estimation procedure allowing for location-specific fixed effects, these locations would not provide any useful information to determine the coefficients on the variables of interest.

For the above-mentioned (practical and empirical) reasons, we do not consider each possible coordinate pair as constituting a potential city location. Instead, we define potential city locations according to one of two criteria that results in considering all locations shown in Figure 4 as a potential city location.

Figure 4. Potential city locations in the sample



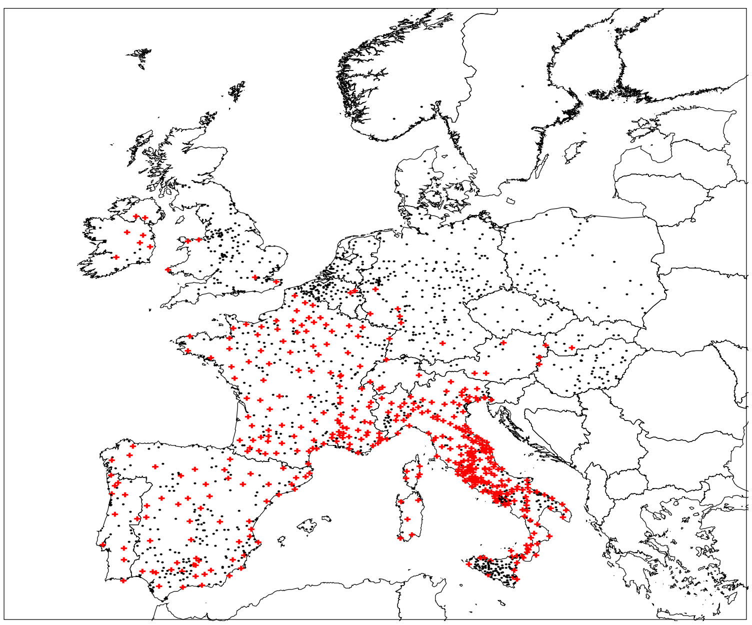
Notes: each black dot represents a potential city location.

The first group of potential city locations we consider is all locations documented in Bairoch (1988). Bairoch (1988) provides population estimates by century for all cities that in some century have more than 5000 inhabitants during the period 800 – 1800 A.D. This gives us a total of 1588 potential city locations. Note however, that by using this criterion we effectively obtain a set of *actual*, and not *potential*, *city*, locations because we know for certain that each of these locations will, in some century between 800 and 1800, become a city according to our definition specified in section 3.2 below.

This is not true for our second group of potential city locations. Here we use the insights from the urban history literature (see section 2.1) and define these locations on the basis of having been a bishopric in 600[1]. We consider these places as potential city locations, given the fact that they were, in 600, important enough to the Catholic Church to turn them into the seats of one of its (arch)bishops. The assumption is that this important role in 600 makes them perfect candidates for possible future (urban) centres as well. A defendable assumption we think, given that – as also outlined in section 2.1 above – locations with an important ecclesiastic function often played an important role in maintaining some urban continuity during the collapse of the Roman urban system in Europe in the early Middle Ages: *"Urban continuity was greatest, of course, in the cases of episcopal centers, although the extent of urban activity outside the walls of the bishops' fortified palaces must have varied widely."*(Hohenberg and Lees, 2004 p.58).

All known bishoprics in Europe are well-documented in Jedin et al. (1980)'s Atlas zur Kirchengeschichte. Figure 5 below shows the location of all these (arch)bishoprics in 600.

Figure 5. (Arch)bishoprics in 600



Notes: (Arch)bishoprics in 600 are denoted by a red cross, other potential city location are denoted by black dots.

In total we found 456[2] such locations in Europe, mostly concentrated in Southern Europe (France, Spain and Italy). This reflects to a large extent the fact that the Catholic Church built on the vestiges of the Roman empire that was heavily oriented towards the Mediterrenean. In

[1] We choose the year 600 as it preceeds the muslim conquests of the Iberian peninsula and parts of Italy (Sicily), so that throughout the region of the former western Roman Empire Catholicism was the predominant religion.
[2] All towns indicated on the maps with different locations but sometimes with similar names have been classified as a separate bishopric.

several robustness checks, we assess the sensitivity of our results to this possible 'Roman empire bias' by restricting our sample to either the *Bairoch*-cities or the countries with (arch)bishoprics present in 600 only. Of these 456 (arch)bishoprics in 600, 260 (or 57%) were already part of our dataset as they were also covered in the Bairoch (1988) dataset. It is the other 196 (or 43%) that provide us with an interesting 'control group', i.e. locations that could have become a city but did not do so during our sample period[1].

Combining the potential city locations selected on the basis of one or both of the above-outlined selection criteria leaves us with a total number of 1784 potential city locations. Table 1 provides some additional detail on the geographical distribution of these potential city locations, documenting how many of these city locations are found in each of the (current-day) European countries in our sample as well as indicating the % of locations that had an (arch)bishop in 600 and the % of locations that eventually became a city according to our definition. It is this definition to which we turn next.

Table 1. Potential city locations

country	# potential city locations (% total sample)	% potential city locations with a (arch)bishop in 600	% potential city locations to become city
Austria	16 (0.9)	25.0	75.0
Belgium	58 (3.3)	1.7	100
Czech Republic	17 (1.0)	0	100
Denmark	8 (0.4)	0	100
Finland	1 (0.1)	0	100
France	341 (19.1)	34.6	90.3
Germany	209 (11.7)	2.9	100
Hungary	48 (2.7)	4.2	97.9
Ireland	27 (1.5)	25.9	77.8
Italy	497 (27.9)	48.1	73.6
The Netherlands	44 (2.5)	2.3	100
Norway	6 (0.3)	0	100
Poland	46 (2.6)	0	100
Portugal	33 (1.8)	30.3	93.9
Slovakia	12 (0.7)	0	100
Spain	255 (14.3)	22.8	94.5
Sweden	8 (0.4)	0	100
Switzerland	15 (0.8)	33.3	86.7
UK	143 (8.0)	3.5	97.9
total	1784	25.6	89.0

Notes: The numbers in the third column are based on the city definition explained in section 3.2, i.e. agglomerations with at least 5000 inhabitants.

3.2 City definition

In this paper we classify a location as being a city as soon as it has at least 5000 inhabitants.

[1] Note that, as already mentioned in the paragraph below Figure 4, such a control group does not add much as soon as one allows for location specific fixed effects when estimating (1) given the fact that these never-to-become-a-city-locations do not show any time-variation in the dependent variable.

In doing so, we basically adopt the definition proposed by Bairoch (1988). He gives the following two reasons for this definition (see also p.137/138 of his book for a more extensive discussion):

a) *"a population of 5,000 is* [...] *a criterion that may be questionable in certain respects but which nevertheless remains for all that the most adequate and especially the most operational."* (p.494)

b) *"One of the essential reasons for adopting the criterion of 5000 is that the margin of error for the number of people living in cities 2000 – 5000 people is much greater than that for the number living in cities of more than 5000 people."* (p.218)

Using this absolute size criterion of 5000 inhabitants to define a city may in certain cases be too low and thus wrongly ascribe an urban role to a location (see e.g. Malanima (1998a,b) on Sicilian agrotowns). On the other hand, the opposite, i.e. the cutoff being to high, has also been argued, especially for the early medieval period [see Bairoch, 1988 p.217; or Dyer, 1995].

The alternative to our employed absolute population cutoff would be to either define a city according to a size criterion that is allowed to change over time (see e.g. Black and Henderson, 1998), or to define cities on the basis of more than just its total population, such as having city rights, or certain economic (presence of a market, fair or mint), religious or institutional features.

The former, although arguably useful when looking at aggregate features of the urban system (such as the overall city size distribution or overall urbanization rates), would in our case, focussing on the probability of a certain location becoming a city, result in several conceptual difficulties that have to do with the composition of our sample. Suppose for example that we let our cutoff increase each century by 1000 inhabitants. In an extreme case, a city that in 900 for the first time has 5000 inhabitants and over the next centuries increases its population by 1000 inhabitants each century, would be classified as becoming a city in each century. Similarly, a city, that we classify as becoming a city in a certain century but that does not further increase its population thereafter, would, when using such an increasing city definition, in the following centuries lose its city status without losing any of its inhabitants. Given these complications, and the fact that there is no a priori preferred way to let the size criterion change over time, we opt for the use of an absolute size criterion.

The other alternative, defining cities on more criteria than population size only, would, in the words of Bairoch (see a) above), be much less operational (see also De Vries, 1984 p.21/22). Not only would this constitute a very time consuming exercise. Also, to agree on what features a certain town would have to have in order to qualify as a city would be subject to much debate. Are city rights sufficient, or should it also have a fair, a market or a mint in order to qualify as a city? And, if so, should these fairs or markets be of a certain size, or of regional importance, before a location qualifies as being a city? Even if we were to agree on which features to include in this city definition, the substantial institutional, political and religious differences between the different societies in Europe further complicate the tasks of consistently applying this definition. E.g., city rights in one part of Europe would not necessarily be directly comparable to those in other parts.

The use of an absolute population cutoff to define a city, in our view, avoids these issues of comparability, making the city definition much less subjective, more transparent, and much more up to scrutiny as one can easily compare the results using different population cutoffs[1]. Using our absolute size criterion of 5000 inhabitants, we find that 1588 of our potential city locations do, at least once, qualify as being a city over our sample period (see Table 1 for a country by country decomposition). Also, as Figure 1 already showed, the number of cities increases steadily over our sample period, from 34 in 800 to 1478 in 1800[2]. Table 2 complements Figure 1, by showing the unconditional probability of becoming a city in any century during our sample period, which turns out to be about 12%.

Table 2. Gaining / losing city status

P(gaining / losing / maintaining city status)		
	all locations	
city time t \ t-1	Yes	No
Yes	2105 (85%)	1809 (12%)
No	365 (15%)	13651 (88%)
	no 1400 & 1700 (Black Death)	
city time t \ t-1	Yes	No
yes	1480 (93%)	1586 (13%)
no	**114 (7%)**	11092 (87%)

Table 2 also shows evidence of a lock-in effect (briefly touched upon in section 2.2): the unconditional probability of a city losing its city status is only 7% if one does not consider the devastating effects of the big plague epidemics that swept through Europe in the 14th and 17th

[1] We will do this in our empirical section.

[2] See Table A1 in the Appendix for a century by century decomposition of the number of cities, showing a steady increase in this probability culminating in the 18th century (which saw the largest increase in the number of cities).

century. *"beyond a certain size, once a certain threshold has been crossed, cities rarely die"* (Bairoch, 1988 p.496). Even when using the threshold of 'only 5000 inhabitants' this appears to be true. This finding makes looking at the probability of becoming a city the more interesting. Once a city is established in a certain location, it is almost always there to stay (see also Hohenberg, 2004).

3.3 Explanatory variables determining city creation

Having specified our dependent variable in detail, we now turn to the discussion of the explanatory variables we include in our analysis to capture the effect of 1st and 2nd nature geography[1].

3.3.1 1st nature geography

The first thing we did was locate each potential location by establishing its coordinates (its longitude and latitude) from *http://www.heavens-above.com*, a website that provides the coordinates of over 2 million places in the world. Next, to capture a location's 1st nature characteristics we collected information on each location's possibilities for water- and land-based transportation. More specifically we construct dummy variables that indicate whether or not a location has direct access to the sea, to a navigable waterway, and if it was located on the old Roman road network. The information concerning location at sea or on navigable waterways is from Dumont and Mieremans (1959). When a town was lying along a waterway that is presented on one of the maps in the Atlas with a scale of at least 1:2,000,000, it is classified as being located on a navigable waterway. It is classified as located at sea when there was a possibility to beach or harbor boats along the coast where the city was located.

The information on the presence of a Roman road was collected from Talbert (2000). Besides classifying whether or not a location was located on a (former) Roman road, we also classified locations where two (or more) Roman roads crossed as hub locations. To determine if a potential city location was lying on a Roman road or was located at sea, the original location of the city and coastline was used, and not the current, sometimes much more extensive, surface that a city occupies nor the current position of the coastlines. Finally we also collected information on each potential location's elevation (again from *http://www.heavens-above.com*), as a proxy of both its accessibility and its agricultural possibilities.

[1] Table A2 in Appendix A complements the discussion in this section by providing several descriptive statistics for both all potential city locations as well as for those potential locations that become a city at some point only.

