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ABSTRACT

City seeds: Geography and the origins of the European city system*

Geography is widely viewed as the important determinant of city location. This paper empirically disentangles the different roles of geography in shaping the European city system. We present a new database that covers all actual cities as well as potential city locations over the period when the foundations for the European city system were laid. We relate each location's urban chances to its physical, first nature, geography characteristics, and develop a novel empirical strategy to assess how the existing urban system surrounding each location (second nature geography) determines its urban prospects. First nature geography is the dominant determinant of city location until the sixteenth century. Second nature geography becomes important from the seventeenth century onwards, in a way that corresponds closely to predictions from new economic geography theory.

JEL Classification: N93, O18 and R10
Keywords: city origins, economic geography, Europe

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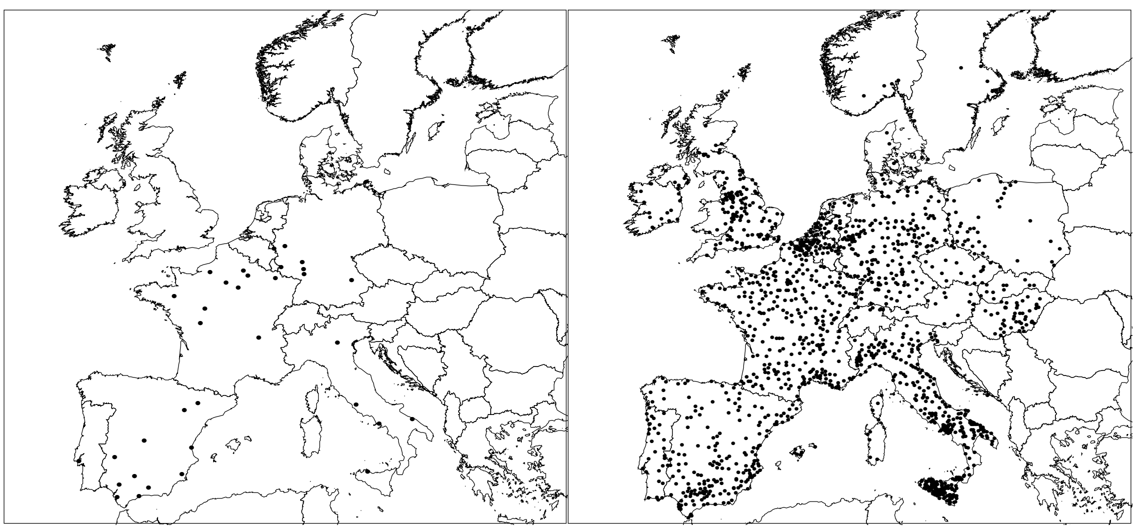
"In a more advanced era, when better methods would permit man to conquer Nature […], it would doubtless have been possible to build towns anywhere the spirit of enterprise and the quest of gain might suggest a site. But it was quite another matter in a period when society had not yet acquired enough vigor to rise above the physical conditions in the midst of which it developed. […] the towns of the Middle Ages were a phenomenon determined as much by physical surroundings as the course of rivers is determined by the conformation of the mountains and the direction of the valleys." (Henri Pirenne, 1925 p.138/39).

1 Introduction

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. Over the next millennium this changed dramatically, and cities started to appear on an unprecedented scale[1]. These cities appeared virtually everywhere on the continent. Figure 1a and 1b show that whereas in 800 we only find a few scattered cities in mainly Spain, France, Germany and Italy, in 1800 they can be found all over the continent[2].

Figure 1. The European city system in 800 and 1800



a) 800 b) 1800

Notes: cities are denoted by black dots [see section 3.2 for more detail on the city definition used]. In 800 there are 34 cities, in 1800 this number has increased to over 1,450.

The rise of the city in the European landscape is important for several reasons. Throughout history, cities have been the important loci for technological innovation, institutional progress,

[1] Figure A1 and Table A1 in Appendix A further illustrate the rise of the city in the European landscape. Over our sample period, Europe's urbanization rate increased from only 3% in 800 to 15% in 1800. Urban population increased 30-fold from 0.7 to 21 million, whereas total population increased 6-fold from 23 to 137 million.

[2] For the situation in 1300 see Figure A2 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.

(international) trade, political power, and culture (Bairoch, 1988; Pirenne, 1925; Hohenberg and Lees, 1995). Also, cities are generally more productive places. The concentration of many people e.g. allows for a greater degree of specialization, carries positive externalities such as knowledge spillovers, and facilitates a more efficient provision of public goods (Lampard, 1955; Marshall, 1890). It may therefore not be surprising that cities are argued to have played a very important role in Europe's economic 'take-off' during the late Medieval and Early Modern period. Economic development and urbanisation often go hand in hand (Acemoglu et al., 2005; De Vries, 1984; Galor, 2005). Today, an estimated 75% of world production takes place in cities (World Bank, 2009). The importance of cities in the development process makes understanding their origins of great interest.

Cities do not develop everywhere. The question "*why they form in particular locations and not, or only much later, in others that a priori often appear equally viable city sites*" lies at the heart of this paper. In particular, we empirically uncover the role(s) of geography, often stated as the most important determinant of a location's urban chances, in 'sowing the seeds' of the European city system.

Many authors, in both the narrative urban (economic) history (e.g. Pirenne, 1925; De Vries, 1984; or Bairoch 1988), the economic geography (e.g. Christaller, 1935; Lösch, 1940; Ullman, 1941; Lampard, 1955; Duranton, 1999), or the more recent urban economic and geographical economics literature (Krugman, 1993a; Fujita and Mori, 1997; Behrens, 2007), stress two important, but very different, roles for geography in the origins of an urban system.

The first is in 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, although already stressed by e.g. Christaller (1935) and Lösch (1938; 1940)[3], has received renewed attention in the economics literature following Krugman (1991; 1993b). While not denying an important role of 1st nature geography, this line of literature stresses the importance of a location's position relative to the rest of the (potential) urban system, its *2nd nature geography*, for its urban prospects. As already acknowledged by Pirenne (1925, p.145), some locations may be well 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."*

[3] An even earlier contribution focussing on 2nd nature geography is von Thünen (1826). He however considered the evolution of only one isolated city in relation to its hinterland, instead of the evolution of a system of cities.

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 empirical evidence. Instead, it relies on historical narratives, largely descriptive accounts of European urbanization, and detailed case studies looking at one particular city or region only. 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, we empirically uncover the (relative) importance of 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. This is largely due to the work of Bairoch et al. (1988) and De Vries (1984). They have constructed comprehensive data sets providing population estimates for many cities in Europe starting as early as the year 800[4]. Our dataset builds on this data. We extend its coverage to also cover potential city locations, locations that in principle could have become a city but never did. Also, we complement the existing population data with, most importantly for the purposes of this paper, detailed information on each location's 1st and 2nd nature geography (it also contains information on several religious, educational and institutional characteristics).

Second, all this data is available for the period, 800 – 1800, during which one can forcefully argue that the seeds for the eventual European city system were sown. Following the eclipse of the Roman empire, cities in Europe withered (Pirenne, 1925; Greif, 1992). But, over the next millennium Europe witnessed an unprecedented revival of urban activity and the establishment of cities on a scale not seen before[5]. 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 development of*

[4] This data has up to now been used either to provide descriptive accounts of urban expansion (Bairoch et al., 1988; De Vries, 1984), 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; Kim, 2000; or Bosker et al, 2010). By looking at city size *conditional* on a city's existence, although very interesting in itself, these papers effectively take cities' location as given and refrain from shedding empirical light on the question why these cities were formed at their particular locations in the first place. They do not answer the question why other, often a priori equally viable, locations never became a city or only did so at a much later stage. 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"*.
[5] See Figure 1, and Figures A1 and A2 and Table A1 in the Appendix.

cities […] *kept going on the basis of improvements in agriculture and transport, the opening of new lands and new trade routes*".

Using our data set, we quantify the role of 1st and 2nd nature geography in conditioning the spread of cities across the European continent. We explicitly base our empirical analysis on the main theoretical insights regarding the role of 1st and 2nd nature geography in sowing the seeds of cities. These insights come from the economic and urban history literature on the one hand, and from the more recent new economic geography literature on the other hand. They serve as the theoretical underpinnings of our empirical analysis, guiding the selection of 1st and 2nd nature geography variables to consider, as well as which potential city locations to consider. In case of 2nd nature geography this results in developing a novel, more flexible, way to quantify the effect that an already established city exerts on the urban chances of its surroundings.

We find that both 1st and 2nd nature geography played an important role in the origins of the European city system. However, the (relative) importance of 1st and 2nd nature geography shows substantial changes over time. 1st nature geography dominates in the early stages of the formation of the European city system. But, as trade costs fall, economies of scale increase, and the overall European population increases, 2nd nature geography gains in importance and starts to be an equally important determinant of city location from the seventeenth century onwards. Interestingly, the effect that an already existing urban centre exerts on the urban chances of its surroundings turns out to correspond closely to the predictions made by economic geography theory.

2 *Theory*

2.1 *Economic and urban history*

Traditionally, the debate on cities' origins was conducted within the realm of the, largely narrative, economic and urban history literature (Pirenne, 1925; Weber, 1922; Bairoch, 1988; De Vries, 1984). This literature stresses 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 between locations, what we call *1st nature geography*, arise most notably from economic motives related to either resource abundance or transportation possibilities. Attractive city locations were those close to natural resources (fertile plains, mineral deposits, thermal springs, etc.) and locations with good access to the main trade routes (see e.g.

Pirenne, 1925 p.133; Ratzel, 1891). Given that the city relies on exchange with its hinterland (most notably for the feeding of its population), location on a navigable river, an overland transport route, or at sea offers substantial advantages in terms of transportation possibilities.

Besides these economically motivated spatial inhomogeneities, other 1st nature geography characteristics that have been stressed as important determinants of city location mostly concern defensive and religious motives (see Hohenberg, 2004; Bairoch, 1988 p.121; Pirenne, 1925 p.72/74; or Hohenberg and Lees, 1995 p.30). Cities were established near places with an important religious function (an abbey, monastery or local shrine) or at a strategic location (a river crossing, the foot of a mountain pass or a hill overlooking the countryside). However, the earlier-mentioned economic motives, and most notably a location's transportation possibilities, are often viewed to overshadow these religious and defensive motives. As put by Bairoch (1988, p.143) *"The critical role played by transport in the location of cities does not rule out exceptions, but statistically speaking these are in the minority."*

2.2 Economic geography

Spatial inhomogeneities also feature prominently in the economic (geography) literature on city creation (Duranton, 1999; Anas, Arnott, Small, 1998; Fujita and Mori, 1996; Krugman, 1993a, Behrens, 2007). Although this literature does not deny endowments of minerals, soil or climate to be important determinants of city location (see Anas, Arnott and Small, 1998), the 1st nature geography characteristic that receives most attention in this literature is (again) preferential location on the main trade routes (Krugman, 1993a; Fujita and Mori, 1996; Behrens, 2007; Konishi, 2000). Transportation or, more generally, trade costs[6], together with scale economies, are viewed as the crucial elements in the process of city formation.

Trade 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 very high, this results in the so-called tyranny of distance and cities only form in locations offering good 1st nature geography conditions so that sufficient food can be imported from nearby. *"With the tyranny of distance,* […] *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).

[6] All costs associated with moving goods from one location to another, including not only transportation costs but also tolls, tariffs and less tangible costs associated with differences in e.g. language, institutions or culture.

However, when trade costs diminish due to e.g. developments in transportation technology or lower tangible or intangible trade barriers (decreased tariffs, safer roads, improved freight insurance, etc), the tyranny of distance is alleviated and the (relative) importance of 1st nature geography diminishes. Since agricultural products can now be shipped over longer distances at lower costs, it becomes possible to establish cities at locations that, given their lack of 1st nature geography advantages, were previously unviable to host a city.

Despite the diminishing importance of 1st nature geography, not all locations become equally viable as future city sites. This depends on their *2nd nature geography characteristics*, i.e. their position relative to the rest of the (potential) urban system. Earlier contributions in the geography literature (e.g. Christaller, 1935; Lösch, 1938 or 1940; Pirenne, 1925; or Ullman, 1941) already stressed that *"no city is ever an island existing in and of itself"* (Lampard, 1955). Yet, it was only recently that several papers explicitly focus on the *where-do-cities-form* question in a theoretical framework of endogenous city location that formalizes the idea that already-existing cities influence the urban chances of their surroundings[7].

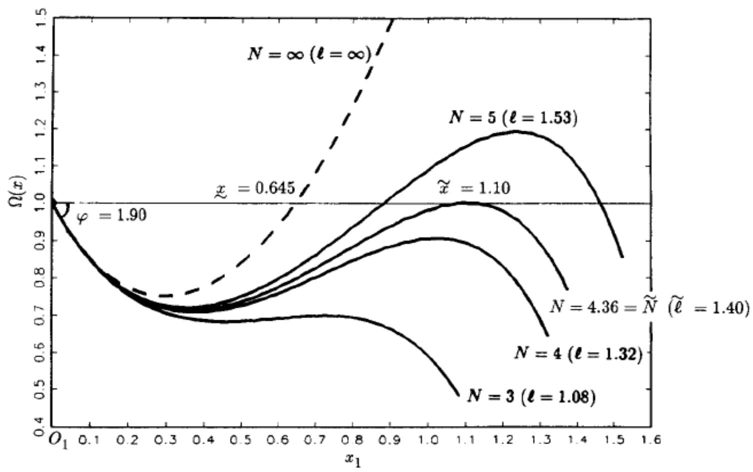
Started with contributions by Krugman (1993a,b), Fujita (1993), and Fujita and Krugman (1995), these papers (Fujita and Mori, 1996 and 1997; Fujita, Krugman and Mori, 1999 and Behrens, 2007) not only establish theoretically, using fully specified general equilibrium models, under what conditions a city (or subsequent cities) will form, they also make clear predictions about which locations are more likely to become a city than others.

Figure 2 (taken from Fujita and Mori, 1996) illustrates how an already existing city affects the urban chances of other locations. It depicts so-called market potential curves[8] that can be interpreted as indicating the likelihood 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, it is in principle a viable new city location. Whether or not this is the case depends first and foremost on a location's distance to the already existing urban center (see also Fujita, Krugman and Mori, 1999 and Fujita and Mori, 1996). Locations too close to an

[7] Earlier urban economic theories relying on scale economies and transport costs remain silent on the *where do cities from*-question, instead focussing on the *why do cities form*-question. A city's relative location is either completely disregarded (e.g. Henderson, 1974 or Black and Henderson, 1999b) and bears no consequences for its further development, or, often despite assuming no differences in 1st nature geography characteristics between locations (i.e. a continuous homogenous plain), the (relative) position of a discrete number of possible city locations is a priori assumed (see e.g. von Thünen, 1826; Christaller, 1935; Lösch, 1940). Moreover, a drawback of these latter models is that the final structure of the urban system does not follow endogenously from a set of assumptions concerning the behavior of firms and consumers (see Ottaviano and Thisse, 2005 for an extensive and very useful overview of the history of location analysis in urban economic and economic geography theory).

[8] 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.

Figure 2. 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: 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.

already existing city face too strong competition with that city, both for agricultural produce and for inhabitants (or, not uncommon in medieval times, the existing city uses force to prevent any competitor city forming in its immediate backyard). On the other hand, locations too far from an already existing city can not take full advantage of (cheap) trading possibilities with the already existing 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 locations at too close range.

The strength, and spatial reach, of this 2nd nature geography effect depends on the important model parameters. Most importantly, when total population is too small, trade costs are too high, and/or the productivity advantages of co-locating in a city are too low (compared to the disadvantages of co-locating in a city), 2nd nature geography plays no role in determining the location of new cities. Also, when transportation costs are extremely low, or the productivity advantages of co-location are very high, the models predict that only one city will emerge. Only at intermediate values of trade costs and scale economies, and given a sufficiently large overall population, does the above-described non-linear 2nd nature geography effect come into play[9].

[9] Our exposition is admittedly a bit too stylized and does not do entire justice to the richness of the models, where the relevance of the discussed 2nd nature geography effect depends delicately on *the interaction between* trade costs (and the relative size of those for agricultural and non-agricultural goods respectively), (dis)economies of scale, the share of agricultural consumption in overall consumption, and overall population

Figure 2 totally abstracts from any 1st nature geography advantages (i.e. each potential city location is a priori the same except for their distance to the existing city). Fujita and Mori (1996) and Behrens (2007) take note of this and show that locations with a 1st nature geography advantage in terms of transportation possibilities (hubs) produce sharp positive kinks in the market potential function, making them more likely future city candidates than other locations without such an advantage (see e.g. Figure A3 in the Appendix). 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.

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 more dynamic answer to the *where-do-cities-form* question than the much more static[10] 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 new dataset on the basis of which we can empirically identify the (relative) importance of both 1st and 2nd nature geography in 'sowing the seeds' of the European city system.

3 Data and descriptives

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 corresponds closely to the main theoretical insights presented in section 2.2.