The latter, accurate information on each location's agricultural possibilities is arguably the most important piece of information missing from our dataset. Agricultural conditions are by many viewed as one of the most crucial 1st nature geography determinant of a location's urban prospects (see Pirenne, 1922; Bairoch, 1985 or Duranton, 1999). So far we have not been able to find any accurate location-specific information on agricultural conditions. It would require collecting information on each location's soil conditions as well as, and even more difficult to come by given their time-varying nature, location specific climatic conditions by century. In the absence of such data, our strategy to overcome this difficulty is to capture the possibly time-varying agricultural conditions by including *country-century* specific fixed effects in our baseline estimations. In robustness checks, we also show results including *ecozone-century* effects, where we use a division of Europe on the basis of agricultural potential (see Buringh et al., 1975). Based on the local soil classification and local climate data (water, light, evaporation, etc.), that in combination govern the potential local agricultural production, Buringh et al. (1975) identify five different types of regions in Europe ranging from very high (e.g. the Po Valley) to very low (e.g the Alps, Pyrenees, or northern Scandinavia) agricultural potential. Besides including these ecozone-century effects, we also provide results that allow for time-varying geographically clustered unobserved effects by grouping locations on the basis of their coordinates instead of the country they are part of. Finally, we also show results controlling for time-invariant *location-specific* fixed factors that may be correlated with the variables of interest[1].

3.3.2 2nd nature geography

We propose a novel way to adequately capture the effect(s) of 2nd nature geography. We construct several dummy variables that, in our view, are much better able to put the insights from section 2.2 into practice than the measures of 2nd nature geography that have thus far been used in the empirical urban literature. The most commonly used measure is a location's market or urban potential (see e.g. De Vries, 1984; Black and Henderson, 2003; Dobkins and Ioannides, 2001; Ioannides and Overman 2004; Bosker et al., 2008). This measure, which we will, as De Vries (1984), refer to as a location's *foreign urban potential (FUP)* is the distance weighted sum of the population of all other, already existing, cities[2].

[1] We also add a location's longitude and latitude as additional proxies for agricultural conditions.

[2] Sometimes additional weights are introduced in (3). For example cities with higher wages are given more weight than others (Ioannides and Overman, 2004) or, alternatively, the distance between cities that both share favourable conditions for transport, e.g. both are located at sea, is downweighted (Bosker et al, 2008).

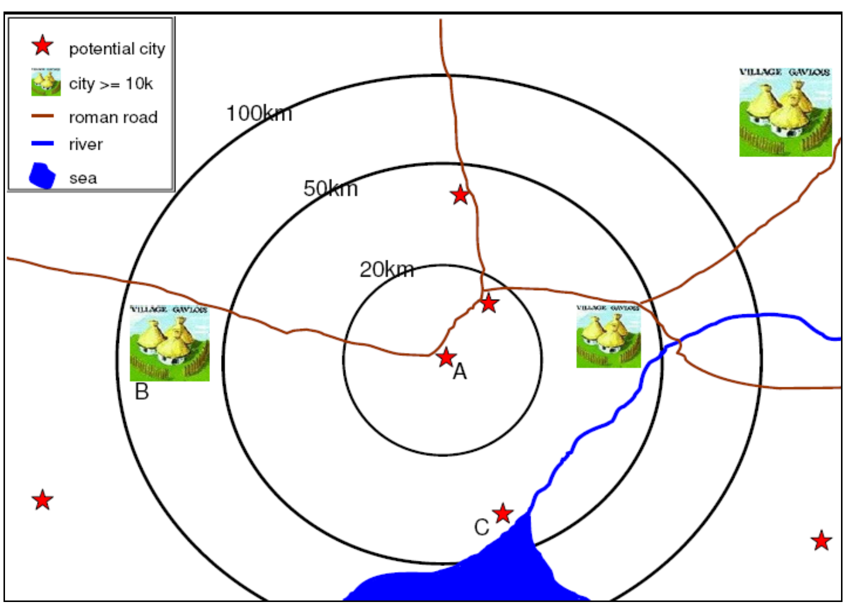
$$FUP_i = \sum_{j=1, j\neq i}^{N} \frac{pop_j}{D_{ij}} \qquad (3)$$

We argue that such *FUP*-type measures do not do justice to the theory when looking at the establishment of new cities. The way *FUP* is constructed allows the impact of 2nd nature geography to diminish with the size of, and distance to, other already existing cities. But, using this measure of 2nd nature geography implicitly assumes that the impact of the urban system already in place on a location's urban chances is either always negative or always positive (depending on the sign of the estimated coefficient on *FUP*).

This is clearly too strong a restriction when looking at Figure 3. That figure showed that an existing urban centre exerts a strong urban shadow, prohibiting the formation of new cities at close range. Being too close to an existing centre clearly does not help a location's chances of ever becoming a city. Also, potential locations that are too far removed from the already existing cities have little chance of becoming a city. It are those locations that are located at medium distance from an already existing city that have the best urban chances. In sum, theory predicts that an existing city exerts a non-linear effect on its surroundings: a negative effect at close range, a positive effect at medium range, and again a negative effect at large range. *FUP*-type measures fail to adequately capture this.

To do more justice to the insights from theory, we adopt the following dummy variable approach. We draw three concentric circles around each potential city location at ever further distance.

Figure 6. Constructing dummy variables to capture 2nd nature geography.



Next, we construct three dummy variables that indicate whether or not we find at least one already existing urban centre within each of the three constructed distance bands. And, to capture possible competition effects between potential city locations, we also create three dummy variables that indicate whether or not we find at least one other potential city location within each of the distance bands.

Furthermore, we can allow for even more flexibility, and construct additional dummy variables indicating e.g. the presence of more than one already-existing city, or competitor locations with certain 1st nature characteristics within each of the specified distance bands. Using this dummy variable approach does not constrain the effect of 2nd nature geography to be positive or negative at all distances[1] as the use of *FUP*-type measures does.

Figure 6 illustrates in some more detail how we construct these dummy variables in case of a hypothetical potential city location, A. In case of location A, the dummy variables indicating the presence of an established urban centre are 1 in case of the 20-50km distance band and the 50-100km distance band dummy variable (there are no already existing urban centres within 20km of A). Instead, the dummy variables indicating the presence of a competitor potential location are only 1 in case of the 0-20km and 20-50km distance band dummy variables (there is no competitor between 50-100km from A). These competitor dummy variables can easily be extended to e.g. take account of the 1st nature characteristics of possible competitor locations. To do this we would construct additional dummy variables indicating e.g. the presence of a competitor located at sea (in case of A only within the 20-50km distance band) or the presence of a competitor located at a hub of roman roads (in case of A only in case of the 0-20km distance band). Similarly, we could also further extend the already existing city dummy variables, by e.g. creating additional dummy variables indicating the presence of at least two existing cities within each of the distance bands (which would always be 0 in case of A).

In the above-outlined fashion, we construct several already-existing-city-, and competitor-dummy variables for each of the 1784 potential city locations in our sample in each of the 11 centuries we consider[2].

In our baseline estimations we include six dummy variables. Two for each distance band (defined as 0-20, 20-50 and 50-100km from a potential city location), indicating the presence of:

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[1] It does constrain the effect to be the same within each distance band. But, one can experiment with different distance bands (see the section 5.1.2).
[2] We calculate great circle distances between locations on the basis of each location's coordinates to construct the three distance bands around each city.

1) at least one already existing city larger than 10000 inhabitants[1]
2) at least one competitor location

But in further extensions (see section 5.2) we also consider more elaborately specified dummy variables of the type explained in the paragraph below Figure 6.

3.3.3 Non-geography related (control) variables

Finally, to complete our data section, we briefly mention some other variables we include in some of the robustness checks to our baseline specification. These concern the political, religious and educational characteristics of a location. We know for each location in any of the centuries we consider whether or not it was home to a bishop or archbishop, whether or not it was the capital of a large political entity, and whether it had a university or not. These data are the same as those used in Bosker et al. (2009) and we refer to the Data Appendix of that paper for more detail on these non-geography related variables[2]. Finally, given the important role of total population size discussed in section 2.2, we include the total population size and the growth in population size of the (current-day) country a location belongs to in some specifications of our estimated model. This data is taken from McEvedy and Jones (1979). Note however that in most specifications these variables drop out given that they are fully captured by the included country-century fixed effects.

4 Empirical framework

Having discussed our dataset in detail, this section spells out the empirical framework that we use to empirically quantify the effect of a location's 1st and 2nd nature geography characteristics on its chances of becoming a city *given that is was not already a city*. We specify the following empirical model for the probability of becoming a city conditional on not already being a city one century before:

$$P\left(c_{ict}=1 \mid c_{ict-1}=0, X_{ict-1}, X_i, \alpha_{ict}\right)=F\left(X_{it-1}\beta_1+X_i\beta_2+X_{ct-1}\beta_3+\alpha_{ict}\right) \tag{1}$$

In most of the paper F denotes the CDF of the standard normal distribution, Φ (i.e. we estimate a probit model), but in robustness checks we also allow it to be the logistic function

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[1] We construct the dummy variables on the basis of existing cities larger than 10000 inhabitants instead of 5000 inhabitants to limit possible endogeneity issues from including a spatially lagged variable. We will further limit endogeneity issues by considering these dummy variables lagged one century (see section 4).

[2] This can be downloaded at http://maartenbosker.googlepages.com/bagdadnaarlondon-dec2008.pdf.

(a logit model) or simply be I, the identity function (a linear probability model[1]). c_{ict}, the dependent variable, is a dummy variable indicating whether or not location i in country c is a city at period t, X_{it-1} are variables at the location level in period $t-1$ that possibly vary over time, X_i are time *in*variant variables at the location level, and X_{ct-1} are variables at the country level in period $t-1$ that possibly vary over time. We include the time-varying variables lagged one century to limit potential endogeneity issues resulting from possible simultaneity. Finally, α_{ict} captures any unobserved effects at the city, country or century level. In the main specification we specify the unobserved effects to be *country-century-specific* fixed effects: $\alpha_{ict} = \alpha_{ct}$. We also show, in various robustness checks, results allowing for a less, or more, strict specification of the α_{ict}, (1) including *country and century specific* fixed effects: $\alpha_{ict} = \alpha_t + \alpha_c$, (2) assuming away any unobserved heterogeneity: $\alpha_{ict} = \alpha$, or (3) also capturing unobserved heterogeneity at the location-level by [see Wooldridge, 2005] specifying the distribution of an unobserved *location-specific* effect conditional on the initial value of c_{ict}, c_{ic800}, the individual specific mean of X_{it}, $\overline{X}_{i\cdot}$, and the country-century specific fixed effects, α_{ict}: $\alpha_{ict} = \alpha_{ct} + c_{ic800}\zeta + \overline{X}_{i\cdot}\xi + \eta_i$, with $\eta_i \mid \alpha_{ct}, c_{ic800}, \overline{X}_{i\cdot} \sim N(0, \sigma_\eta^2)$.

Note that instead of, but equivalent to, (1) we could also estimate a full dynamic model of the probability of being a city at period t with all included variables also present interacted with c_{ict-1}:

$$\begin{aligned} &P(c_{ict} = 1 \mid c_{ict-1}, X_{ict-1}, X_i, \alpha_{ict}) = \\ &\quad F\left(X_{it-1}\beta_1 + X_i\beta_2 + X_{ct-1}\beta_3 + \alpha_{ict} + X_{it-1}c_{ict-1}\beta^1 + X_i c_{ict-1}\beta^2 + X_{ct-1}c_{ict-1}\beta^3 + \alpha^{ict}c_{ict-1}\right) \end{aligned} \tag{2}$$

This would give the same estimation results for our parameters of interest, the β_i's, as when estimating (1). As (1) is merely a special case of (2), (2) helps in establishing the conditions under which estimating (1) using only those observations for which $c_{it-1} = 0$, and thus discarding those observations for locations that have already become a city, gives us consistent estimates of the parameters of interest. We will come back to this issue in our results section.

5 *Results*

Table 3 builds up to our baseline result. As our baseline 1st nature geography variables [the X_i

[1] In this case we need to add an error term to (1). This is implicit in the probit or logit case, by defining F to be a normal or logistic distribution function.

in (1)] we include the dummy variables for location at sea, at a river, on a crossing of two or more roman roads (hub), and on a roman road. Besides these transport related 1st nature geography variables, we also include the log of a location's elevation (in meters), that besides proxying for a location's ease of access, also serves as a crude indication of a location's agricultural possibilities. As our baseline 2nd nature geography variables [the X_{it-1} in (1)], we include the six dummy variables that were discussed in the last paragraph of section 3.3.2. Finally, in the first two columns of Table 3, we include the log of the total population of the current-day country that a location belongs to (also lagged one century), as well as that country's population growth during the preceding century [the X_{ct} in (1)].

Table 3. Baseline results

P(city t | no city t-1)	1	2	**3 (BASELINE)**
ln country population (t-1)	0.057***	0.077***	-
	[0.000]	[0.000]	-
D country population (t-1 -> t)	0.424***	0.188***	-
	[0.000]	[0.000]	-
sea	0.031***	0.031***	0.036***
	[0.002]	[0.000]	[0.000]
river	0.044***	0.060***	0.070***
	[0.000]	[0.000]	[0.000]
hub	0.005	0.018**	0.018**
	[0.581]	[0.022]	[0.027]
road	-0.027***	-0.012**	-0.013**
	[0.000]	[0.019]	[0.021]
ln elevation	0.000	0.001	0.001
	[0.847]	[0.772]	[0.780]
city >= 10k? (t-1)			
0 - 20 km	0.041***	-0.002	0.000
	[0.000]	[0.758]	[0.994]
20 - 50 km	0.049***	0.009*	0.012**
	[0.000]	[0.055]	[0.022]
50 - 100 km	0.058***	0.006	0.010*
	[0.000]	[0.176]	[0.055]
competitor? (t-1)			
0 - 20 km	-0.036***	-0.011**	-0.014***
	[0.000]	[0.021]	[0.006]
20 - 50 km	-0.064***	-0.004	-0.006
	[0.000]	[0.626]	[0.525]
50 - 100 km	-0.076***	-0.016	-0.028
	[0.001]	[0.430]	[0.236]
country FE	no	yes	-
century FE	no	yes	-
country/century FE	no	no	yes
nr observations	15322	15322	13341
ln pseudo likelihood	-4574.4	-3474.1	-3243.0
LR – test statistic	-	2201	462.2
5% critical value χ^2(n)	-	42.6 χ^2(29)	212.3 χ^2(180)

Notes: p-values between square brackets. *, **, *** denotes significance at the 10%, 5%, 1% respectively. Instead of the estimated coefficient in (1), the table reports average partial effects. The p-values are however based on the estimated coefficient and their standard errors. If a likelihood ratio test statistic and a 5% critical value are reported in a column, they are used to test whether or not the specification in that column is statistically preferred over the preceding column (to the left).

Going from column 1 to column 3, we move from a very strict definition of the unobserved α_{ict} to our preferred specification of the α_{ict} that allows for unobserved country-century-specific variables to control for unobserved country ànd century specific factors influencing a location's urban chances, most notably a location's agricultural or climatic conditions. But at the same time, the included country-century specific dummies in column 3 also capture economic or institutional developments at the country level that may leave their effect on a location's chance to become a city.

Note that the results in Table 3 and, unless noted explicitly, all other results in the paper, do not show the estimated coefficients of (1), but the Average Partial Effects (APEs) that are calculated on the basis of these. The estimated coefficients of any nonlinear model (such as a probit or logit model) are only useful to assess the significance, direction (positive or negative) and relative importance (compared to the other included variables) of each included variable's effect. They do not show the absolute magnitude of a variable's impact, which is often what most interests us. To get at this we calculate APEs (see e.g. Wooldridge, 2005), that are an estimate of the derivative of the expected value of the independent variable with respect to the included variables of interest; e.g. in case of X_{it-1}:

$$\frac{1}{NT}\sum_{it}\frac{\partial F\left(X_{it-1}\hat{\beta}_1 + X_i\hat{\beta}_2 + X_{ct-1}\hat{\beta}_3 + \hat{\alpha}_{ict}\right)}{\partial X_{it-1}} = \hat{\beta}_1\frac{1}{NT}\sum_{it}F'\left(X_{it-1}\hat{\beta}_1 + X_i\hat{\beta}_2 + X_{ct-1}\hat{\beta}_3 + \hat{\alpha}_{ict}\right) \quad (3)$$

In case of the linear model, i.e. with F the identity function, this would simply be $\hat{\beta}_1$. When F is a nonlinear function, this is no longer so.

Column 1 shows the results when ignoring any potential unobserved heterogeneity by assuming that $\alpha_{ict} = \alpha$. Under this strict assumption, we find that of the 1st nature geography variables, location at sea and on a river significantly positively affects a location's chances of becoming a city, whereas location on a roman road has a surprising negative effect. Being located on a hub of roman roads has or at a higher altitude does not significantly affect a location's urban chances. In contrast, *all* the 2nd nature geography variables are significant under the assumption stated above. This suggests strong evidence for potential city locations, surrounded by other already existing cities at close or medium-large distance, to have much higher chances of becoming a city than more isolated city locations. On the contrary, and as expected, fiercer competition from other potential city locations at close or medium-large range diminishes a location's own urban chances. Finally, note that both the size and the growth rate of a country's total population have a very significant and, as expected, positive effect on the urban chances of all locations within that country.

Turning to the 2nd column we see that the above conclusion is far too preliminary. When loosening the assumption on the unobserved heterogeneity by allowing for country- (but century-invariant) and century- (but country-invariant) specific fixed effects, i.e. $\alpha_{ict} = \alpha_c + \alpha_c$, the above results change substantially. First note that this specification of the α_{ict} is statistically preferred (see the likelihood ratio test reported at the bottom of column 2) over assuming away any unobserved heterogeneity. The results regarding the included 1st nature geography and overall country population variables hardly change, although we now do find the expected significantly positive effect of being located on a hub of overland transport routes.

The results on the 2nd nature geography variables however change substantially. This is not that surprising. A location that is located in a country that is, for unobserved reasons (most notably agricultural conditions), a good seedbed for city development, will have a high probability of becoming a city. But, so do other locations in the same country, so that this location is also more likely to already be surrounded by some existing cities. When not adequately controlling for geographically clustered unobserved heterogeneity, one will thus easily, and wrongly so, ascribe an important effect to 2nd nature geography.

This is exactly what happens, the included 2nd nature geography variables are much less significant than in column 1. Strikingly however, the 2nd nature geography results become much more in line with the theoretical predictions following from the standard economic geography models discussed in section 2.2. We find clear evidence of the nonlinear effect that an already existing city is predicted to have on other locations' urban chances. The effect of another already existing city is only significantly positive at medium range (20-50km). Being located too close (0-20km) or too far (50-100km) from an already existing city does not significantly affect a location's probability to become a city. On the contrary, the results on the competitor dummy variables shows that competition with other potential locations is fiercest at close range: only having a rival potential location within 0-20km diminishes a location's own chances to become a city.

The above results hold up, or become even stronger, in our preferred baseline specification of the α_{ict}, controlling for possibly time-varying heterogeneity at the country level by allowing for country-century specific fixed effects (i.e., $\alpha_{ict} = \alpha_{ct}$). This specification of the unobserved heterogeneity is preferred over including only country- and century specific dummies (again see the likelihood ratio test at the bottom of column 3). So that we can summarize our baseline results as follows:

1) *1st nature geography* is very important in determining a location's urban chances. Especially preferential location for *water-based* transport substantially increases a location's probability to become a city (confirming earlier results by Acemoglu et al., 2005 and Bosker et al., 2008): 7 ppt in case of location on a navigable waterway and 3.6 ppt in case for coastal locations, compared to 'only' 1.8 ppt for location on a hub of overland transport routes.

2) *2nd nature geography* is also important, but to a lesser extent. What is extremely interesting however, is that our flexible modelling strategy uncovers almost the exact prediction made by theory of a nonlinear effect of the urban system already in place on a location's chances to become a city. Only those locations at medium range (20-100km) from already existing cities have better urban chances. These locations have about a 1 ppt higher probability to become a city than locations located closer than 20km to, or more than 100km away from, already existing urban centres. On the contrary, competition with other potential locations is fiercest at close range. Only a competitor within the nearest 20km diminishes a location's urban chances by about 1.4 ppt.

These are our baseline results. In the rest of the paper, we will show that these results hold up to a wide variety of robustness checks. Besides that, we will refine the results in two important ways. The most important extension is the finding that the above-reported effect of 2nd nature geography only starts to appear from the 17th century onwards, whereas the effect of 1st nature geography somewhat diminishes over our sample period. Besides that, we show refinements of both the already-existing-city- and the competitor-dummy variables along the lines discussed in section 3.3.2, e.g. allowing the competition effect to depend on the 1st nature characteristics of a location's competitors or allowing the effect of already existing cities within each distance band to depend on their number or total population size.

5.1 Robustness

5.1.1 Estimation technique

The first robustness checks, reported in Table 4 below, concern the estimation technique that we use to obtain our baseline results. First, we change the assumption made on F in (1). Instead of assuming F to be the standard normal CDF, column 1 and 2 show the results when taking the logistic distribution function or the identity function instead, and estimating (1) using logit or OLS techniques respectively. This shows that our baseline results do not crucially depend on the assumption made on *F* (except that location on a hub of roman roads turns insignificant when using OLS).

Second, we estimate (2) instead of (1). The results in column 3 show that, as claimed in section 4, estimating (1) is indeed equivalent to estimating (2). The estimated coefficients of interest, i.e. those on the left-hand side of column 4, are virtually equivalent to our baseline results in Table 3. Focussing on the restricted sample (selecting on not being a city one century before) is warranted as long as there are no *unobserved factors* that are associated with both becoming city and remaining a city once established. In our baseline estimations we control for any such unobserved factors by allowing for *unobserved time-varying* heterogeneity at the *country* level (including country-century specific dummies).

Besides that one could stress the need to also control for *unobserved time-invariant* factors at the *location level*[1] and further specify α_{ict} to allow for time-invariant heterogeneity at the location level. However, allowing for such location-specific unobserved heterogeneity when employing non-linear panel data techniques (such as in our baseline probit or the logit case) is not as straightforward as in linear panel data models, where one can simply include a dummy variable for each location and obtain consistent estimates of the parameters of interest (see e.g. Heckman, 1981; Wooldridge, 2005; Fernández-Val, 2009 or Carro, 2007). In our baseline probit, or in the logit, case, including such dummy variables results in inconsistent estimates of the parameters of interest (unless one has a large *T*-dimension, which is not so in our case where $T = 10$).

To get around this problem when employing probit techniques, we use the conditional random effects (CRE) strategy proposed by Wooldridge (2005) and specify the distribution of the unobserved *location-specific* effects conditional on the individual specific mean, $\overline{X}_{i\cdot}$, of the included X_{it-1} variables, the country-century specific fixed effects, α_{ct}, and given the dynamic nature of our empirical model a location's initial city status in 800, c_{ict800}, i.e.: $\alpha_{ict} = \alpha_{ct} + c_{ic800}\zeta + \overline{X}_{i\cdot}\xi + \eta_i$, with $\eta_i \mid \alpha_{ct}, c_{ic800}, \overline{X}_{i\cdot} \sim N(0, \sigma_\eta^2)$. Under this assumption for the *location-specific* unobserved heterogeneity, we can employ random effect probit techniques to get consistent estimates of our parameters of interest.

[1] Our baseline results are only valid under the assumption of no such time-invariant location-specific heterogeneity (even when this heterogeneity is uncorrelated with the variables of interest, i.e. random effects, would we get incorrect estimates of our parameters of interest). Also controlling for *unobserved time-varying* factors at the city level is virtually impossible unless actual data is available on such factors (making them *no longer unobserved*). In column 1 and 2 of Table 5 we include several of such *time-varying* variables at the location-level to our baseline empirical model.