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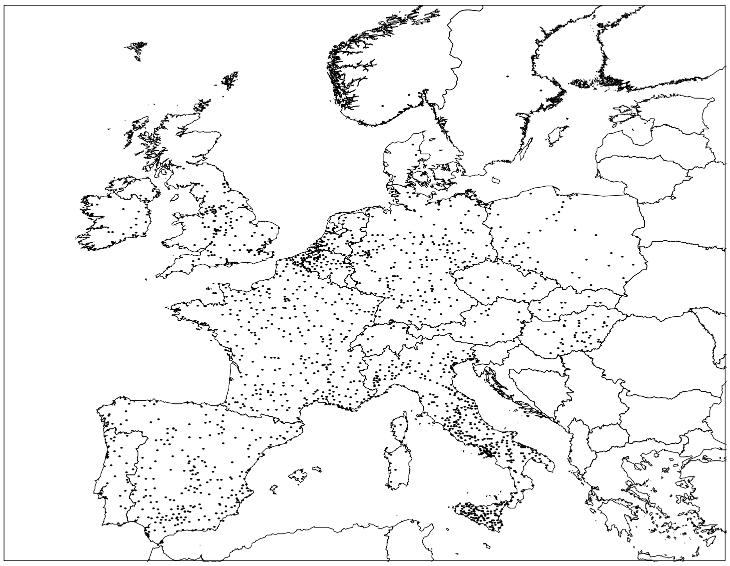
size (for particular configurations of these model parameters, it can even be the case that only one city, or even no city, emerges). However, the effect of an existing city is always negative at close and at large distances from an already existing city. It is the positive effect at medium range (and the extent of this range) that depends delicately on the model parameters. We take this non-linear effect exerted by an already existing city as the main insight from theory that we take to the data in our empirical sections.

[10] Not completely static however. The importance of particular spatial inhomogeneities, or the inhomogeneities themselves, may change over time. A good example is cities formed for defensive purposes only. Located at impregnable locations, these offer limited possibilities for expansion in more peaceful times. Another poignant example is location near natural resources. These locations lose their attractiveness once the resource is depleted or becomes obsolete. Coal reserves are a good example here. Before the industrial revolution this bore no particular advantage. This changed substantially following the industrial revolution, and new cities emerged near the vast coal reserves in e.g. Germany's Ruhr area, Sweden, north-east England or the Limburg provinces of Belgium and the Netherlands. However with the importance of coal increasingly diminishing as oil became the dominant energy source, cities established in these coal-rich areas began (and often continue) to wither. In section 5.2 we allow the importance of several 1st nature geography characteristics to change over the centuries.

3.1 Potential city locations

In order to empirically study the rise of cities in Europe[11], the first important choice to make is what locations to consider as potential city locations. Figure 3 shows all potential city locations that we consider in our baseline estimations. They are based on fulfilling one of the following two criteria.

Figure 3. Potential city locations



Notes: each black dot represents a potential city location.

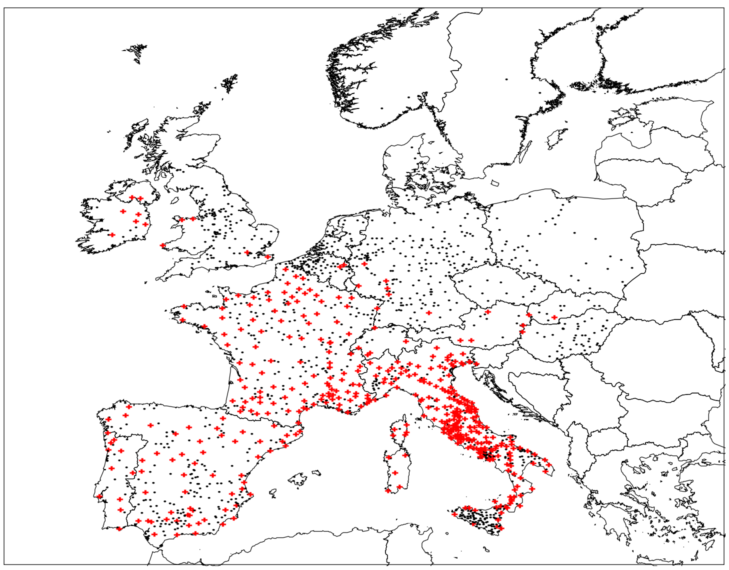
The first group of potential city locations comprises all locations documented in Bairoch et al. (1988). Bairoch et al. (1988) provide centennial population estimates for all cities in Europe that in some century have more than 5,000 inhabitants during the period 800 – 1800[12]. This gives us a total of 1,588 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).

[11] We define Europe as roughly everything west of the line Trieste – 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 border of the Latin West: it coincides with the border of the Catholic Church during the Middle Ages. See also De Vries (1984) or Findlay and O'Rourke (2007). 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.

[12] There are no population estimates for 1100. For this century we have linearly interpolated the reported 1000 and 1200 population estimates. This could in principle leave its effect on our results. However in practice all results reported in this paper are fully robust to excluding these interpolated 1100 numbers from the analysis. Results available upon request.

This is not true for our second group of potential city locations. Based on insights from the urban history literature (see section 2.1), these locations are selected on the basis of their religious importance. In particular, we consider all (arch)bishoprics in 600 as potential city locations[13]. The assumption is that these places were in principle all perfect candidates to become future cities given that they were, in 600, important enough to the Catholic Church to turn them into the seats of one of its (arch)bishops. A defendable assumption in our view as the Church played an important role in maintaining some urban continuity following the collapse of the Roman urban system in Europe during the early Middle Ages (Hohenberg and Lees, 1995 p.58; Bairoch, 1998 p.121).

Figure 4. (Arch)bishoprics in 600



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

All known bishoprics in Europe are documented in Jedin et al. (1980)'s *Atlas zur Kirchengeschichte*. In total we found 456 (arch)bishoprics in 600. Figure 4 shows that they are mostly concentrated in the parts of Europe that were at some point under Roman control, reflecting the fact that the Catholic Church initially built on the vestiges of the Roman empire. Of these 456 (arch)bishoprics, 260 (or 57%) are also present in the Bairoch et al. (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.

We also consider other samples of potential city locations in various robustness checks (see section 5.2.1) to address concerns regarding the possible endogeneity of our baseline

[13] 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.

sample (note that in order to obtain consistent estimates of our parameters of interest, we only require exogeneity of our sample *conditional on all other included regressors* in our empirical specification)[14]. For example, we extend our baseline sample with an additional 217 potential city locations that never had more than 5,000 inhabitants during our sample period, but did so in 1850[15]. Or alternatively, we consider all coordinate pairs to be potential city locations and do our estimations based on a random sample of over 2,000 coordinate pairs.

On the basis of our two main selection criteria, we obtain a total number of 1,784 potential city locations (those depicted in Figure 3). They constitute the baseline sample we consider in most of our empirical analysis. Table A2 in the Appendix provides some additional detail on the geographical distribution of these potential city locations, documenting how many of them 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.

3.2 City definition

We define a city as an agglomeration of at least 5,000 inhabitants. In doing so, we basically adopt the definition proposed by Bairoch (1988). He gives the following two reasons for using this definition (see 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 5,000 is that the margin of error for the number of people living in cities 2,000 – 5,000 people is much greater than that for the number living in cities of more than 5,000 people."* (p.218)

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[14] The issue of endogenous sample selection effectively becomes irrelevant when using an estimation strategy that allows for location-specific fixed effects. In that case the fixed effects perfectly predict the urban history of all locations that never develop into a city. We do not adopt this as our baseline empirical strategy as it comes at the cost of being unable to say anything about the relevance of most of our 1st nature geography variables. In section 5 we show that the results on our time-varying variables are robust to using such an estimation strategy.

[15] We do not consider this 1850 data in our baseline sample for two reasons. First, it would add the Industrial Revolution to our sample (see e.g. Ashton, 1948). The rapid and substantial change during that period in terms of transportation (railroads, steamships), production (both industrial and agricultural), and the importance of different natural resources (coal), turned many locations that would previously never have had any chance of becoming a city into potential city sites (e.g. many locations in the coal-rich areas of Germany, Sweden, North-East England, and the Limburg provinces of both Belgium and The Netherlands). Including the Industrial Revolution would in our view require a detailed account of its effects, something that lies beyond the scope of this paper. Second, the rest of our data is available on a centennial basis. Including the 1850 data would constitute a substantial shortening (halving) of the sampling period, with possibly unwanted consequences for the statistical analysis.

Such an absolute size criterion of 5,000 inhabitants 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 too high, has also been argued, especially for the early medieval period (see Bairoch, 1988 p.217; or Dyer, 1995). Both Bairoch (1988) and De Vries (1984, pp. 53/54) view the use of a population cutoff of 5,000 inhabitants provides a 'best of both worlds'[16] [17].

The alternative to using an 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, 1999a), or to define cities on the basis of more than just its total population (e.g. having city rights or certain economic, 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. Suppose for example that we let our cutoff increase each century by 1,000 inhabitants. In an extreme case, a city that in 900 for the first time has 5,000 inhabitants and over the next centuries increases its population by 1,000 inhabitants each century, would be classified as becoming a city in each century. Similarly, a location that becomes a city in a certain century but 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[18].

The other alternative, defining cities on more criteria than population size only, would, in the words of Bairoch (1988, p.494) be 'much less operational' (see also De Vries, 1984 p.21/22 or p.52/53). Not only would this constitute a very time consuming exercise; to agree on what features a certain location 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

[16] *"So long as the only criterion* [to define a city] *systematically available to us is population size it is advisable to be prudent.* […] *Thus our examination of European urbanization will generally extend no further than cities of 5000."* (De Vries, 1984 pp.53/54).

[17] Also in archaeology, its is common practice to define cities as population centres with more than 5,000 inhabitants. See for example Fagan (1997, p.27) or Bahn (1996, p.57).

[18] We do employ a time-varying definition of a city when verifying the sensitivity of our main results to our chosen absolute population cutoff of 5,000 inhabitants (see Table A8 in Appendix A).

on which features to include in this city definition (and data on all these features would be readily available), the substantial institutional, political and religious differences between the different societies in Europe further complicates the task of consistently applying this definition (e.g., city rights in one part of Europe are not necessarily directly comparable to those in other parts).

An absolute population cutoff to define a city avoids these issues of comparability, it makes the city definition less subjective, more transparent, and much more up to scrutiny as one can easily compare the results using different population cutoffs.

3.3 Explanatory variables determining city creation

The main explanatory variables that we include in our analysis capture the effect of either 1st or 2nd nature geography[19].

3.3.1 1st nature geography

To capture a location's opportunities for water- and land-based transportation, we use a set of dummy variables that indicate whether or not it has direct access to the sea, to a navigable waterway, or to the former Roman road network. 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.

The information concerning location at sea or on navigable waterways is from Dumont and Miermans (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 located on a navigable waterway[20]. It is classified as located at sea when there was a possibility to beach or harbor boats along the coast where the city was situated.

The information on the presence of a Roman road comes from Talbert (2000). We use location on a roman road instead of on an actual road for two reasons. First, the roman road network is argued to have played an important role in trade long after the withering of the empire itself[21]. Roman roads constructed using similar methods and adhering to uniform

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[19] Table A3 in Appendix A provides descriptive statistics on all variables discussed in this section. It presents these descriptives both for all potential city locations as well as for the subsample of potential locations that do actually become a city at some point.

[20] The use of this scale results in classifying many more (smaller) waterways than only the major European rivers as navigable. We think this is warranted given that *"navigation expanded wherever a rivulet of water offered even the slightest alternative to the beaten path or the ruined public highway"* (Lopez, 1956 p.21).

[21] Glick 1979, p.23 gives several examples of policies by medieval Spanish states and cities to maintain the system of Roman roads. See also Bairoch (1988, p.110) or Lopez (1956). The latter offers a much more critical view on the importance of Roman roads in the centuries after the demise of the Roman Empire.

quality standards can be found throughout the formerly Roman parts of Europe. Second, using location on a roman road or a hub of roman road avoids some of the reverse causality issues that could arise when using actual roads (i.e. roads being built to future city locations, instead of a road increasing the urban chances of locations along this road).

Besides these transportation related 1st nature geography variables, we collected information on each potential location's elevation [in meters] and on its ruggedness [calculated as the standard deviation of elevation of the terrain within 10km of each particular location]. Both serve as a proxy of a location's accessibility, although both can also be argued to be related to its agricultural possibilities.

The latter, a location's agricultural conditions are by many viewed as one of the crucial 1st nature geography determinants of a location's urban prospects (see Pirenne, 1925; Bairoch, 1988 or Duranton, 1999). To capture this, we use data from Ramankutty et al. (2002). That study combines information on climatic conditions (surface air temperature, precipitation and potential sunshine hours) and soil quality (total organic content [carbon density], availability of nutrients [pH] and water holding capacity) into one index that gives the probability that a certain location will be cultivated. This data is available in gridded form at a resolution of 0.5 degrees latitude-longitude (in case of our sample this corresponds to a grid of on average 56 km by 39 km). We match each potential city location to this data on the basis of its coordinates. As a result, locations within the same grid cell have the same cultivation probability.

The Ramankutty et al. (2002) data provides a time-invariant indication of a location's agricultural possibilities. It it not unlikely that a location's agricultural conditions (and most notably its climatic conditions) vary over the centuries. To our knowledge however, historical climate data is not available at a sufficiently disaggregated scale to be useful for our purposes. To overcome this difficulty we capture the possibly time-varying agricultural conditions at a somewhat more aggregated spatial scale by including *country-century* fixed effects in all our baseline model specifications[22]. Besides controlling for possibly time-varying agricultural conditions that moreover possibly differ between European countries, these *country-century* fixed effects also capture any country-specific institutional, political, demographic or economic developments that may have left their mark on locations' urban chances.

In robustness checks we also use three other fixed effects specifications. The first involves adding *ecozone-century* fixed effects that are based on a division of Europe in terms

[22] We also include our agricultural potential variable interacted with a timetrend in most of our specifications.

of agricultural potential (see Buringh et al., 1975). Based on local soil classification and climate data (water, light, evaporation, etc.) Buringh et al. (1975) identify five different classes of agricultural potential in Europe, ranging from very high (e.g. the Po Valley) to very low (e.g the Alps, Pyrenees, or northern Scandinavia) [see Figure A3 in the Appendix for a map of these ecozones]. Second, we provide results that allow for time-varying, geographically clustered, unobserved effects by including *block-century* fixed effects, with locations grouped in geographically clustered blocks on the basis of their coordinates. Finally, we also show results when controlling for unobserved *time*-in*variant location-specific* fixed factors that may be correlated with the variables of interest[23].

3.3.2 2nd nature geography

We propose a novel way to uncover the effect(s) of 2nd nature geography. The most commonly used measure of a location's 2nd nature geography is its market or urban potential (see e.g. Stewart, 1947; De Vries, 1984; Black and Henderson, 2003; Dobkins and Ioannides, 2001; Ioannides and Overman 2004; Bosker et al., 2008). This measure is the distance weighted[24] sum of the population of all other already existing cities. In each century *t*, city *i*'s urban potential (*UP*) is calculated as follows:

$$UP_{it} = \sum_{j=1,\, j \neq i}^{N} \frac{pop_{jt}}{D_{ijt}} \qquad (1)$$

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

This is clearly a too strong restriction when looking at Figure 2. An existing urban centre exerts an urban shadow at close range, prohibiting the formation of new cities in its

[23] Note that, given our 1000-year sample period, truly time-invariant location specific characteristics are hard to imagine. Even when a particular characteristic is truly time-invariant, it is likely that its effect on a location's urban chances shows significant changes over such a long period. Controlling for unobserved heterogeneity at a higher spatial scale (the country in our baseline specifications), while coming at the cost of having to assume a similar effect across locations within each country, does not preclude the (effect of) unobservables to change over the centuries. This, and the fact that we cannot identify the effect of our 1st nature geography variables when controlling for unobserved time-invariant location-specific heterogeneity, explains our choice of including *country-century* fixed effects in all our baseline specifications.

[24] Sometimes additional weights are introduced in (1). 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).

immediate neighborhood. At the same time, potential locations that are too far removed from the already existing cities also have little chance of becoming a city. It are the locations at medium distance from an already existing city that have the best urban chances. Theory thus 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. *UP*-type measures fail to adequately capture this.

To do more justice to the insights from theory, we adopt the following dummy variable approach. We first draw three concentric circles around each potential city location at ever further distance. 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[25]. Moroever, to capture possible competition effects between different 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. Using this dummy variable approach does not constrain the effect of 2nd nature geography to be positive or negative at all distances as the use of *UP*-type measures does[26].

Figure 5. Constructing dummy variables to capture 2nd nature geography.