Table 4. Robustness (estimation technique)

P(city t | no city t-1)	logit	LP	estimating (2) instead of (1)		CRE	FE logit[a]	FE LP	ecozones/ century FE	blocks/ century FE
			if no city at t-1	if city at t-1					
sea	0.035***	0.026***	0.034***	0.050	0.033***	-	0.033***	0.033***	0.033***
	[0.000]	[0.001]	[0.000]	[0.111]	[0.001]	-	-	[0.000]	[0.001]
river	0.071***	0.056***	0.067***	0.076***	0.065***	-	-	0.059***	0.068***
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	-	-	[0.000]	[0.000]
hub	0.015*	0.012	0.017**	0.080***	0.018**	-	-	0.014*	0.017*
	[0.075]	[0.113]	[0.027]	[0.000]	[0.017]	-	-	[0.076]	[0.055]
road	-0.016***	-0.015***	-0.012**	0.033*	-0.011**	-	-	-0.015***	-0.006
	[0.006]	[0.004]	[0.021]	[0.096]	[0.038]	-	-	[0.002]	[0.336]
ln elevation	0.002	0.001	0.001	-0.029***	0.000	-	-	0.001	-0.002
	[0.446]	[0.511]	[0.780]	[0.000]	[0.899]	-	-	[0.529]	[0.509]
city >= 10k? (t-1)									
0 - 20 km	0.003	0.000	0.000	0.002	-0.002	0.081	-0.002	0.003	-0.006
	[0.715]	[0.961]	[0.994]	[0.938]	[0.827]	[0.807]	[0.910]	[0.708]	[0.509]
20 - 50 km	0.013**	0.012***	0.011**	0.010	0.024***	0.739***	0.039***	0.013***	0.015**
	[0.015]	[0.029]	[0.022]	[0.591]	[0.001]	[0.000]	[0.000]	[0.006]	[0.010]
50 - 100 km	0.012**	0.009*	0.010*	-0.011	0.005	-0.102	0.007	0.013***	0.012**
	[0.041]	[0.058]	[0.055]	[0.593]	[0.413]	[0.584]	[0.360]	[0.005]	[0.050]
competitor? (t-1)									
0 - 20 km	-0.014**	-0.012**	-0.014***	-0.003	-0.010	-0.147	-0.023	-0.014***	-0.009
	[0.011]	[0.015]	[0.006]	[0.857]	[0.460]	[0.701]	[0.320]	[0.002]	[0.102]
20 - 50 km	-0.006	-0.007	-0.006	0.083***	-0.005	-0.808*	-0.016	-0.008	-0.004
	[0.576]	[0.524]	[0.525]	[0.000]	[0.775]	[0.060]	[0.568]	[0.365]	[0.717]
50 - 100 km	-0.028	-0.023	-0.027	0.008	0.065	0.368	0.059	-0.018	-0.020
	[0.238]	[0.313]	[0.236]	[0.866]	[0.197]	[0.440]	[0.120]	[0.382]	[0.388]
country/century FE	yes	yes	yes		yes	country trends	yes	no	no
nr observations	13341	15322	15968		13341	13386	15322	14937	11827

	# (%) of-the-chart predictions	**p-values H0: $\beta^i = 0$**	# (%) of-the-chart predictions	
sea	in sample	[0.111]	in sample	
river	2528 (17%)	[0.000]***	7666 (50%)	
hub	total	[0.000]***	total	
road	6830 (35%)	[0.096]*	11968 (61%)	
ln elevation		[0.000]***		
city >= 10k? (t-1)				
0 - 20 km		[0.938]		
20 - 50 km		[0.591]		
50 - 100 km		[0.593]		
competitor? (t-1)				
0 - 20 km		[0.857]		
20 - 50 km		[0.000]***		
50 - 100 km		[0.866]		

Notes: p-values between square brackets. *, **, *** denotes significance at the 10%, 5%, 1% respectively. Instead of the estimated coefficient in (1), the table reports average partial effects. The p-values are however based on the estimated coefficient and their standard errors.

[a] Given that one cannot calculate average partial effects after estimating a conditional logit model, this column reports the estimated coefficients. When including country-century FE, conditional logit estimation has difficulties converging, which is why in this column we include country dummies, time dummies and country-specific time trends instead. Given that we do not include country-century FE, we also include ln country population and D ln country population in the estimated model. The estimated coefficients [p-values] on these variables are 5.393 [0.000] and 5.391 [0.000].

Instead of sticking to probit estimation, one could instead turn to logit techniques, that by virtue of the properties of the logistic function, allows one to condition out the unobserved location-specific heterogeneity without making any explicit assumptions about its nature as CRE probit does. However, because the unobserved heterogeneity is conditioned out, one can no longer calculate APEs which requires actual estimates of the unobserved location-specific effects [see (3)]. A big cost, as it becomes impossible to say anything about the absolute magnitude of the effect of any of the included variables on a location's urban chances. Another alternative is to turn to a simple linear probability model and employ standard linear fixed effect panel data estimation techniques. However, the linear probability model does not take account of the fact, as both probit and logit do, that the dependent variable is a probability and as such is restricted to the [0,1] interval. It can result in severe off-the-chart predictions (especially so in the fixed effects case – see the bottom of column 2 and 6).

Column 4, 5 and 6 show the results of using each of the three above-mentioned methods. The results in all three columns are very similar. In all three cases the effect of 2nd nature geography is somewhat weakened. We no longer find evidence of any significant competition effect among potential city locations. The nonlinear effect exerted by an already existing city is however still present. Locations at medium distance (20-50km) from an already existing city have a significantly higher probability (2.4 ppt) to become a city than those located closer to, or farther away from, that city.

Although serving as a nice robustness check to our 2nd nature geography results, a big drawback of all three methods for our purposes, is that it becomes no longer possible to say anything regarding the relevance of our 1st nature geography variables. Given their time-invariant nature, these variables 'drop out' of the results in case of logit or linear probability given their collinearity with the location-specific fixed effects. In case of CRE probit, although we still appear to obtain estimates of the effects of the 1st nature geography variables, we can actually not separately identify their partial effect on a location's urban chances from their partial correlation with the location-specific unobserved effect (see Wooldridge, 2005).

Given the main aim of our paper to quantify the relative importance of 1st and 2nd nature geography in determining cities' location, this is the main reason to report the results of employing these three methods as robustness checks rather than as our baseline results. Although we have to assume away any time-invariant unobserved location-specific heterogeneity, we are willing to make this assumption in our baseline model (and some of the extensions to it) in order to obtain estimates of the relevance of both 1st and 2nd nature geography. Note also that it is a priori not that easy to think of such *time-invariant* location specific factors (i.e. not changing over the period 800 – 1800) besides those already included in our model, that are not already (at least to a large extent) captured by the included of country-century fixed effects.

Given that our baseline results hinge on the inclusion of country-century fixed effects, with countries defined along their 1990 boundaries, one could question the sensitivity of the results to using this, from a medieval or pre-modern perspective, arbitrary country specification. The final two columns address this concern. In column 6 and 7 we include *ecozone*-century and *block*-century specific fixed effects instead of *country*-century fixed effects as an alternative way to take account of possibly time-varying agricultural and climatic conditions. In column 6, we divide Europe in five different types of regions (*ecozones*) based on their agricultural potential made by Buringh et al. (1975). Next in column 7, we divide Europe into 25 geographically clustered *blocks* using the 20th, 40th, 60th and 80th quantile of the distribution of all locations' latitude and longitude as boundaries. Our baseline results hold up to using either of these different geographically clustered divisions of the sample[1].

5.1.2 Changing the distance bands used to construct the 2nd nature geography variables

The second set of robustness checks we do concerns the sensitivity to the chosen distance bands (0 – 20km, 20 – 50km and 50 – 100km) to construct our 2nd nature geography variables (see section 3.3.2) . Table 5 shows the results using various different distance bands. The results leave the effect of a competitor location largely unaffected: a competitor at too close distance always diminishes a location's urban chances and is quite insensitive to the specific distance band used. This is not always true for the effect of already existing cities. Only changing the lowest distance cutoff to 15 or 25 km in column 1 and 2 respectively, this leaves the results unchanged. The results are a bit more sensitive to changing the middle distance cutoff. In column 3 and 4, changing this cutoff to 40 or 60 km respectively, the positive effect of an already existing city in the furthest distance band turns insignificant. This also happens when only changing the highest distance cutoff to 125 km in column 5. Next, in column 6 and 7 we lower or increase each of the three distance cutoffs at the same time. Setting them higher at 40, 80 and 120 km respectively leaves the results unchanged, but lowering them now turns the effect at medium distance insignificant: setting the lowest distance cutoff too low, turns

[1] The baseline results also hold up to include both the block-century and the country-century fixed effects, or both ecozone-century and country-century fixed effects. Also using 16 (with the 25th, 50th and 75th quantiles of the distribution of all locations' longitude and latitude) instead of 25 geographically clustered blocks does not change the results.

the effect insignificant as the 2nd distance band starts to overlap too much with the existing cities' urban shadow.

Finally, the last column shows the results of adding two additional distance bands (100 – 150 km and 150 – 200 km) to the empirical model. They further confirm the theoretical insights from section 2.2. The effect of an already existing city within 100 – 150 km is still significant and positive, but the effect disappears for the 150 – 200 km distance band.

Table 5. Robustness: using different distance bands(whole sample)

P(city t | no city t-1)	x = 15 y = 50 z = 100	x = 25 y = 50 z = 100	x = 20 y = 40 z = 100	x = 20 y = 60 z = 100	x = 20 y = 50 z = 125	x = 40 y = 80 z = 120	x = 10 y = 40 z = 90	baseline + 100 – 150 km 150 – 200 km
sea	0.036***	0.037***	0.034***	0.036***	0.035***	0.036***	0.035***	0.037***
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
river	0.070***	0.070***	0.070***	0.070***	0.070***	0.072***	0.072***	0.070***
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
hub	0.018**	0.018**	0.018**	0.018**	0.018**	0.017**	0.017**	0.017**
	[0.030]	[0.028]	[0.027]	[0.026]	[0.029]	[0.036]	[0.033]	[0.033]
road	-0.013**	-0.013**	-0.013**	-0.013**	-0.013**	-0.013**	-0.013**	-0.013**
	[0.019]	[0.023]	[0.019]	[0.020]	[0.023]	[0.022]	[0.018]	[0.021]
ln elevation	0.001	0.001	0.000	0.001	0.000	0.000	0.000	0.000
	[0.747]	[0.777]	[0.849]	[0.706]	[0.858]	[0.847]	[0.836]	[0.864]
city >= 10k? (t-1)								
0 - x km	-0.001	0.000	0.000	0.000	0.000	0.006	0.004	0.000
	[0.906]	[0.953]	[0.976]	[0.955]	[0.982]	[0.241]	[0.823]	[0.980]
x - y km	0.011**	0.016***	0.011**	0.014***	0.012**	0.013**	0.007	0.011**
	[0.037]	[0.002]	[0.043]	[0.007]	[0.022]	[0.012]	[0.176]	[0.028]
y - z km	0.011**	0.010*	0.006	0.008	0.009	0.012**	0.013***	0.009*
	[0.050]	[0.055]	[0.276]	[0.115]	[0.171]	[0.029]	[0.019]	[0.085]
100 – 150 km	-	-	-	-	-	-	-	0.011*
	-	-	-	-	-	-	-	[0.065]
150 – 200 km	-	-	-	-	-	-	-	0.002
	-	-	-	-	-	-	-	[0.719]
competitor? (t-1)								
0 - x km	-0.012**	-0.014***	-0.014***	-0.014***	-0.014***	-0.017**	-0.008	-0.014***
	[0.023]	[0.006]	[0.008]	[0.009]	[0.007]	[0.029]	[0.162]	[0.006]
x - y km	-0.013	-0.004	-0.009	-0.027**	-0.006	-0.030	-0.013*	-0.007
	[0.232]	[0.623]	[0.210]	[0.036]	[0.568]	[0.103]	[0.085]	[0.512]
y - z km	-0.028	-0.031	-0.036	-0.027	-0.067**	-0.047*	-0.047**	-0.026
	[0.235]	[0.196]	[0.222]	[0.164]	[0.048]	[0.075]	[0.035]	[0.289]
100 – 150 km	-	-	-	-	-	-	-	-0.048
	-	-	-	-	-	-	-	[0.133]
150 – 200 km	-	-	-	-	-	-	-	-0.005
	-	-	-	-	-	-	-	[0.868]
country/century FE	yes	yes	yes	yes	yes	yes	yes	yes
nr observations	13341	13341	13341	13341	13341	13341	13341	13341

Notes: p-values between square brackets. *, **, *** denotes significance at the 10%, 5%, 1% respectively. Instead of the estimated coefficient in (1), the table reports average partial effects. The p-values are however based on the estimated coefficient and their standard errors.

Overall, the results are most sensitive to the specification of the third distance band (columns 3 – 5). The positive effect at medium range is however very robust to making small changing to the distance bands used to construct our 2nd nature geography variables. In Table A4, we show that, when focussing on the post-1600 period only [why this period will become clear in the next 2 sections], the results are even more robust to the same small changes in the distance bands as in Table 5.

5.1.3 Additional variables and sample composition

The second set of robustness checks concerns the inclusion of some additional, non-geography related, variables as well as several checks to establish whether or not the results are primarily driven by developments in a few centuries or particular countries only. Table 6 shows the results. The first three columns add additional variables to our baseline specification. Reassuringly, *in none of the three columns do our baseline results change in any way by the addition of these additional variables*. The results on the extra included variables are of interest by themselves however.

Column 1 controls for two additional 1st nature geography variables, namely a location's latitude and longitude (both also included in their squared versions). Of these two additionally included variables, only a location's latitude has a significant effect on its urban chances. Together, the significantly negative coefficient on latitude per se and the significantly positive (but very small) coefficient on latitude squared, indicate an increasingly negative effect of latitude on a location's urban chances up to a latitude of 44.8^{o} (e.g. Bordeaux) whereafter this negative effect start to decrease again.