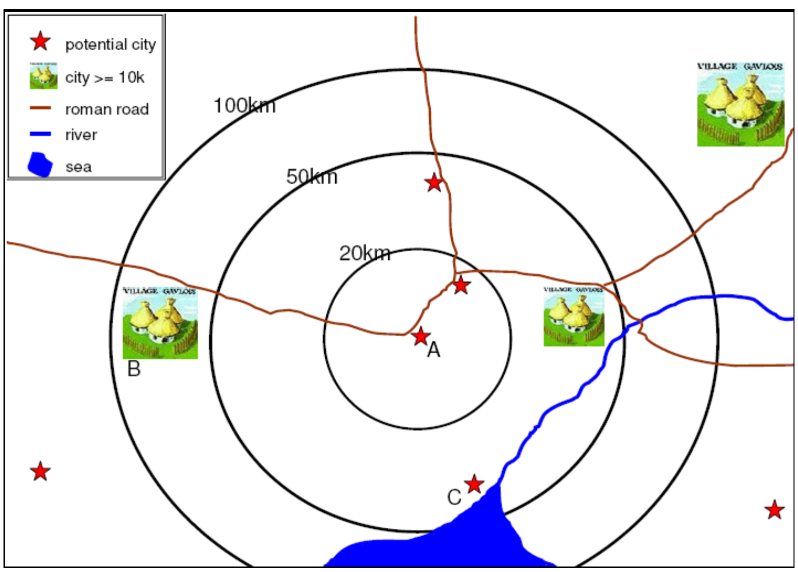

Figure 5 illustrates in some more detail how we construct these dummy variables in case of a hypothetical potential city location A. For this location, the dummy variables indicating the

[25] We calculate great circle distances between all locations in our data set on the basis of their coordinates.
[26] It does constrain the effect to be the same within each distance band. But, one can experiment with different distance bands (see Table A7 in Appendix A).

presence of an established urban centre are only 1 in case of the 20-50km and the 50-100km distance band (there are no already existing urban centres within 20km of A). Instead, the dummy variables indicating the presence of a competitor potential city location are only 1 in case of the 0-20km and 20-50km distance band (there is no competitor potential city location within 50-100km from A).

In our baseline estimations we include six dummy variables, two for each of our three distance bands (defined as 0-20km, 20-50km and 50-100km from a potential city location[27]), indicating the presence of:

1) at least one already existing city with at least 10,000 inhabitants[28]
2) at least one competitor potential city location

In further extensions (see section 6) we also consider more elaborately specified dummy variables indicating e.g. the presence of more than one already-existing city, a competitor potential city location with certain 1st nature geography characteristics, or an already-existing city with more than 25,000 inhabitants, within each of our three specified distance bands. In case of location A in Figure 5, a dummy variable indicating the presence of a competitor potential city location located at sea would for example be 1 in case of the 20-50km distance band (location C). Similarly, the dummy variables indicating the presence of at least two existing cities within each respective distance band would always be 0 in case of location A (none of the distance bands contains two already-existing cities).

3.3.3 Non-geography related (control) variables

Finally, we include some other non-geography related variables in robustness checks to our baseline specification. These concern the political, religious and educational characteristics of a location. We know for each location in each century 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. (2010) and we refer to the Data Appendix of that paper for more detail on these variables[29]. Also, in one of our specifications we control for the total population size and the growth in population size of the

[27] The first distance band is based on the idea that 20 kilometers roughly corresponds to a one day round-trip during most of our sample period (roughly because this depends on mode of transportation, travel on horseback or donkey was generally faster than travel by foot, cart or water).

[28] We construct the dummy variables on the basis of existing cities larger than 10,000 inhabitants instead of 5,000 inhabitants to limit possible reverse causality (simultaneity) issues from including a spatially lagged variable. We further limit these simultaneity issues by considering these dummy variables lagged one century (see section 4). In some robustness checks in section 6.1 we do show results when constructing these dummy variables on the basis of a larger and/or smaller population threshold for existing cities.

[29] This can be downloaded at Bosker's homepage: http://maartenbosker.googlepages.com/.

(current-day) country a location belongs to. This data is taken from McEvedy and Jones (1979). In most specifications these two variables are however fully captured by the included country-century fixed effects.

4 *Empirical framework*

To empirically quantify the effect of a location's 1st and 2nd nature geography characteristics on its chances of developing into a city, we specify the following simple empirical model:

$$P(c_{ict} = 1 \mid c_{ict-1} = 0, X_{ict-1}, X_i, \alpha_{ict}) = F(X_{it-1}\beta_1 + X_i\beta_2 + X_{ct-1}\beta_3 + \alpha_{ict}) \qquad (2)$$

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 (a logit model) or simply be the identity function (a linear probability model[30]). The dependent variable, c_{ict}, 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 reverse causality. The β's are our parameters of interest. They reveal the sign, size and, together with their estimated standard error, (in)significance of our included 1st and 2nd nature geography variables. Finally, α_{ict} captures any unobserved effects at the city, country or century level. In our main specification we specify these unobserved effects to be *country-century-specific* fixed effects: $\alpha_{ict} = \alpha_{ct}$, but we also show results using various different specifications (e.g. using ecozone-century fixed effects, or assuming away any unobserved heteroegenity by taking $\alpha_{ict} = \alpha$).

As our baseline 1st nature geography variables [the X_i in (2)] we include the dummy variables for location at sea, at a river, and on a (hub of) roman road(s). Besides these four transport related 1st nature geography variables, we also include the log of a location's elevation and of its ruggedness as proxies for its ease of access, and we include a location's probability of cultivation as a measure of its agricultural possibilities. We also include a location's probability of cultivation interacted with a time trend in all (but one) of our specifications to allow for a possibly varying effect of this variable over the centuries.

Finally, as our baseline 2nd nature geography variables [the X_{it-1} in (2)], we include the

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[30] In this case we need to add an error term to (2). This is implicit in the probit or logit case, by defining F to be a normal or logistic distribution function.

three 'already existing city'- and the three 'competitor potential city location'-dummy variables discussed below Figure 3 in section 3.3.2.

5 *Results*

Table 1 builds up to our baseline results. Unless noted explicitly, all Tables in our paper do not show the estimated coefficients of (2), but report Average Partial Effects (APEs) instead. The estimated coefficients of any nonlinear model are generally 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 that is often of most interest. 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. In case of our model specified in (2), the APE of X_{it-1} is for example calculated as:

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

Using a linear probability model, with F the identity function, this would simply be $\hat{\beta}_1$. When F is a nonlinear function (Φ in our baseline probit case), this is no longer so.

In column 1, we start by ignoring any potential unobserved heterogeneity and simply assume that $\alpha_{ict} = \alpha$. Under this (strong) assumption, location at a river and at sea both significantly positively affect a location's chances of becoming a city. Good location for land-based transportation instead has a surprising negative effect. Locations on the former roman road network have lower urban chances (even when located on a hub of two roman roads[31]). Also, we find that locations in more rugged areas have significantly lower urban chances. Perhaps most remarkably, these first results suggest that the better a location's agricultural possibilities or the higher its elevation, the worse its urban prospects.

Turning to our 2nd nature geography variables, we find that they are *all* significant. This suggests strong evidence that potential city locations, surrounded by other already existing cities at close or medium-large distance, have much higher chances of becoming a city than more isolated locations. On the contrary, fiercer competition from other potential city locations at close or medium-large range diminishes a location's own urban chances. Finally, both the size and the growth rate of a country's total population have a significantly positive effect on the urban chances of all locations within that country.

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[31] Note that the results on our hub-variable have to be interpreted as the *additional* effect of being a hub location over that of simply being located on a roman road.

Table 1. Baseline results

	P(city t | no city t-1)	1	2 (BASELINE)	3 CRE	4 ecozone/ century FE	5 blocks/ century FE	6 ecozone- & blocks- & country-century FE
X_{ct-1}	ln country population (t-1)	0.063***	-	-	-	-	-
		[0.000]	-	-	-	-	-
	D country population (t-1 -> t)	0.420***	-	-	-	-	-
		[0.000]	-	-	-	-	-
X_i	sea	0.017*	0.013	0.012	0.014*	0.008	0.013
		[0.054]	[0.134]	[0.149]	[0.082]	[0.397]	[0.206]
	river	0.034***	0.061***	0.057***	0.050***	0.061***	0.066***
		[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
	hub	0.002	0.015*	0.015**	0.011	0.015*	0.015
		[0.828]	[0.070]	[0.049]	[0.151]	[0.088]	[0.106]
	road	-0.016***	-0.010*	-0.009	-0.009*	-0.003	-0.003
		[0.006]	[0.074]	[0.129]	[0.071]	[0.608]	[0.627]
	ln elevation	0.005**	0.002	0.002	0.004*	0.001	0.004
		[0.034]	[0.341]	[0.497]	[0.061]	[0.826]	[0.183]
	ruggedness	-0.012***	-0.008***	-0.008***	-0.007***	-0.008***	-0.005*
		[0.000]	[0.001]	[0.001]	[0.001]	[0.003]	[0.090]
	P(cultivation)	-0.044***	0.114***	0.098***	0.050*	0.050	0.038
		[0.000]	[0.002]	[0.004]	[0.095]	[0.192]	[0.404]
	P(cultivation) * trend	-	-0.013***	-0.011***	-0.007*	-0.003	-0.001
		-	[0.004]	[0.006]	[0.052]	[0.543]	[0.814]
X_{it-1}	city >= 10k? (t-1)						
	0 – 20 km	0.037***	-0.003	-0.007	0.001	-0.009	-0.007
		[0.000]	[0.716]	[0.56]	[0.918]	[0.322]	[0.476]
	20 – 50 km	0.049***	0.010*	0.024***	0.013***	0.012**	0.013**
		[0.000]	[0.051]	[0.001]	[0.006]	[0.039]	[0.045]
	50 - 100 km	0.057***	0.009*	0.005	0.014***	0.011*	0.015**
		[0.000]	[0.084]	[0.432]	[0.003]	[0.085]	[0.031]
	competitor potential city location? (t-1)						
	0 - 20 km	-0.034***	-0.015***	-0.011	-0.013***	-0.010*	-0.012**
		[0.000]	[0.004]	[0.425]	[0.003]	[0.065]	[0.049]
	20 - 50 km	-0.061***	-0.007	-0.005	-0.008	-0.008	-0.008
		[0.000]	[0.471]	[0.797]	[0.374]	[0.437]	[0.486]
	50 - 100 km	-0.078***	-0.027	0.060	-0.019	-0.022	-0.046
		[0.001]	[0.250]	[0.229]	[0.370]	[0.341]	[0.114]
	country/century FE	no	yes	yes	no	no	yes
	nr observations	15156	13228	15156	14771	11715	11034
	ln pseudo likelihood	-4500.5	-3193.4	-3173.2	-3412.5	-3112.4	-2927.2
	LR – test statistic	-	2614.1	-	-	-	-
	2.5% upper tail critical value $\chi^2(n)$	-	225.7 $\chi2(186)$	-	-	-	-

Notes: p-values, based on robust standard errors[32], between square brackets. *, **, *** denotes significance at the 10%, 5%, 1% respectively. Instead of the estimated coefficients in (2), the table reports average partial effects. The p-values are based on the estimated coefficients and their standard errors since these do not depend on the particular calculation of the average partial (or marginal) effects. Result are the same when using the p-values based on the calculated standard errors of the average partial effects. 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). Only in this table we add X_{ct-1}, X_i and X_{it-1} to the left of our variable names to clarify the correspondence between equation (2) and our results.

The results in column 2 however show that the above conclusions are far too preliminary. They depend strongly on the assumption of no unobserved heterogeneity. In column 2 we

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[32] Note that the use of clustered standard errors would violate the assumptions underlying the estimation of our baseline model by standard probit techniques due to the implicit dynamic nature of our model.

include country-century-specific fixed effects (i.e., $\alpha_{ict} = \alpha_{ct}$) to control for any unobserved developments over the centuries, possibly specific to each country, that may have left their mark on each location's urban chances. Moreover, we also allow the effect of a location's cultivation potential to change over time[33].

This specification is statistically strongly preferred over assuming away any unobserved heterogeneity (see the likelihood ratio test at the bottom of column 2). More importantly, it substantially changes our findings.

The results regarding the included 1st nature geography variables change in important ways. First, the surprising negative effect of a location's cultivation potential turns out to be driven by the later centuries. When allowing its effect to change over the centuries, it shows that initially, the better a location's cultivation potential, the higher its urban chances. However this effect becomes significantly smaller over the centuries (its overall marginal effect is insignificant from about the 15th century onwards). This is not only consistent with gradually improving agricultural methods that diminish the relative advantage of being located near highly productive lands, but also with the notion that in the later centuries food could be transported over greater distances at lower costs due to improvements in transportation technology. This diminished the 1st nature advantage of location right next to fields of high agricultural productivity (Duranton, 1999, p.2173). In North-Western Europe e.g. the grain trade with eastern Europe became increasingly important (Hybel, 2002).

Second, we still find that a location's opportunities for water-based transportation are a very important determinant of its urban chances. However, location at sea looses its significance. Only locations on a navigable river have a significantly higher probability of becoming a city of about 6 percentage points. Also, we still find no evidence that location on the former roman road network bore any significant advantages. Non-hub locations on the former roman road system even have significantly lower urban chances. This finding corresponds to the account of Lopez (1956). He argues that the importance of the Roman road network diminished during the Middle Ages. On the one hand water-based transportation gained in importance (no need for maintenance, and easier to ship heavier loads), on the other hand the Roman road system was planned mostly for military purposes so that it did not always correspond to the most economical route[34].

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[33] Invariably, a location's cultivation potential is never significant at the 10% level when not also including it interacted with a time-trend.

[34] As a result (Lopez, 1956 p.21): *"in the later Middle Ages […] little by little a new network of roads was put into effective operation, different totally in structure and methods from the ancient one […] The routing reflected the needs of commerce rather than the convenience of soldiers and civil servants."* The diminishing importance

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

This is exactly what happened in column 1. In column 2 we find that our 2nd nature geography variables are much less significant. Strikingly however, the 2nd nature geography results correspond very closely to the theoretical predictions following from the standard economic geography models discussed in section 2.2. We find 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 (20-100km)[35]. Being located too close (0-20km) or too far (> 100km) from an already existing city does not significantly affect a location's probability to become a city. We also no longer find a significant competition effect with other potential city locations at all distances. The results in column 2 show that competition with other potential city locations is fiercest at close range: only having a rival potential city location within 0-20km significantly diminishes a location's urban chances[36].

Overall, we can summarize our preliminary baseline results as follows:

1) *1st nature geography* is very important in determining a location's urban chances. Especially preferential location for *river-based* transportation substantially increases a location's probability to become a city. Location at (a hub of) overland transport routes does not carry such positive effects. Favorable location in terms of agricultural possibilities also contributes positively to a location's urban chances, but especially so at the beginning of our sample period (a reflection of both gradually improving agricultural production techniques as well as better possibilities to import food grown on farther fields). Finally, we find that better accessible places, located in less rugged terrain, do have better urban chances.

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of the roman road network is further confirmed when allowing the effect of 'hub-location' to vary over the centuries (see section 5.2).

[35] The p-value corresponding to a test of the joint significance of our 20-50km and 50-100km already-existing city dummies is [0.039]

[36] These results also come through when including only the already-existing-city or only the competitor-potential-city dummy variables. Results available upon request.

2) *2nd nature geography* is also important, but to a lesser extent. What is very interesting however, is that our flexible modelling strategy uncovers almost the exact prediction made by new economic geography theory. Locations at medium range (20-100km) from already existing cities have significantly better urban chances. They have about a 1 ppt higher probability to become a city than locations located closer to or further away from other already existing urban centres. On the contrary, competition with other potential city locations is fiercest at close range. Only a competitor within the nearest 20km significantly diminishes a location's urban chances by about 1.5 ppt.

In the remainder of the paper, we show that these baseline results hold up to a wide variety of robustness checks. These checks do result in one important refinement. In particular, the above-reported effect of 2nd nature geography only comes into play from about the seventeenth century onwards, whereas the relevance of 1st nature geography diminishes over the centuries. Furthermore, we present several refinements of our 2nd nature geography results. We e.g. allow the competition effect to depend on the 1st nature characteristics of a location's competitors, or allow the effect of already existing cities to depend on their number or total population size.

5.1 Robustness

We start by presenting several robustness checks to our baseline results that lead the way to our most important refinement that shows the changing importance of both 1st and 2nd nature geography in determining city location over the centuries. Besides those discussed in the main text, Tables A6 – A8 in Appendix A contain additional robustness checks concerning the sensitivity of our baseline results to the estimation strategy used, to the particular distance bands used to construct our 2nd nature geography variables, or to the absolute population cutoff of 5,000 inhabitants that we use to define a city.

5.1.1 Controlling for unobserved heterogeneity

Our first four robustness checks are shown in columns 3 - 6 of Table 1. They concern the way we control for unobserved heterogeneity[37]. In our baseline results we control for any

[37] Our baseline results are only valid under the assumption of no time-invariant location-specific heterogeneity (even when this heterogeneity is uncorrelated with the variables of interest, i.e. random effects, we would get incorrect estimates of our parameters of interest given the implicit dynamic nature of our model). This issue relates closely to possible concerns regarding dynamic selection bias (see Cameron and Heckman, 1998). If city locations get selected on the basis of unobserved characteristics showing persistence over time, this would result in the wrong inference regarding our parameters of interest. The fact that our results hold up to using various

unobserved *country-century-specific* variables that could leave their effect on a location's urban chances. One could still stress the need to also control for *unobserved time-invariant* factors at the *location level*. Despite the drawback that doing this makes it impossible to infer the relevance of our *time-invariant* 1st nature geography variables, it does serve as an additional robustness check on our 2nd nature geography results.