Column 2 controls for several non-geography related variables: a potential city location's religious, political and educational status in period t-1, as well as a dummy indicating whether or not a location was a bishopric in 600. Having an important religious [(arch)bishopric], political [capital], or educational [university] function all substantially increase a location's probability to become a city. Interestingly, after having controlled for all other included variables, having been a bishopric in 600 diminishes a location's urban chances. Note however that the results on these non-geography related variables should be taken with some care. The *extra info on political and religious variables* in Table 6 show that only 0.2% of all our potential city locations are a capital, only 0.3% have a university, and only 1% are an archbishopric, before becoming a city. Although these characteristics significantly improve a location's urban chances, such locations are major exceptions. This does not hold for the locations with a bishopric: 7% of all potential locations are home to a bishopric. The estimated coefficient confirms the importance of the church in conditioning urban development in Europe: having a bishopric increases a location's urban chances by about 16ppt!

Finally, in column 3 we include a dummy variable indicating whether or not a location had ever been a city before. This is done to control for the presence of cities (13% of the sample) that at some point pass the 5000 inhabitants criterion, subsequently fall back below this number, to pass it again in a later century. These cities would – so to speak – be counted double in our sample, which could leave their effect on the results (most notably on the 1st nature geography variables given their time-invariant nature). As mentioned before, this is not the case[1], but interestingly the results do show that a location that once already qualified as a city but subsequently lost its city status, has about a 3 ppt higher probability to gain city status (again) than a location that was not yet a city before.

Next, column 4 and 5 ascertain that the devastating effects of the Black Death (the plague of 1342) do not crucially affect the results. During the 14th century 40% of the existing cities disappeared, i.e. their population fell back to below 5000 inhabitants, whereas only 4% (compared to 9% or 11% during the 13th or 15th century respectively) of potential city locations developed into a city. In column 4 we exclude the 14th and 15th century from our analysis[2], and in column 5 we exclude those cities that lost their city status during the 14th century from the analysis. With the exception of losing the significant positive effect of being a hub location, we find that all our baseline results come through. We will come back to the nonsignificance of the hub effect frequently, it is the least robust 1st nature geography variable depending delicately on the presence of certain countries or centuries in the sample (see already the next paragraph but also the next subsection).

The last two robustness checks both concern the sample composition. In column 6 and 7 we check whether our baseline results are driven by particular countries only. In column six we verify whether or not the results depend on the 'Roman empire bias' in the selection of our potential city locations (see section 3.1). Only considering the potential city locations in countries where at least 20% of all potential city locations were an (arch)bishopric in 600 (see Table 1) again turns the hub effect insignificant, but does not affect the rest of the baseline

[1] The baseline results are also robust to simply removing those locations that had already qualified as a city before. Results available upon request.
[2] We exclude the 15th century as well to abstract from a possible recovery effect following the 14th century plague outbreak. The baseline results are also robust to disregarding either the 14th or the 15th century only. Results available upon request.

Table 6. Robustness (variables included and sample)

P(city t | no city t-1)	longitude and latitude	political and religious function	ever a city before?	plague 1342: no 1400-1500	plague 1342: no 'plague cities'	only > 5% bishop countries	**no Italy**	**< 1600**	**>= 1600**
sea	0.035***	0.035***	0.035***	0.045***	0.025***	0.028***	0.060***	0.018**	0.076***
	[0.000]	[0.000]	[0.000]	[0.000]	[0.005]	[0.008]	[0.000]	[0.039]	[0.002]
river	0.071***	0.051***	0.068***	0.069***	0.057***	0.080***	0.065***	0.054***	0.106***
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
hub	0.019**	0.021**	0.017**	0.013	0.007	0.013	0.022**	0.031***	-0.041**
	[0.023]	[0.011]	[0.036]	[0.170]	[0.374]	[0.118]	[0.035]	[0.000]	[0.063]
road	-0.011*	-0.002	-0.013**	-0.015**	-0.017***	-0.013**	0.004	0.007	-0.060***
	[0.065]	[0.712]	[0.021]	[0.017]	[0.002]	[0.040]	[0.603]	[0.200]	[0.000]
ln elevation	0.001	0.002	0.000	0.002	0.000	0.001	0.001	-0.005**	0.014**
	[0.548]	[0.264]	[0.828]	[0.457]	[0.981]	[0.652]	[0.681]	[0.012]	[0.014]
city >= 10k? (t-1)									
0 - 20 km	-0.001	-0.003	0.000	0.003	0.001	0.010	-0.023*	-0.024**	0.024
	[0.861]	[0.688]	[0.959]	[0.716]	[0.895]	[0.261]	[0.053]	[0.025]	[0.192]
20 - 50 km	0.011**	0.014***	0.012**	0.014**	0.012**	0.019***	0.004	-0.003	0.043***
	[0.035]	[0.005]	[0.018]	[0.017]	[0.013]	[0.001]	[0.570]	[0.532]	[0.001]
50 - 100 km	0.009*	0.016***	0.010*	0.016***	0.010*	0.014**	0.001	-0.005	0.061***
	[0.087]	[0.003]	[0.055]	[0.010]	[0.067]	[0.026]	[0.925]	[0.322]	[0.000]
competitor? (t-1)									
0 - 20 km	-0.015***	-0.011**	-0.014***	-0.013**	-0.014***	-0.011*	-0.014**	-0.012***	-0.018
	[0.005]	[0.030]	[0.007]	[0.029]	[0.006]	[0.060]	[0.028]	[0.017]	[0.180]
20 - 50 km	-0.005	-0.012	-0.006	-0.007	0.001	-0.003	-0.009	-0.009	-0.007
	[0.596]	[0.220]	[0.552]	[0.512]	[0.919]	[0.812]	[0.389]	[0.301]	[0.794]
50 - 100 km	-0.028	-0.021	-0.028	-0.023	-0.025	-0.006	-0.030	-0.023	-0.060
	[0.246]	[0.364]	[0.248]	[0.392]	[0.274]	[0.873]	[0.220]	[0.346]	[0.300]
country/century FE	yes	yes	yes	yes	yes	yes	yes	yes	yes
nr observations	13341	13341	13341	10557	12589	9585	9055	9694	3647

extra included variables

	longitude and latitude	political and religious function	ever a city before?
latitude	-0.031**	-	-
	[0.011]	-	-
latitude^2	0.000**	-	-
	[0.013]	-	-
longitude	-0.002	-	-
	[0.224]	-	-
longitude^2	0.000	-	-
	[0.467]	-	-
bishop t-1	-	0.164***	-
	-	[0.000]	-
archbishop t-1	-	0.221***	-
	-	[0.000]	-
capital t-1	-	0.183***	-
	-	[0.000]	-
university t-1	-	0.064*	-
	-	[0.077]	-
bishop 600	-	-0.065***	-
	-	[0.000]	-
ever a city before?	-	-	0.031***
	-	-	[0.004]

extra info on political and religious variables

	bishop t-1	
city t-1	no (%)	yes (%)
no	14352 (93)	***1018 (7)***
yes	1661 (67)	809 (33)

	archbishop t-1	
city t-1	no (%)	yes (%)
no	15252 (99)	***118 (1)***
yes	2198 (89)	272 (11)

	capital t-1	
city t-1	no (%)	yes (%)
no	15335 (99.8)	***35 (0.2)***
yes	2306 (93)	164 (7)

	university t-1	
city t-1	no (%)	yes (%)
no	15327 (99.7)	***43 (0.3)***
yes	2204 (89)	266 (11)

Notes: p-values between square brackets. *, **, *** denotes significance at the 10%, 5%, 1% respectively. Instead of the estimated coefficient in (1), the table reports average partial effects. The p-values are however based on the estimated coefficient and their standard errors.

results in any other way[1]. This is not the case when excluding Italy, the country contributing the most potential city locations (28%) to our sample (see Table 1)[2]. Column 7 shows that, although the 1st nature geography results and the negative effect of having a competitor location within 20 km hold up, the results on the effect of other already existing cities do not. We no longer find the significant positive effect exerted by already existing cities at medium range. Instead we only find stronger evidence of an urban shadow: an already existing city within 10 km of a potential city location significantly diminishes that location's urban chances.

Before discussing this result further, first note that we find a very similar conclusion when performing our final sample composition robustness check. It turns out that the sensitivity of the results to the inclusion of Italian locations is overshadowed by their sensitivity to splitting the sample along its time dimension. In column 8 and 9 we consider only the period before or after 1600 respectively. When considering only the pre-1600 period, we find a similar result for the effect of other already existing cities on a location's urban chances as when disregarding all Italian cities: there is no longer evidence for a significant effect at medium range, but an already existing city at too close distance (within 10 km) significantly lowers a location's probability to become a city. When instead only considering the post-1600 period, the same pattern in the effect of an already existing city as in our baseline results turns up: only the presence of an existing city at medium distance increases a location's urban chances. In the next subsection we explore this potentially important finding in more detail (also addressing the 'Italy-effect' we found in column 7 of Table 6).

5.1.3 The importance of 1st and 2nd nature geography over time

The last two columns of Table 6 suggest that the importance of some of the included variables differs over the centuries. To verify this in a more rigorous way, in this section we estimate (1) allowing all variables to have a pre- and post-1600 specific effect[3] by interacting each variable with a pre- and a post-1600 dummy. This allows us to formally test the equivalence of the pre- and post-1600 effect of each of the included variables. Column 1 of Table 7 shows the results when doing this for our baseline specification [the t-tests for equality of each

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[1] The same holds excluding only all countries that have no (arch)bishoprics in 600.

[2] The baseline results are fully robust to excluding either France (the second biggest contributor), Spain (the third biggest contributor) or the UK and the Netherlands (the two earliest industrializers) from the sample. Results available upon request.

[3] In Table A3 in the Appendix we show the results when using an even finer decomposition of the sample along its time-dimension. The patterns shown in these results are very similar to those using a pre- and post-1600 split of the sample. For parsimony reasons we decided to show the pre- and post 1600 results in the main text.

variable's effect in the pre- and post-1600 period are found at the bottom of the table]. The other columns show various robustness checks to the baseline results in column 1.

Regarding the 1st nature geography results, we find that the importance of land-based transport diminishes, whereas that of water-based transport increases. Location at a hub of roman roads is beneficial to a location's urban chances in the pre-1600 period only, turning negative (or insignificant) in the post-1600 period. The importance of location on a river or, but insignificantly so, at sea instead gains in importance. This increased importance of good access to navigable waterways or the sea concurs with previous work by e.g. Acemoglu et al. (2005) or Bosker et al. (2009). It also corresponds nicely with narrative accounts of (economic or urban) historians that document the increased dominance of water over land-based transport.

The results on 2nd nature geography confirm the results found in the previous subsection. Only from the 17th century onwards do we find the nonlinear effect that an already existing city exerts on the probability of its surrounding locations to also become a city. This significantly differs from the earlier centuries, where we only find the negative effect on the urban chances of locations at very close range to an already existing city (urban shadow). Also, competition with other potential city locations at close range is fiercest in the pre-1600 period.

Column 2 shows that these baseline results hold up to allowing for time-invariant location-specific unobserved heterogeneity in addition to the unobserved country-century specific heterogeneity controlled for in the baseline estimations[1]. Next, and importantly so, column 3 shows that, and in contrast to the baseline results in Table 3, these more fine-tuned pre- and post-1600 specific results also hold up to excluding all Italian cities from the sample. Both the effect of location at a river or at a hub of roman roads, and the effect of already-existing cities at medium distance differ significantly before and after 1600. The only difference with the baseline results in column 1 is that the effect of an already existing city within 20 – 50km is no longer significantly [only at the 11.5% level] positive in the post-1600 period.

In column 4 and 5 we show two further sample composition robustness checks. In column 4 we do not consider the 18th century. As shown in Figure 1 and Table A1, the 18th century saw an unprecedented increase in the number of cities. Column 4 however shows that

[1] We only show results of estimating a conditional random effects probit model. Results when employing conditional logit or fixed effect linear probability models instead are very similar and available upon request.

Table 7. Pre- and post-1600

P(city t | no city t-1)	**BASELINE**	CRE	no Italy	no 1800	no never cities	>= 6000	>= 7000	>= 10000
sea								
< 1600	0.037***	0.030***	0.050***	0.038***	0.048***	0.028***	0.023***	0.019***
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.001]	[0.002]
>= 1600	0.034	0.044**	0.085***	0.080***	0.093***	0.048**	0.032	0.072***
	[0.121]	[0.057]	[0.002]	[0.001]	[0.000]	[0.029]	[0.105]	[0.000]
river								
< 1600	0.060***	0.050***	0.057***	0.060***	0.054***	0.049***	0.044***	0.032***
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
>= 1600	0.091***	0.107***	0.081***	0.075***	0.036**	0.071***	0.068***	0.085***
	[0.000]	[0.000]	[0.000]	[0.000]	[0.025]	[0.000]	[0.000]	[0.000]
hub								
< 1600	0.043***	0.036***	0.041***	0.036***	0.049***	0.032***	0.032***	0.021***
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
>= 1600	-0.066***	-0.058***	-0.036	-0.013	0.016	-0.022	-0.012	-0.015
	[0.002]	[0.006]	[0.165]	[0.558]	[0.506]	[0.273]	[0.514]	[0.255]
roman road	-0.011*	-0.010*	0.006	0.001	0.017***	-0.006	-0.004	0.005
	[0.051]	[0.069]	[0.447]	[0.877]	[0.009]	[0.262]	[0.426]	[0.227]
ln elevation	0.000	0.000	0.001	0.002	0.001	-0.001	-0.003*	-0.004***
	[0.960]	[0.862]	[0.795]	[0.452]	[0.615]	[0.720]	[0.079]	[0.003]
city >= 10k? (t-1)	0 - 20 km	0 - 20 km	0 - 20 km	0 - 20 km	0 - 20 km	0 - 20 km	0 - 20 km	0 - 20 km
< 1600	-0.020*	-0.024**	-0.025*	-0.020*	-0.024**	-0.012	-0.007	-0.006
	[0.055]	[0.032]	[0.088]	[0.064]	[0.044]	[0.184]	0.374	[0.464]
>= 1600	0.019	0.000	-0.037	-0.009	-0.013	0.019	0.024	0.021**
	[0.313]	[0.994]	[0.135]	[0.717]	[0.520]	[0.295]	0.139	[0.098]
city >= 10k? (t-1)	20 - 50 km	20 - 50 km	20 - 50 km	20 - 50 km	20 - 50 km	20 - 50 km	20 - 50 km	20 - 50 km
< 1600	-0.002	0.006	-0.007	-0.002	-0.004	0.000	0.002	0.003
	[0.706]	[0.299]	[0.340]	[0.734]	[0.472]	[0.926]	[0.696]	[0.481]
>= 1600	0.041***	0.061***	0.025	0.035**	0.027*	0.022*	0.017	0.001
	[0.002]	[0.000]	[0.115]	[0.024]	[0.054]	[0.096]	[0.171]	[0.951]
city >= 10k? (t-1)	50 - 100 km	50 - 100 km	50 - 100 km	50 - 100 km	50 - 100 km	50 - 100 km	50 - 100 km	50 - 100 km
< 1600	-0.004	-0.006	-0.014**	-0.004	-0.007	0.003	0.001	-0.001
	[0.395]	[0.237]	[0.025]	[0.360]	[0.208]	[0.482]	[0.812]	[0.755]
>= 1600	0.062***	0.059***	0.047***	0.073***	0.061***	0.037**	0.045***	0.016
	[0.000]	[0.003]	[0.010]	[0.000]	[0.000]	[0.025]	[0.004]	[0.150]
competitor? (t-1)	0 - 20 km	0 - 20 km	0 - 20 km	0 - 20 km	0 - 20 km	0 - 20 km	0 - 20 km	0 - 20 km
< 1600	-0.011**	-0.009	-0.010	-0.011**	-0.012**	-0.011**	-0.009**	-0.007**
	[0.027]	[0.312]	[0.107]	[0.026]	[0.029]	[0.014]	[0.026]	[0.048]
>= 1600	-0.020	-0.021	-0.022	-0.022	-0.029**	-0.014	-0.007	0.013
	[0.146]	[0.480]	[0.164]	[0.157]	[0.045]	[0.300]	[0.609]	[0.171]
competitor? (t-1)	20 - 50 km	20 - 50 km	20 - 50 km	20 - 50 km	20 - 50 km	20 - 50 km	20 - 50 km	20 - 50 km
< 1600	-0.009	-0.008	-0.014	-0.009	-0.017*	-0.001	0.002	0.006
	[0.320]	[0.560]	[0.183]	[0.324]	[0.099]	[0.892]	[0.804]	[0.362]
>= 1600	-0.003	-0.013	-0.001	-0.053*	-0.037	-0.008	0.000	-0.020
	[0.915]	[0.749]	[0.971]	[0.059]	[0.152]	[0.762]	[0.998]	[0.263]
competitor? (t-1)	50 - 100 km	50 - 100 km	50 - 100 km	50 - 100 km	50 - 100 km	50 - 100 km	50 - 100 km	50 - 100 km
< 1600	-0.024	0.050	-0.023	-0.026	-0.022	-0.012	-0.011	-0.024
	[0.321]	[0.228]	[0.391]	[0.293]	[0.421]	[0.571]	[0.566]	[0.137]
>= 1600	-0.054	0.111	-0.060	-0.049	-0.038	-0.034	-0.077	-0.002
	[0.351]	[0.290]	[0.281]	[0.453]	[0.468]	[0.566]	[0.150]	[0.956]
country/century FE	yes	yes	yes	yes	yes	yes	yes	yes
nr observations	13341	13341	9055	12201	11455	13945	14204	13931

TABLE 7 CONTINUED

	p-value H0: pre 1600 = post 1600							
Sea	[0.057]*	[0.109]	[0.707]	[0.780]	[0.959]	[0.228]	[0.173]	[0.402]
River	[0.011]**	[0.028]**	[0.029]**	[0.005]***	[0.000]***	[0.001]***	[0.001]***	[0.559]
Hub	[0.000]***	[0.000]***	[0.000]***	[0.000]***	[0.008]***	[0.000]***	[0.000]***	[0.000]***
city >= 10k? (t-1)								
0 - 20 km	[0.030]**	[0.025]**	[0.641]	[0.246]	[0.229]	[0.092]*	[0.128]	[0.152]
20 - 50 km	[0.017]**	[0.036]**	[0.076]*	[0.053]*	[0.058]*	[0.305]	[0.548]	[0.623]
50 - 100 km	[0.001]***	[0.000]***	[0.001]***	[0.000]***	[0.000]***	[0.196]	[0.037]**	[0.195]
competitor? (t-1)								
0 - 20 km	[0.634]	[0.572]	[0.959]	[0.794]	[0.921]	[0.295]	[0.205]	[0.017]**
20 - 50 km	[0.555]	[0.667	[0.389]	[0.388]	[0.976]	[0.915]	[0.854]	[0.155]
50 - 100 km	[0.917]	[0.614]	[0.926]	[0.862]	[0.909]	[0.949]	[0.621]	[0.272]

Notes: p-values between square brackets. *, **, *** denotes significance at the 10%, 5%, 1% respectively. Instead of the estimated coefficient in (1), the table reports average partial effects. Whenever the effect of a variables is split in a pre- and post-1600 effect, the average partial effect is calculated using only the observation in the pre- or post-1600 period only. The p-values are however based on the estimated coefficient and their standard errors.

it is not only this episode that drives our results. In addition, column 5 shows that our results do not crucially depend on the 'control group' of bishop cities in 600. When only considering locations that at some time during our sample period did become a city (i.e. the *Bairoch*-cities only), our baseline results[1] again come through.

Finally, the last three columns of Table 7 deal with the sensitivity of our results to our city definition based on the absolute cutoff of having at least 5000 inhabitants[2]. In columns 6, 7 and 8 we increase this absolute size criterion to 6000, 7000 and 10000 inhabitants respectively. Note that in columns 6, 7 and 8 we also change the definition of a competitor location accordingly from being smaller than 5000 inhabitants at period *t-1* to being smaller than 6000, 7000 or 10000 inhabitants at period *t-1* respectively. The results of increasing the cutoff are very similar to our baseline specification when using the 6000 cutoff. When increasing it to 7000 inhabitants, we find two slight changes that are further exacerbated when increasing the absolute city cutoff to 10000 inhabitants. The first is that a location's elevation starts exerting a negative, but small, influence on its urban chances when raising the absolute size criterion. Locations at higher altitudes, often in the more mountainous areas, find it more difficult to become a city the higher the absolute population cutoff used to identify a city.

The second difference is that the positive effect of having an already existing city at medium distance on a potential location's urban chances disappears when raising our city criterion. The positive effect is still there at 20 – 100km when raising the criterion to 6000

[1] This is maybe not that surprising given that the baseline results were already shown to hold to allowing for unobserved location-specific heterogeneity.

[2] Table A4 shows that the results for the post-1600 period also hold up to small changes in the distance bands used to construct our 2nd nature geography variables. Even more so than the original baseline results (see the earlier discussion in section 5.1.2).

inhabitants. When raising it to 7000 inhabitants the effect remains, but only in the farther 50 - 100km range. Raising it even further to 10000 inhabitants, the positive effect disappears entirely. The results show a consistent pattern. Having an existing city at medium range may significantly improve a location's probability of becoming a city of 5000 or 6000 inhabitants; it becomes increasingly difficult to grow larger in the shadow of an already existing urban centre. The positive effect of an already existing city at medium distances disappears when raising the absolute size criterion used to define a city.

Overall, the time-varying impact of 1st and 2nd nature geography is the important refinement to the baseline results in Table 3, following from the wide variety of robustness checks in section 5.1. The pre- and post-1600 first nature geography results shows that good access to water-based transport becomes much more important than being well situated for land-based transport. However, especially the importance of 2nd nature geography is quite heavily dependent on the period we consider. Before the 17th century 2nd nature geography exerts no significant influence on locations' urban chances. 1st nature geography is the dominant determinant of city location during this period. Only from 1600 onwards does the nonlinear effect eminating from existing urban centres, predicted by theory, show up significantly in the data. It is an important finding because it is exactly what has been argued in the literature (see e.g. Behrens, 2007 or Duranton, 1999). Second nature geography only becomes an important determinant of city location when overall transportation or trade costs are sufficiently low and urban population is large enough to sustain multiple urban centres.

5.2 Refining 2nd nature geography

In our baseline regressions the 2nd nature geography variables are dummy variables indicating the presence of *at least one already existing city* or *at least one competitor location* within each of the three specified distance bands. As already mentioned in section 2.2, and illustrated by Figure 6, it is possible to refine the role of 2nd nature geography further by adding additional dummy variables indicating for example the presence of *at least two already existing cities*, or the presence of *competitor locations with certain 1st nature geography characteristics*, within each of the three distance bands. Also, instead of these dummy variables, we can simply include a *FUP* measure [see (3)] in the empirical model, or include the *total number* of existing cities and/or competitor locations within each of the three distance bands. Section 5.2.1 and 5.2.2 do just that. We show that further refining the impact of already existing cities or competitor locations respectively, provides some very useful additional insights into the role of 2nd nature geography in determining cities' location.

5.2.1 *Refining the impact of already existing cities*

Table 8 shows various results of refining the impact of already existing cities, modeling the possible competition between potential locations as in our baseline. The first column shows the result of replacing our dummy variables with the usual *FUP* measure found in the literature [see (3)]. This measure is highly insignificant, corroborating our claim that including such a measure may be too simple to do justice to the patterns in the data. By assuming an always positive or always negative effect of other already existing cities, this measure is unable to a priori allow for the effects predicted by theory (see Figure 3).

Second, columns 2 – 4 further specify the dummy variables included in our baseline estimations. Column 2 includes three additional dummy variables indicating the presence of *at least one already existing city larger than 25000 inhabitants* in each of the three distance bands, and column 3 adds a further dummy variable per distance band indicating the presence of *at least one already existing city larger than 5000 inhabitants.* The results show an interesting pattern: the larger the distance between an existing city and a potential city location, the larger the existing city has to be to exert a positive influence on that location's urban chances. But at the same time, the larger an already existing city the larger its urban shadow. In other words: given a certain distance between an already existing city B and a potential city location A, B needs , on the one hand, to be large enough to have any positive effect on A's urban chances, but, on the other hand, B cannot be too large either to prevent A from falling under B's urban shadow. This effect shows in column 3 (and similarly in column 2) where the existence of a city larger than 5000, 10000 or 25000 *only significantly positively* affects the urban chances of potential locations within 0 – 20km, 20 – 50km or 50 – 100km respectively (see the bottom of the table for the corresponding tests[1]).

A similar result follows from column 4. There we include additional dummies indicating the presence of *at least two cities larger than 10000 inhabitants* in each of the three distance bands. We find that having one, and only one, city larger than 10000 inhabitants

[1] Given the way the different dummy variables are specified (i.e. if there exists a city larger than 25000 inhabitants within a certain distance bands, not only the dummy variable indicating the presence of a city larger than 25000 inhabitants will be 1, so will be the dummy variable indicating the presence of a city of at least 10000 inhabitants), the p-values below the coefficients indicate whether or not the effect of a dummy variable is *significantly different from* the effect of having a smaller city within a distance band.