However, allowing for such location-specific unobserved heterogeneity when employing non-linear panel data techniques 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, 1979; Wooldridge, 2005; Fernández-Val, 2009 or Carro, 2007). In our baseline probit 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[38], 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, $\bar{X}_{i\cdot}$, of the included X_{it-1} variables, the country-century specific fixed effects, α_{ct}, and a location's initial city status in 800[39], c_{i800}, i.e.: $\alpha_{ict} = \alpha_{ct} + c_{i800}\zeta + \bar{X}_{i\cdot}\xi + \eta_i$, with $\eta_i \mid \alpha_{ct}, c_{i800}, \bar{X}_{i\cdot} \sim N(0, \sigma_\eta^2)$. Under this assumption for the location-specific unobserved heterogeneity we can employ random effect probit techniques to get consistent estimates of the parameters of all our second nature geography variables[40].

Column 3 of Table 1 shows that the effect of 2nd nature geography is somewhat weakened when employing this CRE estimation strategy. In particular, we no longer find evidence of any significant competition effect among potential city locations. The nonlinear

different (more or less restrictive) specifications to capture any unobserved heterogeneity (see e.g column 2 of Table 3, or columns 3-6 in Table 1), addresses such concerns.

[38] Table A6 in Appendix A shows that our results are the same when using a conditional logit or fixed-effects linear probability estimation strategy instead. It also reveals that we find the same results when employing a (semi-)parametric Cox proportional hazard model. Using this method can be argued to take better account of any duration-dependence in the probability of becoming a city (i.e. this probability may not be the same depending on the time a location has already not become a city). However, the fact that we include country-century fixed effects in all our baseline specifications can be argued to already go a long way in controlling for duration-dependence (they allow the baseline hazard to (arbitrarily) change over the centuries in a possibly different way across countries).

[39] Given the dynamic nature of the model, the presence of any (random or fixed) location-specific time-invariant unobserved heterogeneity requires the inclusion of this initial value to address the 'initial condition problem'.

[40] Note that although we still appear to obtain estimates of the effects of the 1st nature geography variables, these are misleading since we can not separately identify each 1st nature geography variable's effect on a location's urban chances from its partial correlation with the location-specific unobserved effects (see Wooldridge, 2005). If one is willing to assume that this partial correlation is zero, the coefficients on our 1st nature geography variables can be interpreted. In that case, all our baseline findings, come through.

effect exerted by an already existing city is however robust to also controlling for unobserved time-invariant location-specific effects. 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.

Besides calling for the need to control in an even stricter sense for any unobserved heterogeneity, one could also question the appropriateness of using country-century fixed effects to capture the unobserved heterogeneity in our baseline model. Do our findings critically hinge upon this country-century specification? The final three columns of Table 1 address this concern. In column 4 we instead include ecozone-century fixed effects constructed on the basis of a division of Europe in five different *ecozones* taken from Buringh et al., 1975 (see Figure A4 in the Appendix). Next in column 5, we use block-century fixed effects based on a division of 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. And, in column 6, we include country-, ecozone-, and block-century fixed effects at the same time. All three columns show that our baseline results hold up to using these different specifications to control for time-varying unobserved heterogeneity. Location on a roman road and a location's agricultural potential are most sensitive to these additions. Both loose their significance when including block-century fixed effects[41].

5.1.2 Additional variables and sample composition

The next set of robustness checks concerns the inclusion of additional non-geography related control variables to our baseline model, as well as several checks to establish whether or not our results are primarily driven by developments in a few centuries or in particular countries only. Table 2 shows the results.

Columns 1 – 3 add additional variables to our baseline specification. Reassuringly, and with only few exceptions, all our main baseline results come through[42]. The results on the extra included variables are of interest by themselves however.

Column 1 controls for a potential city location's religious, political and educational status in period *t-1*. We find that having an important religious [(arch)bishopric] or political

[41] Given that our agricultural potential variable is based on a grid of 0.5 by 0.5 degree longitude and latitude, it may not be so surprising that it is especially sensitive to controlling for these block-century fixed effects that are also based on a (be it somewhat larger) longitude and latitude defined, grid-wise division of our sample.
[42] This is even more true, when we allow the effect of 1st and 2nd nature geography to change over the centuries (see e.g. the discussion of the results in column 6 of Table 3 in section 5.2.1).

Table 2. Robustness (variables included and sample composition)

P(city t | no city t-1)	political and religious function	ever a city before?	'Bairoch' history < 5k?	only bishops	only > 20% bishop 600 countries	no UK	**no Italy**	**< 1600**	**>= 1600**
sea	0.012	0.013	0.009	-0.005	0.003	0.016	0.043***	0.003	0.034
	[0.179]	[0.139]	[0.275]	[0.709]	[0.775]	[0.101]	[0.001]	[0.698]	[0.154]
river	0.049***	0.059***	0.057***	0.101***	0.061***	0.061***	0.062***	0.046***	0.096***
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
hub	-0.002	0.014*	0.017**	0.022**	0.009	0.011	0.022**	0.027***	-0.044*
	[0.762]	[0.087]	[0.033]	[0.049]	[0.280]	[0.213]	[0.033]	[0.000]	[0.051]
road	-0.014**	-0.010*	-0.009*	-0.017	-0.008	-0.011*	0.006	0.010*	-0.056***
	[0.016]	[0.072]	[0.097]	[0.209]	[0.182]	[0.076]	[0.442]	[0.076]	[0.000]
ln elevation	0.003	0.002	0.001	-0.007*	0.001	0.002	0.005*	-0.002	0.012**
	[0.171]	[0.389]	[0.683]	[0.064]	[0.552]	[0.32]	[0.086]	[0.285]	[0.045]
ruggedness	-0.005**	-0.008***	-0.008***	-0.003	-0.009***	-0.007***	-0.013***	-0.009***	-0.004
	[0.036]	[0.002]	[0.002]	[0.442]	[0.001]	[0.006]	[0.000]	[0.000]	[0.585]
P(cultivation)	0.093**	0.113***	0.104***	0.065	0.071*	0.104***	0.044	0.078**	-0.227
	[0.014]	[0.002]	[0.003]	[0.255]	[0.070]	[0.007]	[0.300]	[0.027]	[0.509]
P(cultivation) * trend	-0.011**	-0.013***	-0.011***	-0.005	-0.01**	-0.012**	0.001	-0.009	0.021
	[0.018]	[0.004]	[0.01]	[0.513]	[0.036]	[0.011]	[0.852]	[0.101]	[0.542]
city >= 10k? (t-1)									
0 - 20 km	0.001	-0.002	-0.005	-0.049*	0.005	0.001	-0.028**	-0.026**	0.021
	[0.929]	[0.759]	[0.541]	[0.051]	[0.545]	[0.925]	[0.019]	[0.015]	[0.255]
20 - 50 km	0.014***	0.011**	0.009*	0.018*	0.018***	0.013**	0.000	-0.005	0.041***
	[0.004]	[0.041]	[0.088]	[0.097]	[0.002]	[0.019]	[0.999]	[0.345]	[0.002]
50 - 100 km	0.016***	0.009*	0.007	0.019*	0.013**	0.009	-0.002	-0.006	0.060***
	[0.003]	[0.083]	[0.210]	[0.074]	[0.038]	[0.110]	[0.745]	[0.200]	[0.000]
competitor potential city location? (t-1)									
0 - 20 km	-0.007	-0.014***	-0.016***	-0.017	-0.012**	-0.017***	-0.013**	-0.012**	-0.020
	[0.137]	[0.005]	[0.002]	[0.117]	[0.043]	[0.002]	[0.044]	[0.014]	[0.154]
20 - 50 km	-0.010	-0.007	-0.006	-0.007	-0.004	-0.008	-0.012	-0.010	-0.009
	[0.32]	[0.503]	[0.540]	[0.718]	[0.733]	[0.477]	[0.244]	[0.246]	[0.74]
50 - 100 km	-0.028	-0.027	-0.023	-	-0.002	-0.026	-0.032	-0.022	-0.058
	[0.229]	[0.263]	[0.334]	-	[0.963]	[0.302]	[0.188]	[0.362]	[0.315]
country/century FE	yes	yes	yes	yes	yes	yes	yes	yes	yes
nr observations	13228	13228	13228	3242	9567	12197	8960	9610	3618

extra included variables

	political and religious function	ever a city before?	'Bairoch' history < 5k?
bishop t-1	0.147***	-	-
	[0.000]	-	-
archbishop t-1	0.185***	-	-
	[0.000]	-	-
capital t-1	0.181***	-	-
	[0.000]	-	-
university t-1	0.051	-	-
	[0.157]	-	-
ever a city before?	-	0.030***	-
	-	[0.005]	-
>= 1k t-1?	-	-	0.101***
	-	-	[0.000]

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, based on robust standard errors, between square brackets. *, **, *** denotes significance at the 10%, 5%, 1% respectively. Instead of the estimated coefficients in (2), the table reports average partial effects. The p-values are however based on the estimated coefficients and their standard errors.

[capital] function substantially increases a location's urban chances. Note however that the results on these non-geography related variables should be taken with some care. The extra information on the included political and religious variables in Table 2 shows that only 0.2% of all our potential city locations are a capital, 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[43].

Column 2 and 3 instead control for a location's (urban) population history. In column 2 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 our 5,000 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 an effect on the results. This is however not the case[44], but the results do show that locations that once already qualified as a city, but subsequently lost their city status, have a 3 ppt higher probability to (again) gain city status.

Finally, in column 3 we make use of the fact that Bairoch et al. (1988) do in fact report some population estimates below 5,000 inhabitants. Although Bairoch et al. (1988, p.218) stress that these numbers are subject to much greater margins of error than their numbers larger or equal than 5,000 inhabitants, we include an additional dummy variable indicating whether or not a location was already reported to have a population between 1,000 and 4,000 inhabitants in period *t-1*. Again our baseline results come through, only the presence of an existing city within the 50-100km distance band looses its significance. Moreover, the additional 'population history' dummy is significant and has the expected sign: already having a reported number of inhabitants increases a location's chances of becoming a city by about 10ppt.

The other six robustness checks verify whether our baseline results are driven by particular observations, countries or centuries only. In column 4 and 5, we pay special attention to our bishop 600 'control-group' of potential city locations. In column 4 we exclusively focus on this group of 456 observations. Doing this can be argued to address

[43] This is less true for bishoprics: 7% of all potential locations are a bishopric before (possibly) becoming a city. The estimated coefficient confirms the importance of the church in conditioning urban development in Europe (Bairoch, 1988; Hohenberg and Lees, 1995): a bishopric increases a location's urban chances by 16.4ppt.

[44] The baseline results are also robust to simply removing those locations that had already qualified as a city before. We also note that the Black Death (the plague epidemic of 1342) is responsible for many of these 'city-disappearances'. 40% of the existing cities in 1300 'disappear', i.e. fall back below the 5,000 inhabitants thresehold, during the fourteenth century. Our results are also robust to either excluding the plague years (1400 and possibly also 1500 to account for a possible 'recovery' effect), or excluding those cities that 'disappeared' in the fourteenth century. Results available upon request.

possible concerns regarding endogenous sample selection arising from our selection of potential city locations on the basis of actually becoming a city at some point during our sample period[45] (see the discussion in section 3.1). The case that these bishop 600 locations were, conditional upon all the other included regressors in our model, randomly chosen with respect to their future city prospects may be easier to make compared to our Bairoch et al. (1988) locations. Column 4 shows that most of our baseline results hold up to doing this, despite the fact that it involves a substantial reduction in the number of observations (we lose more than 10,000 observations compared to our baseline results)[46].

Column 5 instead verifies whether or not the results depend on the 'Roman empire bias' in the use of our bishop 600 locations that are mainly found within the boundaries of the former Roman Empire. Only considering potential city locations in countries where at least 20% of all potential city locations were an (arch)bishopric in 600 (see Table A2) does however not affect our baseline results.

Similarly, column 6 shows that our baseline results hold up to excluding the UK, the earliest industrializing country[47], from the sample. This is not the case in column 7 where we exclude Italy, the country contributing the most potential city locations (see Table A2)[48], from the sample. Although the 1st nature geography results (with the exception of the agricultural potential variables) and the negative effect of having a competitor potential city location within 20 km hold up, the results on the 2nd nature geography effect of other already existing cities do not. We no longer find the significant positive effect of already existing cities at medium range. Instead, we only find stronger evidence of an urban shadow: an already existing city within 20 km of a potential city location significantly diminishes that location's urban chances.

Although questioning the generality of our findings, it turns out that this sensitivity of the results to the exclusion of all Italian locations is completely overshadowed by their sensitivity to splitting the sample along century lines (see column 3 in Table 3). In column 8

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[45] In Table 3 we further investigate the possible relevance of endogenous sample selection bias by extending or completely changing the sample of potential city locations that we consider.

[46] We no longer find a significant effect of location on a roman road, of a location's cultivation potential nor of its ruggedness. The competitor potential city location dummy for the 50 – 100km distance band drops out because it is perfectly captured by the included country-century fixed effects.

[47] Ashton (1948) dates its start in Britain in the late eighteenth century. In continental Europe it only gathered steam in the first half of the nineteenth century. Excluding also Belgium, the earliest industrializer on the continent, also leaves our results unaffected. Results available upon request.

[48] The baseline results are fully robust to excluding either France (the second biggest contributor), or Spain (the third biggest contributor) from the sample. Results available upon request.

and 9 we consider only the period before or after 1600 respectively[49]. Both the relevance of 1st and 2nd nature geography differs markedly between the earlier and later centuries in our sample.

Regarding 1st nature geography, the different pre- and post-1600 estimates show an increasing importance of location on a navigable river. The importance of the other 1st nature geography variables decreases. Both favourable location for land-based transportation (hub location), as well as a location's accessibility (ruggedness) have a significantly positive effect on a location's urban chance in the pre-1600 period but loose this positive influence in the later centuries. Also, the decreasing importance of favorable location for agriculture (earlier shown by the negative coefficient on cultivation potential interacted with a timetrend) is confirmed: we only find a positive effect of a location's cultivation potential during the earlier centuries in our sample.

Second, regarding 2nd nature geography, we do not find the significant positive effect of having an already existing city at medium distance in the pre-1600 period, but an already existing city at too close distance (within 20 km) does significantly lower a location's probability to become a city during this period (this echoes our 'Italy'-finding above). When instead 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. Moreover, the negative effect of having a competitor potential city location at close range looses its significance in the later period.

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

The above-described difference in results when considering the earlier or later centuries of our sample period is the most important refinement to our baseline results. In this section we further explore this finding. Instead of simply splitting the sample, we estimate (2) allowing all variables to have a pre- and post-1600 specific effect by interacting each variable with a pre- and a post-1600 dummy. This has the advantage that it allows us to formally test the equivalence of the pre- and post-1600 effect of each of the included variables. Column 1 of Table 3 shows the results when doing this for our baseline specification [the p-values corresponding to tests for the equality of each respective variable's effect in the pre- and post-1600 period are found at the bottom of the table]. The other columns show various robustness

[49] In Table A5 in the Appendix we show results when using a finer decomposition of the sample along century lines. The patterns shown in these results are very similar to those using a pre- and post-1600 split of the sample. Only in case of our 'competitor potential city location'-dummy variable do these finer decompositions give less clear-cut results. For parsimony reasons we decided to show the pre- and post 1600 results in the main text.

checks to the baseline results in column 1.

Column 1 generally confirms the results of simply splitting the sample in column 8 and 9 of Table 2. Regarding the 1st nature geography results, we find that the importance of land-based transport significantly diminishes, whereas that of water-based transport, and river-based transport in particular, significantly 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. It shows the gradually diminishing (economic) importance of the former Roman road network (see Lopez, 1956). Instead, the importance of location on a navigable river increases substantially[50]. These findings correspond to many narrative accounts by (economic or urban) historians that document the increased dominance of water- over land-based transport in late Medieval and pre-modern Europe (Lopez, 1956; Bairoch, 1988; Hohenberg, 2004). Also, we again find that a location's agricultural possibilities as well as its accessibility (measured by its ruggedness) become less important over the centuries in determining city location.

The results on 2nd nature geography also confirm the results found in Table 2. Only from the 17th century onwards do we find that locations at medium range (20 – 100km) from an already existing city have significantly higher urban chances than locations located too close to or too far away from existing urban centres. This significantly differs from the earlier centuries, when we do not find this effect. Instead we only find a significant negative effect on the urban chances of locations at very close range to an already existing city. Also, the negative competition effect with other potential city locations at close range is only significant in the pre-1600 period[51].

5.2.1 Robustness of our time-varying results

Before discussing the implications of our findings, we first show that our time-varying findings are very robust (even more than our baseline findings in Table 1).

Column 2 in Table 3 shows that they, except for the competition effect at close range, hold up when estimating a conditional random effects probit model[52] to also allow for any

[50] Location at sea does not play as significant a role in city location as location at a river, also not during the later centuries [in some of the robustness checks we do sometimes find a significant role for location at sea in determining city location, but never does it play a more important role that location at a river].

[51] The post-1600 effect of competition at close range is not significant, but note that we also reject that it changed significantly compared to its pre-1600 effect.

[52] 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. Also, using different specifications to capture possible time-varying unobserved heterogeneity (similar to column 4-6 in Table 1) does not change our main results.

Table 3. Pre- and post-1600 results

P(city t | no city t-1)	**BASELINE**	CRE	no Italy	no UK	no 1800	'Bairoch' history < 5k?	extra '1850' potential city locations	random coordinates 5km match	measurement error ?
sea < 1600	0.013*	0.011*	0.030***	0.016**	0.016**	0.011	0.012*	-0.004	11%
	[0.080]	[0.098]	[0.008]	[0.041]	[0.033]	[0.139]	[0.074]	[0.279]	< 57% >
sea >= 1600	0.007	0.014	0.067**	0.007	0.056**	-0.001	-0.002	0.000	0%
	[0.741]	[0.548]	[0.015]	[0.772]	[0.024]	[0.941]	[0.932]	[0.962]	< 0% >
river < 1600	0.049***	0.041***	0.053***	0.049***	0.048***	0.047***	0.042***	0.000	100%
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.923]	< 100% >
river >= 1600	0.088***	0.102***	0.081***	0.087***	0.080***	0.080***	0.054***	0.016**	100%
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.015]	< 100% >
hub < 1600	0.039***	0.033***	0.040***	0.036***	0.032***	0.040***	0.034***	0.050***	100%
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	< 100% >
hub >= 1600	-0.069***	-0.061***	-0.034	-0.079***	-0.018	-0.061***	-0.057***	0.032	98%
	[0.001]	[0.003]	[0.189]	[0.000]	[0.410]	[0.002]	[0.005]	[0.169]	< 100% >
ruggedness < 1600	-0.009***	-0.008***	-0.010***	-0.009***	-0.011***	-0.009***	-0.009***	0.001	100%
	[0.000]	[0.000]	[0.001]	[0.000]	[0.000]	[0.000]	[0.000]	[0.529]	< 100% >
ruggedness >= 1600	-0.002	-0.006	-0.020**	0.003	-0.012	0.000	-0.007	0.001	0%
	[0.754]	[0.426]	[0.017]	[0.718]	[0.110]	[0.984]	[0.273]	[0.629]	< 0% >
roman road	-0.008	-0.007	0.008	-0.009	0.005	-0.007	0.003	0.036***	0%
	[0.168]	[0.227]	[0.304]	[0.169]	[0.368]	[0.209]	[0.538]	[0.000]	< 5% >
ln elevation	0.002	0.001	0.005	0.002	0.005**	0.000	0.003	-0.003**	0%
	[0.462]	[0.534]	[0.119]	[0.456]	[0.035]	[0.848]	[0.238]	[0.035]	< 0% >
P(cultivation)	0.111***	0.096***	0.070	0.102***	0.101***	0.100***	0.114***	-0.002	100%
	[0.003]	[0.006]	[0.113]	[0.008]	[0.006]	[0.006]	[0.002]	[0.940]	< 100% >
P(cultivation) * trend	-0.013***	-0.011***	-0.002	-0.012**	-0.012**	-0.011**	-0.014***	0.000	99
	[0.006]	[0.009]	[0.661]	[0.013]	[0.014]	[0.016]	[0.001]	[0.946]	< 100% >
city >= 10k? (t-1)				**0 - 20 km**					
< 1600	-0.024**	-0.029**	-0.033**	-0.023**	-0.023**	-0.024**	-0.021**	0.002	89%
	[0.025]	[0.012]	[0.028]	[0.037]	[0.035]	[0.023]	[0.025]	[0.737]	< 100% >
>= 1600	0.019	-0.004	-0.040	0.030	-0.007	0.014	0.020	0.003	3%
	[0.309]	[0.874]	[0.116]	[0.130]	[0.757]	[0.450]	[0.257]	[0.300]	< 9% >
city >= 10k? (t-1)				**20 - 50 km**					
< 1600	-0.004	0.005	-0.009	-0.003	-0.004	-0.004	-0.004	-0.002	0%
	[0.436]	[0.336]	[0.200]	[0.613]	[0.474]	[0.394]	[0.387]	[0.527]	< 0% >
>= 1600	0.042***	0.066***	0.018	0.048***	0.034**	0.037***	0.022*	0.017**	97%
	[0.002]	[0.000]	[0.245]	[0.001]	[0.028]	[0.004]	[0.094]	[0.012]	< 100% >
city >= 10k? (t-1)				**50 - 100 km**					
< 1600	-0.005	-0.006	-0.016***	-0.004	-0.006	-0.006	-0.004	0.003	0%
	[0.254]	[0.197]	[0.009]	[0.399]	[0.229]	[0.170]	[0.279]	[0.693]	< 0% >
>= 1600	0.062***	0.060***	0.042**	0.060***	0.071***	0.054***	0.053***	0.010	100%
	[0.000]	[0.002]	[0.02]	[0.001]	[0.000]	[0.001]	[0.001]	[0.106]	< 100% >
competitor potential city location? (t-1)				**0 - 20 km**					
< 1600	-0.011**	-0.010	-0.009	-0.011**	-0.011**	-0.012**	-0.009**	-	92%
	[0.020]	[0.250]	[0.14]	[0.029]	[0.021]	[0.015]	[0.05]	-	< 100% >
>= 1600	-0.020	-0.024	-0.020	-0.028*	-0.021	-0.022*	-0.027**	-	10%
	[0.146]	[0.408]	[0.202]	[0.057]	[0.183]	[0.097]	[0.043]	-	< 26% >
competitor potential city location? (t-1)				**20 - 50 km**					
< 1600	-0.010	-0.008	-0.014	-0.013	-0.010	-0.010	0.002	-	0%
	[0.248]	[0.556]	[0.15]	[0.163]	[0.266]	[0.237]	[0.814]	-	< 0% >
>= 1600	-0.005	-0.013	-0.009	0.002	-0.056**	0.000	0.023	-	0%
	[0.863]	[0.741]	[0.741]	[0.936]	[0.049]	[0.992]	[0.367]	-	< 0% >
competitor potential city location? (t-1)				**50 - 100 km**					
< 1600	-0.021	0.044	-0.023	-0.012	-0.024	-0.022	-0.061***	-	0%
	[0.361]	[0.277]	[0.373]	[0.628]	[0.305]	[0.312]	[0.005]	-	< 0% >
>= 1600	-0.057	0.095	-0.064	-0.077	-0.051	-0.043	0.002	-	2%
	[0.324]	[0.367]	[0.244]	[0.224]	[0.433]	[0.480]	[0.974]	-	< 8% >
country/century FE	yes	yes	yes	yes	yes	yes	yes	yes	yes
nr observations	13228	15156	8960	12197	12094	13228	14892	5182	-

TABLE 3 CONTINUED				*p-value H0: pre 1600 = post 1600*					
sea	[0.325]	[0.387]	[0.915]	[0.226]	[0.612]	[0.254]	[0.160]	[0.358]	-
river	[0.060]*	[0.110]	[0.043]**	[0.069]*	[0.065]*	[0.055]*	[0.000]***	[0.144]	-
hub	[0.000]***	[0.000]***	[0.000]***	[0.000]***	[0.001]***	[0.000]***	[0.000]***	[0.203]	-
ruggedness	[0.010]***	[0.014]**	[0.791]	[0.003]***	[0.095]*	[0.004]***	[0.012]**	[0.837]	-
city >= 10k? (t-1)									
0 - 20 km	[0.014]**	[0.011]**	[0.411]	[0.010]***	[0.161]	[0.020]**	[0.012]**	[0.866]	-
20 - 50 km	[0.007]***	[0.017]**	[0.082]*	[0.007]***	[0.033]**	[0.010]***	[0.078]*	[0.042]**	-
50 - 100 km	[0.000]***	[0.000]***	[0.001]***	[0.002]***	[0.000]***	[0.001]*	[0.001]***	[0.488]	-
competitor? (t-1)									
0 - 20 km	[0.582]	[0.545]	[0.953]	[0.913]	[0.716]	[0.654]	[0.981]	-	-
20 - 50 km	[0.523]	[0.672]	[0.480]	[0.323]	[0.387]	[0.430]	[0.672]	-	-
50 - 100 km	[0.995]	[0.609]	[0.887]	[0.641]	[0.902]	[0.855]	[0.036]**	-	-

Notes: p-values, based on robust standard errors, between square brackets. *, **, *** denotes significance at the 10%, 5%, 1% respectively. Instead of the estimated coefficients in (2), 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 coefficients and their standard errors. In column 6 the results on the dummy variable indicating whether or not a location was already home to at least 1,000 inhabitants in century *t-1* are not shown, its APE is 0.099 and it is significant at the 1% level. In column 9 we show the percentage of simulations that each respective variable is significant at the 5% or < 10% > level.

time-invariant location-specific unobserved heterogeneity in addition to any country-century specific unobserved heterogeneity controlled for in our baseline.

Next, and importantly so, column 3 shows that in contrast to our non-time-varying baseline results, they also hold up to excluding Italy from the sample. The only difference with the baseline results is that the effect of an already existing city within 20 - 50km is no longer significantly positive in the post-1600 period; it is however significantly larger (at the 10% level) than its pre-1600 effect.

Column 4 (re-)confirms the insensitivity of our main results to excluding the UK, the earliest industrializing country, from the sample. In column 5 we instead do not consider the eighteenth century. As shown in Figure A1 and Table A1 in Appendix A, the eighteenth century saw an unprecedented increase in the number of cities. Column 5 however shows that it is not only this episode that drives our results.

Next, in column 6 we include an additional dummy variable indicating whether or not a location was already reported in Bairoch et al. (1988) to have a population between 1,000 and 4,000. The inclusion of this variable most strongly affected the significance of our already-existing city dummy variables in case of our non-time varying baseline results. Column 6 shows that including this variable does not have such strong effects on our time-varying baseline results. We do however still find that locations with an already-reported number of inhabitants below 5,000 do have higher urban chances than other locations (about 10ppt higher, see the notes to Table 3).

Finally, column 7 and 8 present two important robustness checks that assess the sensitivity of our main results to our particular choice of potential city locations (see section 3.1). As already mentioned when discussing the results of column 4 in Table 2, our results may suffer from possible endogenous selection bias in the potential city locations that we consider in our baseline sample[53]. In column 7 and 8 we look at this issue by either extending or completely changing the potential city locations considered respectively.

In column 7 we add 217 potential city locations to our baseline sample. We include the 217 cities that according to Bairoch et al. (1988) did have a population larger than 5,000 inhabitants in 1850, yet never passed this threshold during our sample period [see section 3.1, and footnote 15 in particular, for the main reason(s) not to include these locations in our baseline specifications]. Table A4 and Figure A5a show some further information on the distribution of these additional '1850 locations' over the European continent. They are mostly situated in the (future) industrial cores or coal-rich areas of Europe (e.g. Belgium, the UK, The Netherlands, Sweden and the German Ruhr-area). Besides adding these locations to the sample, we also consider them when constructing the three different 'competitor potential city location'-dummies. Importantly, our baseline results hold up to this extension of the number of potential city locations.

In column 8, we instead completely change the set of potential city locations. In particular, we consider each possible coordinate pair as a potential city location. We do this by focussing on a randomly drawn sample of 2,067 coordinate pairs, all located within one of the countries present in our baseline sample[54] (see Figure A5b).

For each of these coordinate pairs we collect the same 1st and 2nd nature geography variables that we included in our baseline specification, with the exception of our 'competitor potential city location'-dummy variables. When considering each coordinate pair as a potential city location, each potential city location faces competition from another potential city location at any distance. This leaves us without any variation between locations to identify possible competition effects (the three competitor-potential-city dummy variables would be 1 for all observations).

Next, we matched these randomly drawn coordinate pairs to the original city data from Bairoch et al. (1988) maintaining a margin of error of 5km. That is, we replace a random coordinate pair with a Bairoch city if the random draw lies within a range of *at most 5km* to

[53] Again, we stress that this endogeneity has to result from unobserved variables *other than the regressors already included in our estimations* (including also the country-century fixed effects, and even any time-invariant location-specific variables in case of the results in column 3 of Table 1 or column 2 of Table 3).
[54] We actually drew 2,500 random coordinate pairs, but 433 of these turned out to be located in a sea or lake.

that city. This results in 64 matches, i.e. 64 of our total 2,067 coordinate pairs become a city at some point during our 800-1800 sample period[55]. Using this truly random sample of coordinate pairs, we estimate our baseline specification. Reassuringly, even when using this random sample, our main baseline results regarding the increased importance of water-based transportation over land-based transportation as well as the positive effect of being located at medium range from an existing urban centre come through[56].

Finally, the last robustness check reported in Table 3 deals with the issue of measurement error. Somewhat related, Table A8 in Appendix A.3 shows the (in)sensitivity of our baseline findings to the particular absolute population cutoff used to define a city. Bairoch et al. (1988) acknowledge that their population estimates are very likely to be imprecise, especially for the smaller cities and for the earlier centuries. As we are using a nonlinear transformation of the city population data (by estimating a probit model) such measurement error, even if it were random, could leave its effect on our results (see e.g. Hausman, 2001). To shed some light on this we adopt the following simulation strategy. We assume that each reported population estimate has a similar 40% probability of being misreported. Conditional upon being misreported, we subsequently assume that there is an equal, 10%, chance of being underestimated by 2,000 inhabitants, overestimated by 2,000 inhabitants, underestimated by 1,000 inhabitants, or overestimated by 1,000 inhabitants respectively. Assuming this structure for the measurement error implicitly assumes that Bairoch et al. (1988) made relatively bigger mistakes for smaller population numbers[57]. We generate 1,000 different population samples using this sampling strategy and do our baseline analysis for each of the 1,000 simulated samples. Column 9 reports the percentage of simulations that each variable is significant at a 5% and at a 10% level respectively. Under the assumption of measurement error each of the 1,000 simulated samples is 'equally true'. If we find that a significant variable in our baseline results is less than 90% of the times significant at the 10% level, this would shed some doubts on the actual relevance of this variable.

The simulation results in column 9 show that our main findings hold up to this

[55] Results are the same when using a 10km distance margin to match the random coordinate pairs to our Bairoch data (in that case 228 coordinate pairs ever become a city). When using a 1km matching margin instead, the number of (successfully matched) coordinate pairs that ever become a city reduces to 4 making the results quite sensitive to the particular matches that occur in case of our particular random sample.

[56] We now do find a significantly negative effect of a location's elevation as well as a significantly positive effect of location on a roman road, suggesting that we may underestimate the effect of these variables in our baseline due to lack of variation (i.e. we undersample locations at high altitudes that never become a city as well as locations not located on former roman roads that never become a city)

[57] Bairoch (1988, p.525) explicitly remarks that the margin of error is larger for smaller cities. Overall, he expects a margin of error of about 10% for overall European city population around 1300 and 1500, increasing to 15% in 1000 and even 20% in 800.

measurement error check. The only exception is the positve effect of being located at sea that we found in the pre-1600 period. This is significant at the 10% level in our baseline results, yet it only comes up significant at the 10% level in 57% of the simulation runs. Also, both the effect of an already-existing city as well as of a competitor potential city location within a distance of 0-20km only reach their baseline significance level of 5% in the pre-1600 period in 89% and 92% of the simulations. Both variables are however significant at the 10% level in all simulation runs.

5.3 *A final robustness check: 2^{nd} nature geography results by construction?*

Given the steady increase in the number of cities over the centuries, one may be worried that especially our 2^{nd} nature geography results could be obtained by construction. Europe's urban system becomes denser over the centuries. Besides decreasing the number of potential city locations, this has its effect on our 2^{nd} nature geography variables. The number of potential city locations in vicinity to already existing cities increases, whereas the number of potential city locations facing competition from other potential city locations decreases. Does this change in variation drive our finding of a changing importance of 2^{nd} nature geography over the centuries?[58].

To assess this possibility we adopt the following *Dartboard Approach* in the spirit of Duranton and Overman (2005) and Ellison and Glaeser (1997) as our final robustness check[59]. Using a simulation approach we verify whether we would obtain the same results regarding our 2^{nd} nature geography variables when cities appeared randomly at one of our potential locations instead of at the locations where they appeared in reality. If we do, this means we could be getting our results by construction, shedding doubts on our findings. This *Dartboard Approach* is operationalized as follows:

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1. In each century t, randomly allocate n_t cities, the number of new cities actually appearing in century t, over the k_t available potential city locations in that century. We do this either:

a. *unconditionally*, i.e. $n_t \sim Binomial(k_t, p_t)$, where $p_t = n_t / k_t$

b. *conditional on each potential city location's 1^{st} nature geography characteristics, i.e.* $n_t \sim Binomial(k_t, p_t(X_i))$, where $p_t = \Phi(X_i b + a_{ct})$ and b an a_{ct} are the estimated

[58] Note that this issue is different, yet related, to the possibility of dynamic selection bias that we discussed in footnote 36. However, where dynamic selection bias concerns the dependent variable, the concern that we address here is that the increasing number of cities over time affects our 2^{nd} nature geography regressors with possibly unwanted consequences for our results.