Table 8. Extended 2nd nature geography – existing cities

P(city t | no city t-1)	(a) ln FUP cities >= 10k (b) - (c) -	(a) city >= 10k? (b) - (c) city >= 25k?	(a) city >= 10k? (b) city >= 5k? (c) city >= 25k?	(a) city >= 10k? (b) 2 cities >=10k? (c) -	(a) ln # cities <= 10k (+1) (b) - (c) -	(a) ln city pop <= 10k (+1) (b) - (c) -	(a) ln dist near. city >= 10k (b) ln pop near. city >= 10k (c) -
sea	0.033***	0.034***	0.035***	0.036***	0.038***	0.036***	0.032***
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.001]
river	0.071***	0.070***	0.070***	0.070***	0.070***	0.070***	0.071***
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
hub	0.018**	0.018**	0.019**	0.018**	0.018**	0.018**	0.018**
	[0.027]	[0.028]	[0.023]	[0.028]	[0.030]	[0.030]	[0.025]
road	-0.013**	-0.013**	-0.013**	-0.013**	-0.013**	-0.013**	-0.013**
	[0.018]	[0.022]	[0.023]	[0.022]	[0.027]	[0.020]	[0.020]
ln elevation	0.000	0.000	0.000	0.001	0.001	0.001	0.000
	[0.947]	[0.960]	[0.913]	[0.814]	[0.720]	[0.804]	[0.978]
(a) t-1							
0 - 20 km	0.004	0.003	-0.017	0.001	-0.004	0.000	-0.001
	[0.674]	[0.793]	[0.180]	[0.947]	[0.728]	[0.975]	[0.709]
20 - 50 km	-	0.019***	0.014*	0.011**	0.011**	0.002	-
	-	[0.001]	[0.097]	[0.054]	[0.050]	[0.156]	-
50 - 100 km	-	0.005	0.007	0.005	0.015***	0.004***	-
	-	[0.409]	[0.447]	[0.447]	[0.001]	[0.004]	-
(b) t-1							
0 - 20 km	-	-	0.023**	-0.015	-	-	-0.002
	-	-	[0.015]	[0.495]	-	-	[0.450]
20 - 50 km	-	-	0.006	0.000	-	-	-
	-	-	[0.448]	[0.960]	-	-	-
50 - 100 km	-	-	-0.004	0.012**	-	-	-
	-	-	[0.714]	[0.038]	-	-	-
(c) t-1							
0 - 20 km	-	-0.010	-0.011	-	-	-	-
	-	[0.469]	[0.445]	-	-	-	-
20 - 50 km	-	-0.020**	-0.020**	-	-	-	-
	-	[0.011]	[0.011]	-	-	-	-
50 - 100 km	-	0.010*	0.011*	-	-	-	-
	-	[0.081]	[0.071]	-	-	-	-
competitor? (t-1)							
0 - 20 km	-0.013***	-0.013***	-0.014***	-0.014***	-0.014***	-0.014***	-0.013**
	[0.010]	[0.010]	[0.008]	[0.005]	[0.005]	[0.005]	[0.011]
20 - 50 km	-0.004	-0.007	-0.008	-0.007	-0.006	-0.007	-0.004
	[0.669]	[0.474]	[0.447]	[0.498]	[0.514]	[0.514]	[0.667]
50 - 100 km	-0.027	-0.028	-0.028	-0.028	-0.030	-0.030	-0.027
	[0.255]	[0.245]	[0.238]	[0.238]	[0.214]	[0.215]	[0.266]
country/century FE	yes	yes	yes	yes	yes	yes	yes
nr observations	13341	13341	13341	13341	13341	13341	13341
p-values tests		H0: $\beta_{city>=10}$ >0?	H0: $\beta_{city>=10}$ >0?	H0: $\beta_{2\ cities>=10}$ >0?			
0 - 20 km		-	[0.55]	[0.49]			
20 - 50 km		-	[0.00]***	[0.17]			
50 - 100 km		-	[0.63]	[0.01]***			
		H0: $\beta_{city>=25}$ >0?	H0: $\beta_{city>=25}$ >0?				
0 - 20 km		[0.50]	[0.67]				
20 - 50 km		[0.91]	[0.96]				
50 - 100 km		[0.01]***	[0.04]**				

Notes: p-values between square brackets. *, **, *** denotes significance at the 10%, 5%, 1% respectively. Instead of the estimated coefficient in (1), the table reports average partial effects. The p-values are however based on the estimated coefficient and their standard errors.

exerts a positive influence on the urban chances of locations at 20 – 50km. This significant positive effect disappears when there are more than one already existing city at that distance. The opposite holds for the 50 – 100km distance band: at that distance there needs to be sufficient urban mass (i.e. at least two cities larger than 10000 inhabitants) to have any positive influence on a potential location's probability to become a city.

In column 5 and 6 we abandon the dummy variables altogether and instead include the total number of cities larger than 10000 inhabitants, or the total population in cities larger than 10000 inhabitants, within each of the three distance bands in the empirical model. Including the total number of cities gives similar results as the baseline specifiction. When including the total urban population, we again find a similar result as in columns 2 – 4: a larger urban existing population only increases a potential location's urban chances when this urban mass is located at larger distances.

Finally, in column 7, we completely abandon our distance bands and include the size of, and distance to, the nearest city larger than 10000 inhabitants instead. The results show, as when including *FUP* in column 1, that a priori imposing an always positive or always negative effect of either the size of, or the distance to, neighboring urban centres, is unable to do justice to the 2nd nature geography effects that are present in the data (these are only revealed when using a more flexible specification).

5.2.2 Refining the impact of competitor locations

Table 9 shows the results of refining the impact of competitor locations instead, modeling the impact of already existing locations as in the baseline. Column 1 adds an additional dummy variable for each distance band indicating the presence of *at least two competitor locations*. Having more than one competitor locations within 0 – 20km has a significant negative effect on a location's own urban chances, but it does not significantly decrease them compared to having only one competitor location at this distance. Also, see the *p*-values at the bottom of column 1[1], as when having only one competitor, having more than one competitor does not have any significant effect at larger distances than 20km.

Columns 2 and 3 abandon the dummy approach and include the total number of competitor locations with each distance band and the distance to the nearest competitor location respectively.

[1] Similar to Table 8, the p-values below the coefficients indicate whether or not the effect of having at least two competitor locations is *significantly different from* the effect of having only one competitor location within one of the distance bands.

Table 9 Extended 2nd nature geography – competitors / 1st nature geography

P(city t | no city t-1)	(a) 2 competitors? (b) -	(a) ln # competitors (b) -	(a) dist near. comp. (b) -	(a) sea/river competitor (b) hub competitor	
sea	0.035***	0.034***	0.036***	0.030***	
	[0.000]	[0.000]	[0.000]	[0.002]	
river	0.071***	0.068***	0.070***	0.067***	
	[0.000]	[0.000]	[0.000]	[0.000]	
hub	0.018**	0.017**	0.017**	0.015*	
	[0.027]	[0.032]	[0.037]	[0.062]	
road	-0.013**	-0.013**	-0.013**	-0.007	
	[0.017]	[0.021]	[0.018]	[0.218]	
ln elevation	0.001	0.002	0.000	-0.003	
	[0.742]	[0.448]	[0.920]	[0.182]	
city >= 10k? t-1					
0 - 20 km	0.000	0.002	0.004	-0.001	
	[0.996]	[0.848]	[0.634]	[0.872]	
20 - 50 km	0.012**	0.013**	0.013**	0.012**	
	[0.026]	[0.011]	[0.015]	[0.018]	
50 - 100 km	0.011**	0.012**	0.010*	0.011*	
	[0.047]	[0.032]	[0.052]	[0.052]	
competitor? (t-1)					
0 - 20 km	-0.012**	-	-	-0.001	
	[0.044]	-	-	[0.931]	
20 - 50 km	-0.015	-	-	0.009	
	[0.190]	-	-	[0.379]	
50 - 100 km	0.011	-	-	-0.015	
	[0.693]	-	-	[0.535]	
(a) t-1				sea comp	river comp
0 - 20 km	-0.006	-0.009*	0.013***	0.002	-0.018**
	[0.353]	[0.057]	[0.002]	[0.830]	[0.017]
20 - 50 km	0.016**	-0.009	-	-0.020***	-0.004
	[0.044]	[0.709]	-	[0.002]	[0.464]
50 - 100 km	-0.046**	-0.002	-	-0.012*	-0.001
	[0.012]	[0.037]	-	[0.059]	[0.941]
(b) t-1				hub comp	
0 - 20 km	-	-	-	-0.014*	
	-	-	-	[0.099]	
20 - 50 km	-	-	-	-0.023***	
	-	-	-	[0.000]	
50 - 100 km	-	-	-	-0.014**	
	-	-	-	[0.012]	
country/century FE	yes	yes	yes	yes	
nr observations	13341	13341	13341	13341	

p-values tests	H0: $\beta_{2\ comp.}$ >0?		*p-values tests*	H0: $\beta_{1st\ nature\ comp.}$ >0?	
0 - 20 km	[0.00]***			sea	river
20 - 50 km	[0.96]		0 - 20 km	[0.88]	[0.01]***
50 - 100 km	[0.14]		20 - 50 km	[0.34]	[0.62]
			50 - 100 km	[0.27]	[0.51]
				hub	sea + river
			0 - 20 km	[0.14]	[0.13]
			20 - 50 km	[0.24]	[0.19]
			50 - 100 km	[0.24]	[0.25]
				sea + hub	river + hub
			0 - 20 km	[0.27]	[0.00]***
			20 - 50 km	[0.00]***	[0.11]
			50 - 100 km	[0.10]*	[0.22]
				sea + river + hub	
			0 - 20 km	[0.02]***	
			20 - 50 km	[0.00]***	
			50 - 100 km	[0.25]	

Notes: p-values between square brackets. *, **, *** denotes significance at the 10%, 5%, 1% respectively. Instead of the estimated coefficient in (1), the table reports average partial effects. The p-values are however based on the estimated coefficient and their standard errors.

As when using the dummy approach, only the total number of competitor locations at close distance (0-20km) significantly negatively affects a location's own urban chances. When including the distance to the nearest competitor location instead, we also find a result that is consistent with our baseline findings. The significantly positive average partial effect shows that the further a city is located from potential competitors the better its own urban chances.

The final extension we show in Table 9 builds on our baseline results that show a robust positive 1st nature geography effect of being located at sea or on a navigable river on a location's urban chances. This result also immediately suggest the following implication. Suppose that two potential city locations are located close together. One has direct access to a navigable waterway whereas the other has not. The potential city location without this 1st nature advantage faces competition from a nearby location with much better 1st nature characteristics. One can expect this location to face much stiffer competition from its neighbour than a similar location facing competition from another location that, like itself, does not have any 1st nature advantages. In other words, our baseline results imply that potential locations face stronger competition effects from other locations with advantageous 1st nature characteristics than from those without such an advantage.

To verify this, we include three additional dummy variables for each of the three distance bands. They indicate the presence of at least one competitor location located at sea, at a navigable river, and at a hub of roman roads respectively. The results in column 4 show (again see both the *p*-values below each APE and the *p*-values at the bottom of column 4) that the negative competition effect at close range, which we found in our baseline results, can entirely be attributed to competition with other potential locations that have the 1st nature geography advantage of being located at a navigable waterway. Other locations without this 'river-advantage' do not exert a significantly negative competition effect at 0 – 20km (although the effect of competitors located at sea or a hub is sometimes significantly different from the effect of a competitor without these 1st nature advantages [see the *p*-values below the APEs], their effect is never significantly different from zero [see the bottom *p*-values]).

Besides this interesting 'river-competition effect' we also find a significantly negative competition effect from other potential locations at 20 – 100km that are located *both* at sea and at a hub of roman roads. We refrain from putting too much weight on this finding given that only 1.6% of all competitor locations have both these 1st nature geography characteristics (compared to 34% being located on a navigable waterway).