[59] We thank Marius Brülhart for suggesting this approach to us.

parameters on our included 1st nature geography variables and the estimated country-century fixed effects respectively, obtained by estimating (2) including only our 1st nature geography variables and country-century dummies as explanatory variables.

2. Using this hypothetical city configuration, we estimate our baseline model as in (2) and store the estimated parameters on each of the six 2nd nature geography variables.

3. Repeat the above-outlined procedure 2,500 times to obtain the empirical distribution of all six estimated 2nd nature geography coefficients. Next, for each respective 2nd nature geography variable we establish the (in)significance of its effect by comparing its estimated coefficient to the 0.5%, 2.5%, 5%, 95%, 97.5%, or 99.5% quantile of its simulated empirical distribution instead of to the 0.5%, 2.5%, 5%, 95%, 97.5%, or 99.5% quantile of a standard normal distribution with variance corresponding to the estimated standard error of its estimated effect (as in all other Tables in this paper).

Table 4. Dartboard Approach – simulation results

unconditional	**parameter est. [simulated 5% cv]**	% falsely not rejected at 1%	at 5%	at 10%	**conditional upon 1st nature geo.**	**parameter est. [simulated 5% cv]**	% falsely not rejected at 1%	at 5%	at 10%
city >= 10k? (t-1)					city >= 10k? (t-1)				
0 - 20 km	-0.022 [-0.127]	0.8%	5.5%	10.6%	0 - 20 km	-0.022 [-0.132]	1.0%	5.5%	10.6%
20 - 50 km	0.078** [0.072]	0.8%	5.0%	10.4%	20 - 50 km	0.078* [0.083]	1.0%	5.7%	10.6%
50 - 100 km	0.072* [0.083]	1.0%	5.5%	10.7%	50 - 100 km	0.072* [0.085]	1.6%	6.0%	11.1%
competitor potential city location? (t-1)					competitor potential city location? (t-1)				
0 - 20 km	-0.113*** [-0.072]	1.0%	5.2%	10.1%	0 - 20 km	-0.113*** [-0.080]	1.0%	5.6%	11.0%
20 - 50 km	-0.055 [-0.138]	1.2%	6.2%	11.0%	20 - 50 km	-0.055 [-0.145]	0.9%	5.0%	10.1%
50 - 100 km	-0.207 [-0.331]	1.3%	6.6%	12.7%	50 - 100 km	-0.207 [-0.380]	1.8%	6.6%	11.6%

pre 1600	**parameter est. [simulated 5% cv]**	% falsely not rejected at 1%	at 5%	at 10%	**post 1600**	**parameter est. [simulated 5% cv]**	% falsely not rejected at 1%	at 5%	at 10%
city >= 10k? (t-1)					city >= 10k? (t-1)				
0 - 20 km	-0.273** [-0.236]	1.1%	5.5%	11.0%	0 - 20 km	0.08 [0.151]	1.1%	5.2%	10.6%
20 - 50 km	-0.047 [-0.120]	1.3%	5.5%	11.0%	20 - 50 km	0.175** [0.112]	0.9%	5.0%	10.0%
50 - 100 km	-0.06 [-0.107]	1.6%	5.4%	9.9%	50 - 100 km	0.262*** [0.140]	0.9%	4.7%	10.2%
competitor potential city location? (t-1)					competitor potential city location? (t-1)				
0 - 20 km	-0.128** [-0.108]	0.7%	5.2%	10.6%	0 - 20 km	-0.084 [-0.116]	1.4%	5.5%	11.6%
20 – 50 km	-0.114 [-0.204]	1.2%	5.4%	12.0%	20 - 50 km	-0.019 [-0.208]	0.9%	5.9%	11.1%
50 - 100 km	-0.241 [-0.549]	3.0%	9.6%	14.4%	50 - 100 km	-0.238 [-0.484]	1.7%	5.8%	12.4%

Notes: *, **, *** denotes significance at the 10%, 5%, 1% respectively based on the critical values of the simulated empirical distribution function. All simulated critical values and the '% falsely not rejected' are based on 2,500 simulation runs. The pre- and post-1600 results are 'dart-throws' conditional upon 1st nature geography (where 1st nature geography is also allowed to have a possibly different pre- and post-1600 effect).

The results of doing this are shown in Table 4. We verify the possibility of obtaining 'results by construction' for three different cases. The first two concern the baseline results in Table 1, randomly drawing new cities either unconditionally or conditional upon each potential city location's 1st nature geography characteristics. The third case concerns the baseline pre- and post-1600 results in Table 3, reporting only the results when randomly drawing new cities conditional upon 1st nature geography[60]. Besides reporting the significance of each estimated coefficient on the basis of our simulated empirical distributions, Table 4 also shows (for all six 2nd nature geography variables) the percentage of simulation runs that the null hypothesis of $\beta_1 \neq 0$ is *falsely rejected* when using the standard z-tests to establish the significance of an estimated coefficient at the 1%, 5%, and 10% respectively. Given that we allocate new cities randomly in each century, this percentage should be close to 1%, 5%, and 10% respectively to conclude that the standard tests perform well.

Our simulation results suggest that using the standard z-statistics to assess the (in)significance of the estimated coefficients on our 2nd nature geography variables may indeed not be without problems. In case of our baseline results in Table 1, we find that the standard tests perform reasonably well in case of our three 'already existing city'-dummy variables. The percentage of simulation runs in which we falsely reject the null hypothesis is always quite close to 1%, 5% or 10% respectively (with the exception of the '50 – 100 km'-variant when randomly allocating new cities conditional upon 1st nature geography). This is not the case for the three 'competitor potential city location'-dummy variables, where we falsely reject the null hypothesis too frequently (up to 0.8, 1.6, and 2.7 percentage points more in case of the '50 – 100km' variant than the respective 1%, 5% and 10% it is supposed to be).

The simulation results when distinguishing between the pre- and post-1600 period further corroborate that the denser city system during the later centuries can result in drawing the wrong conclusions when using the standard z-statistics. In the pre-1600 period the standard tests perform quite badly in case of both the 'already existing city'- and the 'competitor potential city location'-dummy variables (with false rejection rates even up to 2, 4.6 or 4.4 ppt higher than acceptable). Their performance however improves in the post-1600 period. There, we only falsely reject the null hypothesis too frequently in case of our three 'competitor potential city location'-dummy variables.

Based on these results we must conclude that obtaining 'results by construction' can indeed be a reality: the standard tests do appear to falsely reject the null hypothesis more frequently thatn the acceptable 1%, 5%, or 10% respectively. However, taking proper account of the 'results by construction'-possibility, by using the critical values of each 2nd nature geography coefficient's simulated empirical distribution, reveals that, in our case, the conclusions regarding the (in)significance of each of our six 2nd nature geography variables do

[60] The results regarding the (in)significance of each of our six 2nd nature geography variables when randomly drawing new cities *unconditionally* are the same (both pre- and post-1600). Results available upon request.

not change. When using the, generally larger (in absolute value) critical values of each simulated empirical distribution instead of those from the theoretical standard normal distribution, the same estimated coefficients are significantly different from zero as in our baseline results (see Tables 1 and 3).

5.4 The importance of our time-varying results

The time-varying impact of both 1st and 2nd nature geography is the most important refinement to our baseline results in Table 1. First, the difference between the pre- and post-1600 1st nature geography results shows that, over our sample period[61], good access to water-based transport becomes much more important than being well situated for land-based transport. This corresponds nicely to earlier accounts by for example Lopez (1956) or Pirenne (1925). Also, it concurs with the notion that improvements in shipping technology (not only in terms of the size and speed of the vessels used, but also in e.g. navigation (van Zanden and van Tielhof, 2009) and canal building (Bairoch, 1988) were larger than those in land transportation despite the fact that e.g. horseshoes, rigid tandem horse collars, and the use of explosives to build tunnels, did all significantly improve land-based transportation (see Lopez, 1956). Moreover, also the importance of a location's agricultural possibilites gradually diminishes over time. A finding that is not only consistent with improving agricultural methods, but also with the notion that in later centuries food could be transported over greater distances at lower costs due to improvements in transportation, hereby diminishing the 1st nature geography advantage of location right next to fields of high agricultural productivity.

Second, the way the importance of 2nd nature geography changes over the centuries is consistent with predictions from theory (see e.g. Behrens, 2007; Fujita and Mori, 1997; or Duranton, 1999). In the early centuries we find that competition at close range, both with other cities and with other potential city locations, is the only significant 2nd nature geography determinant of a location's urban chances. As set out briefly in section 2.2, theory predicts that 2nd nature geography will become an important *positive* determinant of city location only when overall transportation or trade costs are sufficiently low, the advantages of co-locating in a city are sufficiently large compared to its disadvantages, and overall population is large enough to sustain multiple urban centres.

[61] We stress that we do not want to claim in any way that 1600 is the exact year in which these changes occurred. What we do want to stress is that the (relative) importance of 1st and 2nd nature geography in determining city location changed significantly over the centuries. Since our data come at 100 year intervals, taking the year 1600 to be some kind of a crucial 'breakpoint' year would in our view be unwarranted.

Each of these three developments occurred over our 1000 year sample period. Trade costs diminished substantially. Not only did transportation technology improve significantly (as discussed above), also the 'invention' of e.g. the bill of laden, insurance contracts (Greif, 2006 p.24), and other institutional and political changes that improved security and law (Hohenberg and Lees, 1995 p.48; Lopez, 1956[62]) greatly reduced the costs of (long-distance) trade (Greif, 1992; Hohenberg, 2004 p.3025; Duranton, 1999 p.2177). Second, the advantage of co-locating in a city gradually increased due to improved non-agricultural production techniques (e.g. the blast furnace, finery forge, treadwheel crane, (improved) water- and windmills, and the printing press), while its disadvantages decreased (improved living conditions). And finally, overall European population increased markedly over our sample period, largely because of improvements in agricultural production (crop rotation, (improved) heavier plows, the introduction of new crops).

Our finding that 2nd nature geography starts to exert a significant positive influence on locations' urban chances from about the seventeenth century onwards is consistent with these developments. In earlier centuries trade costs, economies of scale and/or overall population were (too) low, making 1st nature geography the dominant determinant of city location. Only with the gradual increase in each of these three measures do we start to find the positive effect of location at medium distance from existing urban centres that corresponds closely to the predictions from economic geography theory.

6. *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 potential city location* within each of the three specified distance bands. As already briefly mentioned in section 3.3.2., it is possible to further refine the role of 2nd nature geography[63]. In this section we show that further refining the impact of already existing cities or competitor potential city locations respectively, provides some very useful additional insights into the role of 2nd nature

[62] Lopez (1956, p.24): " *an English statute of 1285 ordered that along highways between market towns "there be no dyke, tree or bush whereby a man may lurk to do hurt within 200 feet of either side of the way"* "

[63] We could also further refine the impact of 1st nature geography by adding various interaction terms of two (or more) of our included 1st nature geography dummy variables. Doing this generally gives the result that having a favourable location for both land- and water-transport (again river transport in particular) significantly increases a location's urban chances compared to favourable location for only one of the two transport modes. Adding these interaction terms leaves the baseline results regarding 2nd nature geography unchanged. They are available upon request.

geography in determining city location[64]. It also gives further confidence in our baseline 2nd nature geography results[65].

6.1 Refining the impact of already existing cities

Table 5 shows various results of further refining the impact of already existing cities. In column 1 we replace our 'already existing city'-dummy variables with a standard *UP* measure, see (1). The estimated effect of this measure is insignificant, corroborating our claim (see section 3.3.2) that such a measure is, by construction, too restrictive 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 uncover the nonlinear effect (stressed by new economic geography theory) that already existing cities exert on the urban chances of their surroundings.

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 25,000 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 5,000 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 potential city location's urban chances. Put differently, the larger an already existing city the larger its urban shadow (a finding that corresponds nicely with both earlier observations by e.g. Lösch (1940, p.126) or Ullman (1941, p.856), and with predictions from economic geography theory [see e.g. the discussion around figure 6 in Fujita et al., 1999]). This effect shows up in column 2 and 3 where the existence of a city larger than 5,000, 10,000 or 25,000 inhabitants 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[66]).

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[64] An even more elaborate way to refine our 2nd nature geography variables would be to take account of e.g. actual road or river systems, or the ruggedness of the terrain, and come up with more detailed indicators of travel distance between locations than our great circle distances. Aside from the additional data requirements, note that such extensions require making assumptions on the relative importance of each of the additionally considered characteristics in determining overall travel distances. We leave such extensions for future work.

[65] If we would for example find that the presence of an existing city larger than 25,000 inhabitants does exert a positive influence on potential city locations' urban chance within a 0 – 20 km range (whereas an existing city larger than 10,000 does not [i.e. our baseline result]), or that the presence of more than one competitor potential city location alleviates the negative influence of having only one such location within a 0 – 20 km range found in our baseline estimates, this would shed some doubt on our main findings.

Table 5. Extended 2nd nature geography – existing cities

	(a) ln UP cities >= 10k	(a) city >= 10k?	(a) city >= 10k?	(a) city >= 10k?	(a) ln # cities >= 10k (+1)	(a) ln city pop >= 10k (+1)	(a) ln dist near. city >= 10k
	(b) -	(b) -	(b) city >= 5k?	(b) 2 cities >=10k?	(b) -	(b) -	(b) ln pop near. city >= 10k
P(city t | no city t-1)	(c) -	(c) city >= 25k?	(c) city >= 25k?	(c) -	(c) -	(c) -	(c) -
1st nature geography results are not reported. They correspond closely to those in column 2 of Table 1.							
(a) t-1							
0 - 20 km	-0.005	-0.001	-0.019	-0.003	-0.006	-0.001	0.001
	[0.624]	[0.960]	[0.142]	[0.735]	[0.550]	[0.742]	[0.779]
20 - 50 km	-	0.017***	0.014	0.010*	0.009	0.002	-
	-	[0.004]	[0.106]	[0.080]	[0.106]	[0.265]	-
50 - 100 km	-	0.005	0.008	0.004	0.013***	0.004**	-
	-	[0.426]	[0.394]	[0.516]	[0.003]	[0.012]	-
(b) t-1							
0 - 20 km	-	-	0.022**	-0.009	-	-	-0.002
	-	-	[0.024]	[0.696]	-	-	[0.457]
20 - 50 km	-	-	0.004	-0.002	-	-	-
	-	-	[0.612]	[0.797]	-	-	-
50 - 100 km	-	-	-0.005	0.012**	-	-	-
	-	-	[0.612]	[0.044]	-	-	-
(c) t-1							
0 - 20 km	-	-0.010	-0.010	-	-	-	-
	-	[0.489]	[0.475]	-	-	-	-
20 - 50 km	-	-0.019**	-0.019**	-	-	-	-
	-	[0.014]	[0.015]	-	-	-	-
50 - 100 km	-	0.009	0.009	-	-	-	-
	-	[0.146]	[0.134]	-	-	-	-
Results for the 'competitor potential city'-dummy variables are not reported. They correspond closely to those in column 2 of Table 1.							
country/century FE	yes	yes	yes	yes	yes	yes	yes
nr observations	13228	13228	13228	13228	13228	13228	13228
p-values tests		H0: $\beta_{city>=10}$ >0?	H0: $\beta_{city>=10}$ >0?	H0: $\beta_{2\ cities>=10}$ >0?			
0 - 20 km		-	[0.682]	[0.593]			
20 - 50 km		-	[0.005]***	[0.351]			
50 - 100 km		-	[0.793]	[0.011]**			
		H0: $\beta_{city>=25}$ >0?	H0: $\beta_{city>=25}$ >0?				
0 - 20 km		[0.375]	[0.517]				
20 - 50 km		[0.785]	[0.870]				
50 - 100 km		[0.031]**	[0.089]*				

Notes: p-values, based on robust standard errors, between square brackets. *, **, *** denotes significance at the 10%, 5%, 1% respectively. Instead of the estimated coefficients in (2), the table reports average partial effects. The p-values are however based on the estimated coefficients and their standard errors. All regressions contain the same 1st nature geography variables and the same 'competitor potential city'-dummy variables as in column 2 of Table 1. The estimated parameters on these variable correspond closely to those reported in column 2 of Table 1. They are available upon request.

A similar result follows from column 4. There we include additional dummies indicating the presence of *at least two cities larger than 10,000 inhabitants* in each of the three distance bands. We find that the presence of only one city larger than 10,000 inhabitants exerts a positive influence on the urban chances of locations at 20 – 50km. This significant positive

[66] Given the way the different dummy variables are specified (i.e. if there exists a city larger than 25,000 inhabitants within a certain distance band, not only the dummy variable indicating the presence of a city larger than 25,000 inhabitants will be 1, so will be the dummy variable indicating the presence of a city of at least 10,000 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.

effect disappears when there are more than one already existing cities 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 10,000 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 10,000 inhabitants, or the total population in cities larger than 10,000 inhabitants within each of the three distance bands. Doing this confirms the results in columns 2 – 4: a larger number of existing cities or a larger urban population in these existing cities (or city) only significantly increases a potential location's urban chances at larger distances (50 – 100 km).

Finally, in column 7, we completely abandon our distance bands and include the size of, and distance to, the nearest city larger than 10,000 inhabitants instead. The results show, as when including *UP* 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 our more flexible dummy specification). Both variables are insignificant.

6.2 Refining the impact of competitor locations

Table 6 shows the results of refining the impact of competitor potential city 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 potential city locations*. Having more than one competitor potential city location within 0 – 20km has a significant negative effect on a location's own urban chances, but it does not significantly decrease these chances compared to having only one competitor potential city location at this distance. Also, similar to having only one competitor, the presence of more than one competitor does not have any significant effect at larger distances than 20km (again see the *p*-values at the bottom of column 1)[67].

Column 2 abandons the dummy approach and includes the distance to the nearest competitor potential city location instead. Again, we find a result that is consistent with our baseline findings. The significantly positive average partial effect shows that the further a potential city location is located from its nearest competitor, the better its urban chances.

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[67] Similar to Table 5, 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 6. Extended 2nd nature geography – competitors / 1st nature geography

P(city t | no city t-1)	(a) 2 competitors? (b) -	(a) ln dist near. comp. (b) -	(a) sea/river competitor (b) hub competitor	
1st nature geography results are not reported. They correspond closely to those in column 2 of Table 1.				
Results for the 'already existing city'-dummy variables are not reported. They correspond closely to those in column 2 of Table 1.				
competitor potential city location? (t-1)				
0 - 20 km	-0.014**	-	-0.001	
	[0.022]	-	[0.847]	
20 - 50 km	-0.014	-	0.008	
	[0.24]	-	[0.431]	
50 - 100 km	0.012	-	-0.015	
	[0.666]	-	[0.543]	
(a) t-1			sea comp	river comp
0 - 20 km	-0.003	0.013***	0.004	-0.019**
	[0.657]	[0.002]	[0.631]	[0.011]
20 - 50 km	0.013	-	-0.018***	-0.006
	[0.107]	-	[0.005]	[0.31]
50 - 100 km	-0.047**	-	-0.010	-0.001
	[0.011]	-	[0.124]	[0.877]
(b) t-1			hub comp	
0 - 20 km	-	-	-0.014*	
	-	-	[0.092]	
20 - 50 km	-	-	-0.025***	
	-	-	[0.000]	
50 - 100 km	-	-	-0.015***	
	-	-	[0.006]	
country/century FE	yes	yes	yes	
nr observations	13228	13228	13228	
p-values tests	H0: $\beta_{2\ comp.}$ >0?	*p-values tests*	H0: $\beta_{1st\ nature\ comp.}$ >0?	
0 - 20 km	[0.011]**		sea	river
20 - 50 km	[0.923]	0 - 20 km	[0.738]	[0.005]***
50 - 100 km	[0.147]	20 - 50 km	[0.394]	[0.812]
		50 - 100 km	[0.314]	[0.503]
			hub	
		0 - 20 km	[0.112]	
		20 - 50 km	[0.165]	
		50 - 100 km	[0.218]	

Notes: p-values, based on robust standard errors, between square brackets. *, **, *** denotes significance at the 10%, 5%, 1% respectively. Instead of the estimated coefficients in (2), the table reports average partial effects. The p-values are however based on the estimated coefficients and their standard errors. All regressions contain the same 1st nature geography variables and the same 'already existing city'-dummy variables as in column 2 of Table 1. The estimated parameters on these variable correspond closely to those reported in column 2 of Table 1. They are available upon request.

The final extension we show in Table 6 builds on our baseline finding of a robust positive 1st nature geography effect of being located at a navigable river on a location's urban chances. This result also immediately suggests 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 geography advantage faces competition from a nearby potential city location with much better 1st nature geography characteristics. One can expect this potential city location to face much stiffer competition from its neighbour than a similar location facing competition from another potential city location that, like itself, does not have any 1st nature geography advantages. In other words, our baseline results imply that potential city locations face stronger competition effects from other potential city locations with advantageous 1st nature geography 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 potential city location located at sea, at a navigable river, and at a hub of roman roads respectively. Doing this reveals that (again also see the *p*-values at the bottom of column 3) the negative competition effect at close range, which we found in our baseline results, can be largely attributed to competition with other potential city locations that have the 1st nature geography advantage of being located at a navigable waterway. Other potential city 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 at a hub of Roman roads is sometimes significantly different from the effect of a competitor without this 1st nature geography advantage [see the *p*-values below the APEs], their overall effect is never significantly different from zero [see the *p*-values at the bottom of column 3].

7. Conclusions

Instead of the largely narrative historical accounts on the importance of geography in shaping the European system, this paper empirically disentangles the different roles of geography in determining the location of European cities. We introduce a new data set that covers all actual European cities as well as many potential city locations during the 800 – 1800 period, when the foundations for the eventual European city system were laid. Using this data, we empirically uncover the (relative) importance of a location's physical, 1st nature, geography characteristics and the, 2nd nature geography, characteristics of the urban system that surrounds it in determining its own urban chances. In doing so, we develop a novel, more flexible, way to empirically model the effect that an already established city exerts on the urban chances of its surroundings.

Our results, that hold up to a wide-variety of robustness checks, show that both 1st and 2nd nature geography have played an important role in sowing the seeds of European cities. However, their (relative) importance changes substantially over the centuries.

First nature geography is the dominant geographical force during the early stages of the formation of the European city system. Locations that are favourably located for water- or land-based transportation as well as those with excellent agricultural possibilities, and good accessibility, have the best urban chances during the Middle Ages. But, this dominance of 1st nature geography gradually decreases over the centuries. Only favourable location for water-based transportation remains an important determinant of city location during the later centuries. The importance of a location's agricultural potential, and accessibility, loose their significance as a city seed, a reflection of both improved agricultural production techniques as well as better (and cheaper) possibilities to transport food over ever larger distances.

Second nature geography instead gains in importance over the centuries. Moreover, and by virtue of our flexible modelling strategy, we show that it does so in a way that corresponds closely to predictions from recent economic geography theory (Behrens, 2007; Fujita and Mori, 1997). In the earlier centuries we only find evidence of (negative) competition effects with a limited spatial scope: being located too close (0 – 20km) to an already existing city, or to another potential city location, decreases a location's own urban chances. But, as trade costs gradually decrease, the advantages of co-locating in cities increasingly outweigh its disadvantages, and overall population increases due to improvements in agricultural productivity, we start to find strong empirical evidence of a positive effect of being located at medium range from an already existing city from about the seventeenth century onwards. This is consistent with predictions from economic geography theory: locations at medium distance from an existing city combine the advantages of cheaper trade with the existing city compared to locations at further distance with that of weaker competition with the existing city compared to locations at closer distance.

Overall, our results show that geography indeed played a crucial role in laying the foundations of the European city system as we know it today. First nature geography is an especially important determinant of city location when trade costs are prohibitively high or when the advantages of co-location are simply outweighed by its disadvantages (in accordance with claims by e.g. Krugman, 1993b; Duranton, 1999 or Behrens, 2007). Only with sufficiently low trade costs and increasing net benefits of co-location does 2nd nature geography become an important positive determinant of city location.

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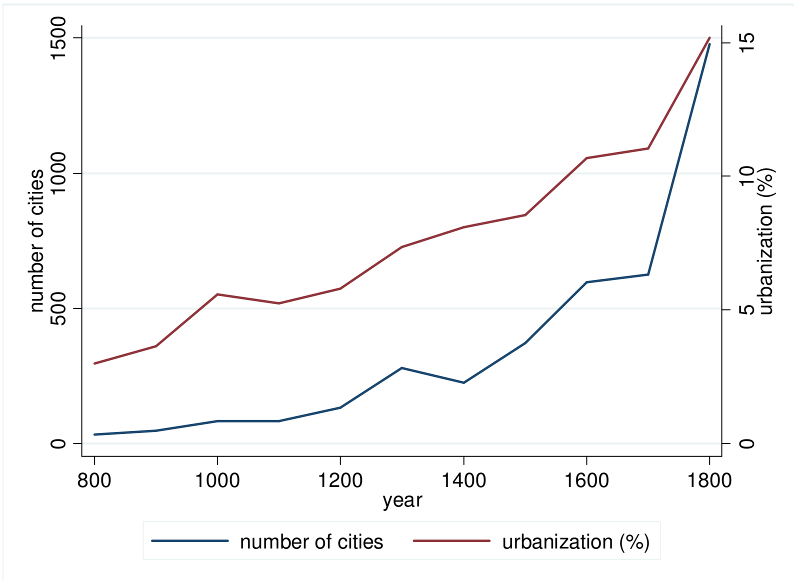
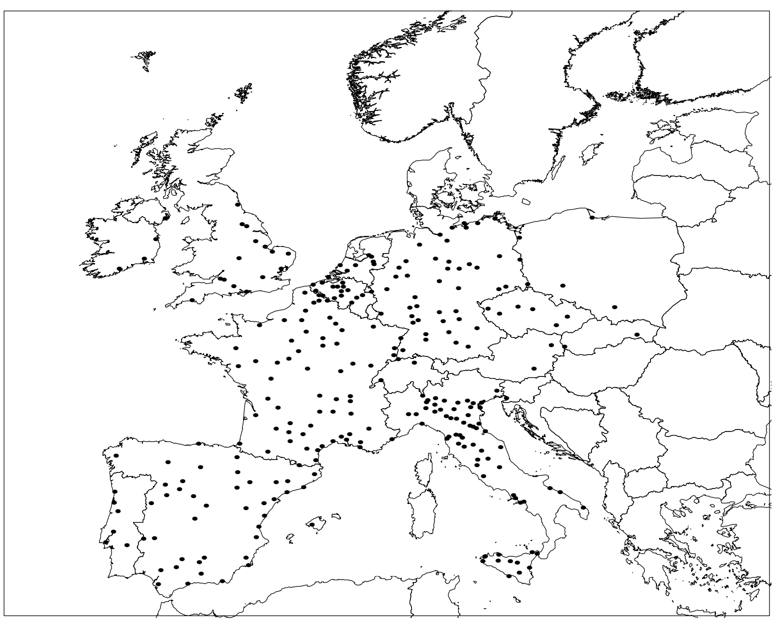
Appendix A. Additional results

Figure A1. Urbanization and the number of cities in Europe, 800 – 1800



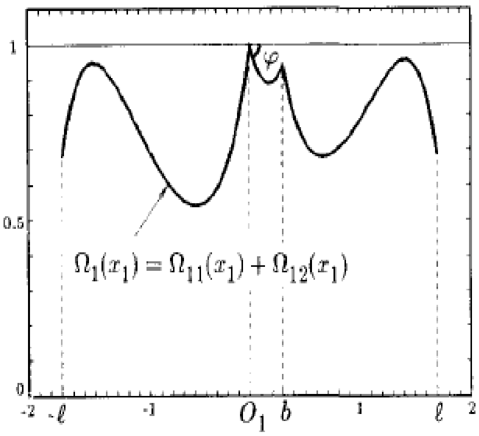
Notes: Both the number of cities and the urbanization rate are based on defining cities as population centres with at least 5,000 inhabitants [see section 3.2 for more detail on this definition]. The urbanization rate is calculated by dividing total urban population (i.e. the total number of people living in cities with at least 5,000 inhabitants) by total population. Total population figures are taken from McEvedy and Jones (1979).

Figure A2. The European city system in 1300



Notes: cities are denoted by black dots [see section 3.2 for more detail on the city definition used]

Figure A3. 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).

Figure A4 Ecozones according to Buringh et al. (1975)

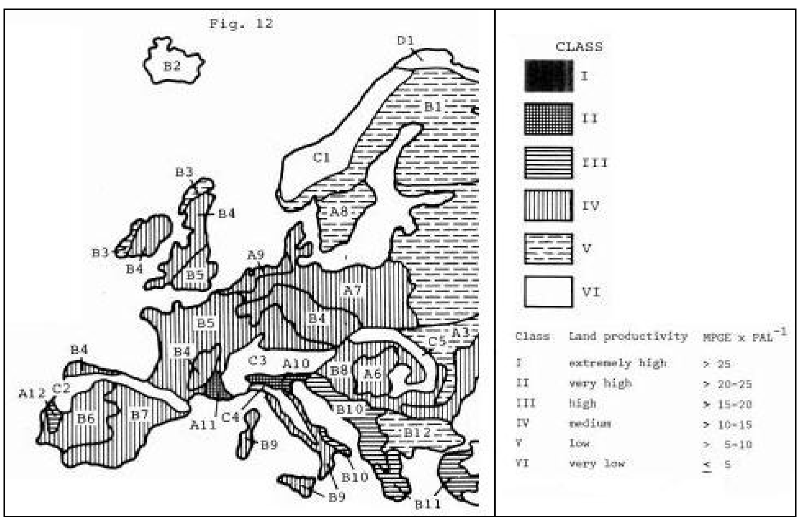
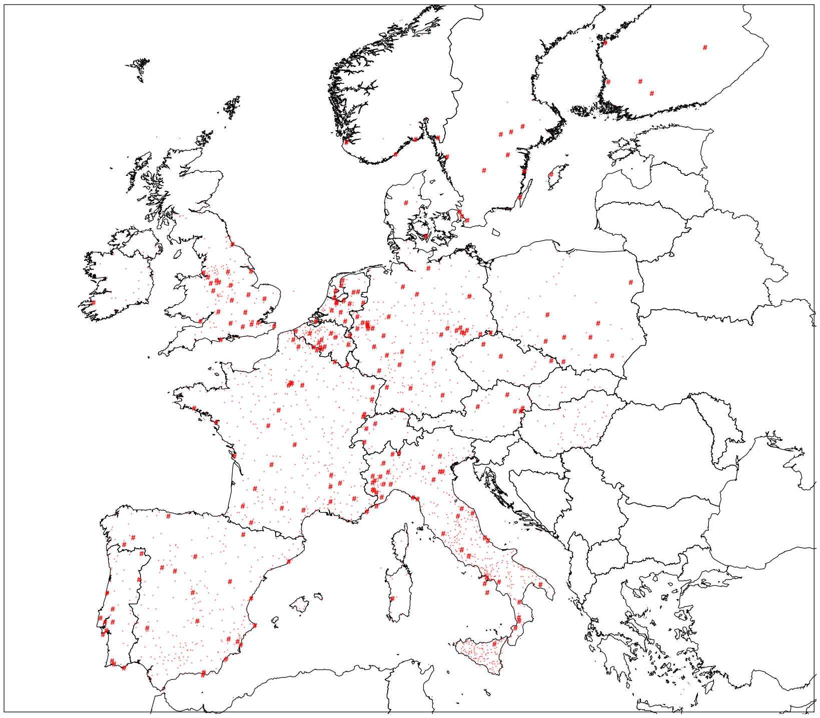
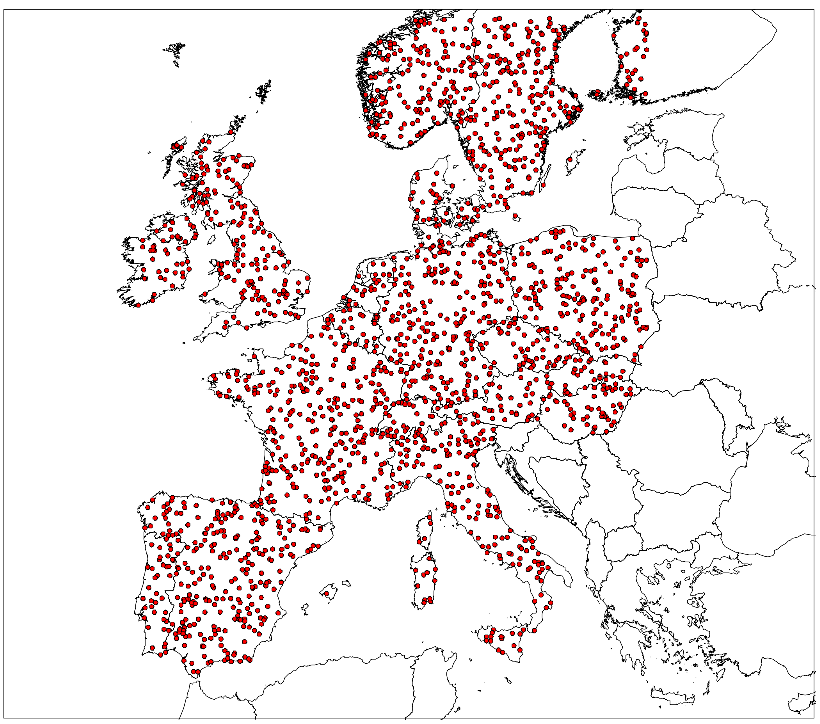


Figure A5a Additional potential city locations (Bairoch's 1850 cities)



Notes: smallest red dots denote baseline potential city locations [see section 3.1 for more detail]. The larger red dots denote the 217 additional '1850 Bairoch' potential city locations used in several robustness checks.