5. Conclusions

< TO BE COMPLETED >

References

< TO BE COMPLETED >

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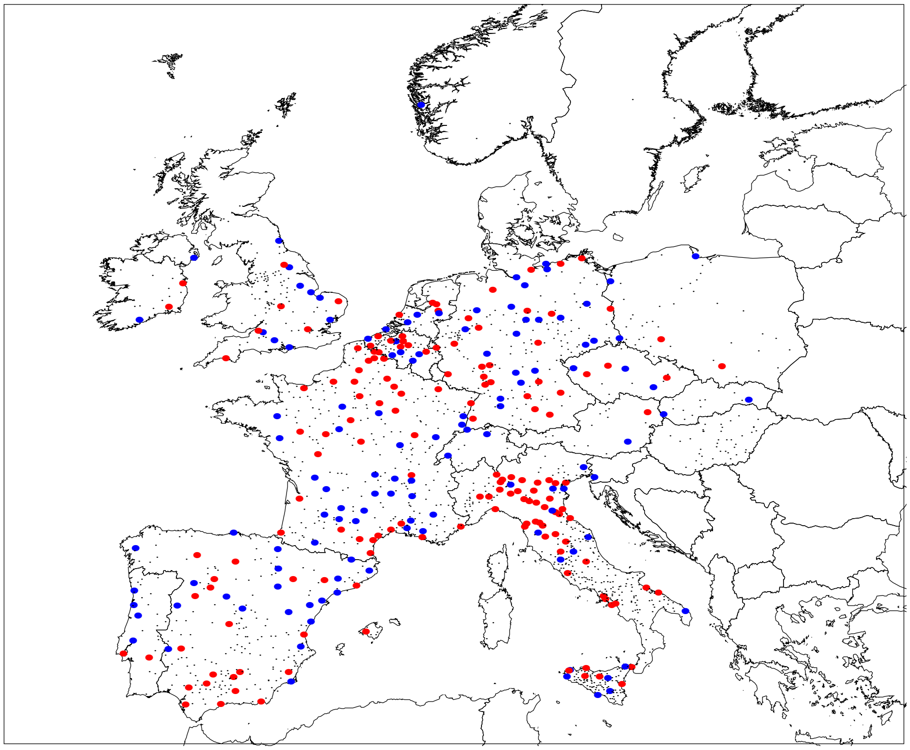
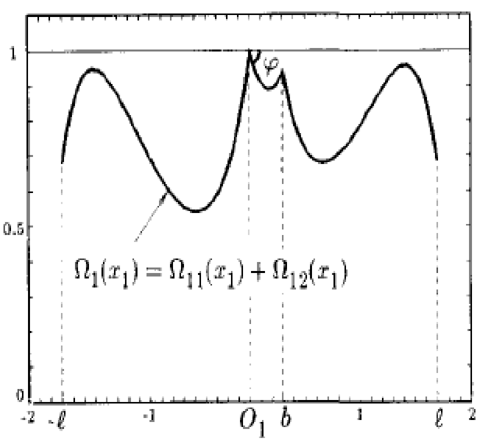
Appendix A

Figure A1. The European city system in 1300



Notes: black dots denote potential city locations [see section 3.1 for more detail], blue dots denote cities with at least 5000 inhabitants and red dots denote cities with at least 10000 inhabitants.

Figure A2. Market potential curves with 1st nature geography



Notes: The figure is taken from Fujita and Mori (1996, p.109). The location at *b* has a first nature geography advantage in the ease of transporting goods (i.e. it is a hub location).

Table A1 Century specific probability of becoming a city

	city yes/no?	
year	no: nr (%)	yes: nr (%)
800	1750 (98)	34 (2)
900	1738 (97)	46 (3)
1000	1702 (95)	82 (5)
1100	1703 (96)	81 (5)
1200	1652 (93)	132 (7)
1300	1504 (84)	280 (16)
1400	1561 (88)	223 (13)
1500	1413 (79)	371 (21)
1600	1188 (67)	596 (33)
1700	1159 (65)	625 (35)
1800	306 (17)	1478 (83)

Table A2 Descriptives

1st or 2nd nature	mean	sd	min	max	mean	sd	min	max
characteristic	all locations				locations ever becoming a city >= 5000			
seaport	0.14	0.35	0	1	0.13	0.34	0	1
river	0.37	0.48	0	1	0.41	0.49	0	1
hub	0.15	0.36	0	1	0.13	0.34	0	1
rroad	0.42	0.49	0	1	0.37	0.48	0	1
elevation (m)	218	238	-4	1176	214	235	-4	1176
--------------	distance to other potential city location (km)				distance to other potential city location (km)			
median	1086	261	739	2024	1093	266	739	2024
nearest	22	20	1	390	22	20	1	390
--------------	distance to existing city >= 10k (km)				distance to existing city >= 10k (km)			
median	1046	295	502	2400	1047	301	502	2400
nearest	106	124	1	1424	107	128	1	1424
--------------	nr. cities >= 10k				nr. cities >= 10k			
0 – 20km	0.12	0.45	0	7	0.13	0.46	0	7
20 – 50km	0.62	1.23	0	12	0.64	1.27	0	12
50 – 100km	1.67	2.57	0	27	1.70	2.62	0	27
--------------	nr. competitors				nr. competitors			
0 – 20km	1.29	2.05	0	13	1.25	2.08	0	13
20 – 50km	5.86	6.39	0	37	5.63	6.32	0	37
50 – 100km	14.9	12.7	0	66	14.1	12.2	0	64

Table A3 Finer century decomposition

dependent variables: *P(city t | no city t-1)*

period	APE	[p-value]	period	APE	[p-value]
	sea			sea	
800 - 900	0.068***	[0.000]	800 - 1000	0.049***	[0.000]
1000 - 1200	0.026***	[0.008]	1100 - 1400	0.049***	[0.000]
1300 - 1500	0.040***	[0.010]	1400 - 1600	0.036**	[0.037]
1600 - 1800	0.034	[0.113]	1700 - 1800	0.007	[0.794]
	river			river	
800 - 900	0.036**	[0.013]	800 - 1000	0.037***	[0.000]
1000 - 1200	0.035***	[0.000]	1100 - 1400	0.069***	[0.000]
1300 - 1500	0.094***	[0.000]	1400 - 1600	0.077***	[0.000]
1600 - 1800	0.092***	[0.000]	1700 - 1800	0.103***	[0.000]
	hub			hub	
800 - 900	0.015**	[0.050]	800 - 1000	0.043***	[0.000]
1000 - 1200	0.040***	[0.000]	1100 - 1400	0.038***	[0.000]
1300 - 1500	0.044***	[0.001]	1400 - 1600	0.036**	[0.023]
1600 - 1800	-0.067***	[0.002]	1700 - 1800	-0.109***	[0.000]
roman road	-0.011**	[0.060]	roman road	-0.012**	[0.045]
ln elevation	0.000	[0.886]	ln elevation	0.000	[0.826]
city >= 10k? (t-1) 0-20km			city >= 10k? (t-1) 0-20km		
800 - 900	-	-	800 - 1000	-	-
1000 - 1200	-0.021	[0.304]	1100 - 1400	-0.033*	[0.091]
1300 - 1500	-0.028	[0.126]	1400 - 1600	-0.014	[0.437]
1600 - 1800	0.019	[0.307]	1700 - 1800	0.033	[0.133]
city >= 10k? (t-1) 20-50km			city >= 10k? (t-1) 20-50km		
800 - 900	0.004	[0.583]	800 - 1000	0.006	[0.400]
1000 - 1200	0.005	[0.441]	1100 - 1400	-0.012	[0.130]
1300 - 1500	-0.012	[0.233]	1400 - 1600	0.023***	[0.030]
1600 - 1800	0.041***	[0.002]	1700 - 1800	0.030*	[0.070]
city >= 10k? (t-1) 50-100km			city >= 10k? (t-1) 50-100km		
800 - 900	-0.017*	[0.088]	800 - 1000	-0.008	[0.185]
1000 - 1200	0.004	[0.451]	1100 - 1400	0.001	[0.903]
1300 - 1500	-0.011	[0.223]	1400 - 1600	0.025**	[0.026]
1600 - 1800	0.062***	[0.000]	1700 - 1800	0.032	[0.164]
competitor? (t-1) 0-20km			competitor? (t-1) 0-20km		
800 - 900	0.010*	[0.072]	800 - 1000	-0.006	[0.302]
1000 - 1200	-0.012**	[0.022]	1100 - 1400	-0.006	[0.453]
1300 - 1500	-0.012	[0.201]	1400 - 1600	-0.024**	[0.026]
1600 - 1800	-0.020	[0.147]	1700 - 1800	-0.012	[0.474]
competitor? (t-1) 20-50km			competitor? (t-1) 20-50km		
800 - 900	0.000	[0.989]	800 - 1000	-0.001	[0.912]
1000 - 1200	-0.006	[0.573]	1100 - 1400	-0.021	[0.101]
1300 - 1500	-0.018	[0.285]	1400 - 1600	-0.027	[0.166]
1600 - 1800	-0.003	[0.913]	1700 - 1800	0.037	[0.240]
competitor? (t-1) 50-100km			competitor? (t-1) 50-100km		
800 - 900	-0.059	[0.017]	800 - 1000	-0.049*	0.092]
1000 - 1200	0.487***	[0.000]	1100 - 1400	0.029	[0.364]
1300 - 1500	-0.027	[0.517]	1400 - 1600	-0.021	[0.663]
1600 - 1800	-0.055	[0.349]	1700 - 1800	-0.107	[0.125]

Notes: p-values between square brackets. *, **, *** denotes significance at the 10%, 5%, 1% respectively. Instead of the estimated coefficient in (1), the table reports average partial effects. The p-values are however based on the estimated coefficient and their standard errors.

Table A4 Robustness: using different distance bands (post 1600 only)

P(city t | no city t-1)	x = 15 y = 50 z = 100	x = 25 y = 50 z = 100	x= 20 y = 40 z = 100	x= 20 y = 60 z = 100	x= 20 y = 50 z = 125	x = 40 y = 80 z = 120	x = 10 y = 40 z = 90	baseline + 100 – 150 km 150 – 200 km
sea	0.075***	0.074***	0.073***	0.075***	0.071***	0.074***	0.076***	0.075***
	[0.002]	[0.002]	[0.003]	[0.002]	[0.003]	[0.002]	[0.002]	[0.002]
river	0.105***	0.106***	0.105***	0.107***	0.106***	0.111***	0.110***	0.106***
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
hub	-0.043*	-0.041*	-0.040*	-0.042*	-0.041*	-0.041*	-0.040*	-0.042*
	[0.056]	[0.063]	[0.071]	[0.061]	[0.064]	[0.065]	[0.074]	[0.057]
road	-0.061***	-0.061***	-0.062***	-0.060***	-0.061***	-0.061***	-0.062***	-0.059***
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
ln elevation	0.014**	0.014**	0.013**	0.014**	0.013**	0.013**	0.014**	0.014**
	[0.014]	[0.017]	[0.019]	[0.013]	[0.021]	[0.023]	[0.017]	[0.019]
city >= 10k? (t-1)								
0 - x km	0.023	0.023	0.024	0.024	0.026	0.038	0.023	0.025
	[0.442]	[0.214]	[0.188]	[0.192]	[0.168]	[0.005]	[0.549]	[0.183]
x - y km	0.046***	0.042***	0.040***	0.046***	0.043***	0.047***	0.038***	0.042***
	[0.001]	[0.002]	[0.003]	[0.001]	[0.002]	[0.001]	[0.005]	[0.002]
y - z km	0.062***	0.062***	0.057***	0.053***	0.043**	0.031*	0.053***	0.060***
	[0.000]	[0.000]	[0.002]	[0.001]	[0.048]	[0.060]	[0.001]	[0.000]
100 – 150 km	-	-	-	-	-	-	-	0.021
	-	-	-	-	-	-	-	[0.279]
150 – 200 km	-	-	-	-	-	-	-	-0.008
	-	-	-	-	-	-	-	[0.720]
competitor? (t-1)								
0 - x km	-0.022	-0.016	-0.019	-0.016	-0.017	-0.006	0.011	-0.019
	[0.119]	[0.237]	[0.178]	[0.249]	[0.225]	[0.760]	[0.489]	[0.172]
x - y km	-0.014	-0.019	0.001	-0.046	-0.003	-0.046	0.000	-0.006
	[0.613]	[0.408]	[0.966]	[0.152]	[0.904]	[0.294]	[0.997]	[0.826]
y - z km	-0.059	-0.065	-0.086	-0.043	-0.123	-0.072	-0.069	-0.045
	[0.307]	[0.263]	[0.253]	[0.348]	[0.203]	[0.262]	[0.234]	[0.434]
100 – 150 km	-	-	-	-	-	-	-	-0.149
	-	-	-	-	-	-	-	[0.089]
150 – 200 km	-	-	-	-	-	-	-	-0.007
	-	-	-	-	-	-	-	[0.921]
country/century FE	yes	yes	yes	yes	yes	yes	yes	Yes
nr observations	3647	3647	3647	3647	3647	3647	3647	3647

Notes: p-values between square brackets. *, **, *** denotes significance at the 10%, 5%, 1% respectively. Instead of the estimated coefficient in (1), the table reports average partial effects. The p-values are however based on the estimated coefficient and their standard errors.