Figure A5b Random coordinate pairs as potential city locations



Notes: red dots denote the 2067 randomly drawn coordinates pairs used as potential city locations in column 8 of Table 3.

Table A1. Century specific probability of being 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. 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. population centres with at least 5,000 inhabitants.

Table A3. Descriptives

1st or 2nd nature characteristic	mean	sd	min	max	mean	sd	min	max
	all locations (1784)				locations ever >= 5,000 (1588)			
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
ruggedness	86.8	96.3	0	721	78.9	87.1	0	721
P(cultivation)	0.72	0.24	0.004	0.999	0.71	0.23	0.006	0.999
latitude	45.73	5.45	36.02	63.42	46.06	5.59	36.02	63.42
longitude	6.47	7.66	-9.28	23.25	6.10	7.70	-9.28	23.25
--------------	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 A4. Additional '1850 Bairoch' potential city locations by country

country	# obs.	% extra locations	country	# obs.	% extra locations
Austria	5	31	The Netherlands	16	36
Belgium	13	22	Norway	4	67
Czech Republic	3	18	Poland	9	20
Denmark	2	25	Portugal	12	36
Finland	6	600	Slovakia	0	0
France	27	8	Spain	20	8
Germany	33	16	Sweden	12	150
Hungary	0	0	Switzerland	4	27
Ireland	1	4	UK	22	15
Italy	28	6	**total**	**217**	12

Table A5. A finer century decomposition

dependent variables: *P(city t | no city t-1)*					
period	APE	[p-value]	period	APE	[p-value]
sea			sea		
800 - 900	0.040***	[0.000]	800 – 1000	0.024***	[0.005]
1000 - 1200	0.006	[0.414]	1100 – 1400	0.018*	[0.092]
1300 - 1500	0.008	[0.576]	1400 – 1600	0.007	[0.672]
1600 - 1800	0.007	[0.729]	1700 – 1800	-0.017	[0.522]
river			river		
800 - 900	0.021***	[0.001]	800 – 1000	0.025***	[0.000]
1000 - 1200	0.028***	[0.000]	1100 – 1400	0.056***	[0.000]
1300 - 1500	0.075***	[0.000]	1400 – 1600	0.065***	[0.000]
1600 - 1800	0.088***	[0.000]	1700 – 1800	0.098***	[0.000]
hub			hub		
800 – 900	0.014*	[0.067]	800 – 1000	0.040***	[0.000]
1000 – 1200	0.037***	[0.000]	1100 – 1400	0.034***	[0.001]
1300 – 1500	0.040***	[0.003]	1400 – 1600	0.031**	[0.042]
1600 – 1800	-0.069***	[0.001]	1700 – 1800	-0.111***	[0.000]
ruggedness			ruggedness		
800 – 900	-0.001	[0.832]	800 – 1000	-0.005**	[0.031]
1000 – 1200	-0.006***	[0.001]	1100 – 1400	-0.009***	[0.004]
1300 – 1500	-0.014***	[0.001]	1400 – 1600	-0.014***	[0.003]
1600 – 1800	-0.002	[0.725]	1700 – 1800	0.007	[0.409]
roman road	-0.008	[0.198]	roman road	-0.008	[0.155]
ln elevation	0.002	[0.422]	ln elevation	0.002	[0.423]
P(cultivation)	0.124***	[0.001]	P(cultivation)	0.118***	[0.002]
P(cultivation) * trend	-0.014***	[0.002]	P(cultivation) * trend	-0.013***	[0.004]
city >= 10k? (t-1) 0-20km			city >= 10k? (t-1) 0-20km		
800 – 900	-	-	800 – 1000	-	-
1000 – 1200	-0.021	[0.321]	1100 – 1400	-0.035*	[0.073]
1300 – 1500	-0.035*	[0.060]	1400 – 1600	-0.022	[0.23]
1600 – 1800	0.019	[0.307]	1700 – 1800	0.036	[0.108]
city >= 10k? (t-1) 20-50km			city >= 10k? (t-1) 20-50km		
800 – 900	0.007	[0.357]	800 – 1000	0.006	[0.416]
1000 – 1200	0.001	[0.808]	1100 – 1400	-0.017**	[0.040]
1300 – 1500	-0.015	[0.130]	1400 – 1600	0.021**	[0.047]
1600 – 1800	0.042***	[0.002]	1700 – 1800	0.034**	[0.044]
city >= 10k? (t-1) 50-100km			city >= 10k? (t-1) 50-100km		
800 – 900	-0.011*	[0.088]	800 – 1000	-0.008	[0.119]
1000 – 1200	0.001	[0.767]	1100 – 1400	0.000	[0.954]
1300 – 1500	-0.012	[0.185]	1400 – 1600	0.023**	[0.040]
1600 – 1800	0.062***	[0.000]	1700 – 1800	0.035	[0.125]
competitor potential city location? (t-1) 0-20km			competitor potential city location? (t-1) 0-20km		
800 – 900	0.008	[0.121]	800 – 1000	-0.006	[0.266]
1000 – 1200	-0.012**	[0.028]	1100 – 1400	-0.006	[0.459]
1300 – 1500	-0.014	[0.138]	1400 – 1600	-0.026**	[0.014]
1600 – 1800	-0.020	[0.147]	1700 – 1800	-0.011	[0.514]
competitor potential city location? (t-1) 20-50km			competitor potential city location? (t-1) 20-50km		
800 – 900	-0.002	[0.865]	800 – 1000	-0.002	[0.879]
1000 – 1200	-0.007	[0.488]	1100 – 1400	-0.023*	[0.075]
1300 – 1500	-0.020	[0.219]	1400 – 1600	-0.028	[0.149]
1600 – 1800	-0.004	[0.870]	1700 – 1800	0.034	[0.296]
competitor potential city location? (t-1) 50-100km			competitor potential city location? (t-1) 50-100km		
800 – 900	-0.076**	[0.020]	800 – 1000	-0.068*	[0.094]
1000 – 1200	0.483***	[0.000]	1100 – 1400	0.027	[0.409]
1300 – 1500	-0.024	[0.561]	1400 – 1600	-0.021	[0.674]
1600 – 1800	-0.057	[0.322]	1700 – 1800	-0.110	[0.112]

Notes: p-values, based on robust standard errors, between square brackets. *, **, *** denotes significance at the 10%, 5%, 1% respectively. Instead of the estimated coefficients in (2), the table reports average partial effects. The p-values are however based on the estimated coefficients and their standard errors. The 0 – 20km version of the 'already existing city'-dummy variable drops out during the earliest centuries as it is perfectly captured by the included country-century fixed effects.

A.1 Robustness to choice of estimation technique

The additional robustness checks reported in Table A6 below all concern the estimation technique that we use to obtain our baseline results in Table 1.

Table A6. Robustness (estimation technique)

P(city t | no city t-1)	logit	LP	cox duration model	FE logit[a]	FE LP
sea	0.011	0.010	1.083	-	-
	[0.238]	[0.191]	[0.355]	-	-
river	0.062***	0.050***	1.532***	-	-
	[0.000]	[0.000]	[0.000]	-	-
hub	0.013	0.010	1.123	-	-
	[0.144]	[0.187]	[0.160]	-	-
road	-0.013**	-0.012**	0.858***	-	-
	[0.025]	[0.018]	[0.002]	-	-
ln elevation	0.003	0.003	1.036	-	-
	[0.238]	[0.187]	[0.114]	-	-
ruggedness	-0.008***	-0.007***	0.924***	-	-
	[0.004]	[0.003]	[0.001]	-	-
P(cultivation)	0.132***	0.036**	4.123***	-	-
	[0.002]	[0.050]	[0.003]	-	-
P(cultivation) * trend	-0.015***	-0.005	0.864***	0.018	-0.001
	[0.004]	[0.229]	[0.001]	[0.925]	[0.787]
city >= 10k? (t-1)					
0 - 20 km	0.000	-0.001	0.981	0.028	-0.004
	[0.979]	[0.912]	[0.747]	[0.933]	[0.832]
20 - 50 km	0.011**	0.011**	1.088*	0.758***	0.039***
	[0.041]	[0.049]	[0.052]	[0.000]	[0.000]
50 – 100 km	0.011*	0.008*	1.099*	-0.092	0.007
	[0.056]	[0.071]	[0.060]	[0.621]	[0.325]
competitor potential city location? (t-1)					
0 - 20 km	-0.014***	-0.012**	0.917**	-0.165	-0.024
	[0.007]	[0.012]	[0.046]	[0.664]	[0.294]
20 - 50 km	-0.007	-0.008	0.923	-0.798*	-0.018
	[0.47]	[0.471]	[0.305]	[0.064]	[0.524]
50 – 100 km	-0.027	-0.022	0.843	0.376	0.059
	[0.261]	[0.329]	[0.325]	[0.431]	[0.118]
country/century FE	yes	yes	yes	country trends + century FE	yes
nr observations	13228	15156	14594	13220	15156
		# (%) of-the-chart predictions			# (%) of-the-chart predictions
		in sample			in sample
		2614 (17%)			4229 (28%)
		total			total
		7082 (36%)			8697 (44%)

Notes: p-values, based on robust standard errors, between square brackets. *, **, *** denotes significance at the 10%, 5%, 1% respectively. Instead of the estimated coefficients in (2), the table reports average partial effects. The p-values are however based on the estimated coefficients and their standard errors. Column (3) reports hazard rates instead of estimated coefficients, i.e. a hazard rate larger (smaller) than 1 indicates that the corresponding characteristic increases (decreases) the probability to become a city. [a]Given that one cannot calculate average partial effects after estimating a conditional logit model, column (4) reports estimated coefficients. When including country-century FE, conditional logit estimation has difficulties converging which is why in this column we include 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 5.343 [0.000] and 5.358 [0.000] respectively.

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 (2) using logit or OLS techniques respectively. All our main baseline results do not crucially depend on the assumption made on *F*.

Our column 3 results show that our baseline results also come through when we completely change our modelling strategy and adopt a duration model (of the time until becoming a city) instead of the transition model (becoming a city conditional upon not being a city before) that we employ throughout the paper. Using a duration model can be argued to take better account of any duration-dependence in the probability of becoming a city (i.e. this probability may not be the same depending on the time a location has already not become a city). Although the inclusion of country-century fixed effects in all our baseline specifications can be argued to already go a long way in controlling for duration-dependence (in duration terms: they allow the baseline hazard to (arbitrarily) change over the centuries in a moreover possibly different way across countries), it is reassuring that we basically find the same results when adopting a semi-parametric Cox proportional hazard model. Column 3 reports hazard ratios. A hazard ratio significantly larger than 1 indicates that the corresponding characteristic increases a location's baseline hazard to become a city. Similarly, a hazard ratio significantly smaller than 1 indicates that the corresponding characteristic decreases a location's baseline hazard to become a city (e.g. location on a navigable river increases a location's baseline hazard to become a city by 53.2%, the presence of a competitor potential city location within a 0 – 20km range decreases it by 8.3%, and the presence of an already existing city within a 20-50km range increases it by 8.8%).

As in columns 1 and 2, the results in columns 4 and 5 are also based on using either logit or linear probability techniques, but in these two columns we, in addition to controlling for unobserved *country-century* specific heterogeneity, control for unobserved *time-invariant location-specific* heterogeneity. As such, these two columns are readily comparable to column 3 in Table 1 that employs a CRE-probit estimation strategy. Instead of sticking to this CRE probit technique, one could instead turn to a conditional logit approach, 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 (see the specification on p.24). 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 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 5).

Column 4 and 5 show the results of using each of the two above-mentioned different methods to control for unobserved time-invariant location-specific heterogeneity. As in column 3 of Table 1, in both cases the effect of 2^{nd} nature geography is somewhat weakened compared to our main baseline results in column 2 of Table 1. We no longer find evidence of any significant competition effect among potential city locations at close range. 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 to become a city than those located closer to, or farther away from, that city.

A.2 Changing the distance bands

Another set of robustness checks we did, concerns the sensitivity to the chosen distance bands (0 – 20km, 20 – 50km and 50 – 100km) to construct our 2^{nd} nature geography variables. Table A7 shows the results using various different distance bands[68].

Doing this leaves the effect of a competitor potential city location largely unaffected: a competitor potential city location at too close distance always diminishes a location's urban chances and is quite insensitive to the specific distance band used.

Similarly, the effect of an already existing city is also largely unaffected. Changing only the lowest distance cutoff to 15 or 25 km in column 1 and 2 respectively leaves the results unchanged. Being located too close to an existing city has a (significantly) negative on a location's urban chances. The positive effect of an already existing city at medium distance is also very robust to making small changes to the distance bands. But, its significance falls slightly when decreasing the lowest distance cutoff (to 15 km in column 1) an indication that at this distance the 2^{nd} distance band starts to overlap too much with the existing city's urban shadow[69]

The results are most sensitive to the specification of the third distance band (see columns 3 – 5). When changing one of this band's cutoff distances (its lower distance

[68] Our pre- and post-1600 results are also robust to the same changes in distance bands as presented in Table A7. Results are available upon request.

[69] It turns insignificant when further lowering the first distance cutoff to 10km.

Table A7. 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	baseline + 100 – 150 km 150 – 200 km
sea	0.013	0.012	0.012	0.013	0.012	0.013
	[0.136]	[0.157]	[0.183]	[0.148]	[0.179]	[0.127]
river	0.061***	0.061***	0.061***	0.061***	0.061***	0.061***
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
hub	0.015*	0.014*	0.015*	0.015*	0.014*	0.014*
	[0.072]	[0.073]	[0.071]	[0.067]	[0.075]	[0.08]
road	-0.010*	-0.010*	-0.011*	-0.010*	-0.010*	-0.010*
	[0.067]	[0.076]	[0.065]	[0.071]	[0.082]	[0.077]
ln elevation	0.002	0.002	0.002	0.002	0.002	0.002
	[0.332]	[0.397]	[0.375]	[0.308]	[0.369]	[0.400]
ruggedness	-0.008***	-0.008***	-0.008***	-0.008***	-0.008***	-0.008***
	[0.002]	[0.001]	[0.001]	[0.001]	[0.001]	[0.002]
P(cultivation)	0.112***	0.115***	0.117***	0.112***	0.115***	0.110***
	[0.002]	[0.002]	[0.001]	[0.002]	[0.002]	[0.003]
P(cultivation) * trend	-0.013***	-0.013***	-0.013***	-0.013***	-0.013***	-0.013***
	[0.004]	[0.003]	[0.003]	[0.004]	[0.004]	[0.005]
city >= 10k? (t-1)						
0 - x km	-0.005	-0.012*	-0.002	-0.003	-0.003	-0.003
	[0.617]	[0.084]	[0.772]	[0.755]	[0.737]	[0.749]
x - y km	0.009*	0.015***	0.010*	0.011**	0.010*	0.010*
	[0.091]	[0.005]	[0.078]	[0.025]	[0.053]	[0.057]
y - z km	0.009*	0.010*	0.005	0.008	0.006	0.009
	[0.083]	[0.064]	[0.362]	[0.132]	[0.365]	[0.107]
100 – 150 km	-	-	-	-	-	0.008
	-	-	-	-	-	[0.159]
150 – 200 km	-	-	-	-	-	-0.001
	-	-	-	-	-	[0.907]
competitor potential city location ? (t-1)						
0 - x km	-0.011**	-0.014***	-0.014***	-0.014***	-0.014***	-0.015***
	[0.043]	[0.01]	[0.007]	[0.006]	[0.006]	[0.004]
x - y km	-0.013	-0.007	-0.011	-0.027**	-0.006	-0.007
	[0.228]	[0.448]	[0.123]	[0.036]	[0.516]	[0.468]
y - z km	-0.028	-0.032	-0.035	-0.025	-0.063*	-0.024
	[0.243]	[0.173]	[0.235]	[0.192]	[0.060]	[0.308]
100 – 150 km	-	-	-	-	-	-0.049
	-	-	-	-	-	[0.135]
150 – 200 km	-	-	-	-	-	0.000
	-	-	-	-	-	[0.995]
country/century FE	yes	yes	yes	yes	yes	yes
nr observations	13228	13228	13228	13228	13228	13228

Notes: p-values, based on robust standard errors, between square brackets. *, **, *** denotes significance at the 10%, 5%, 1% respectively. Instead of the estimated coefficients in (2), the table reports average partial effects. The p-values are however based on the estimated coefficients and their standard errors.

cutoff in columns 3 and 4, or its highest distance cutoff in column 5), the positive effect of an already existing city in the furthest distance band turns insignificant. Finally, the last column shows the results when adding two additional distance bands (100 – 150 km, and 150 – 200 km) to our baseline model. Again our baseline results come through. The results on the two added distance bands further confirm the nonlinear effect that an existing city exerts on its surroundings: both the presence of an already-existing city within 100 – 150 km or within 150 – 200 km does not significantly affect a location's urban chances.

Overall, the negative competition effect at close range and the positive effect of an existing city at medium range are the two baseline results that are most robust to changes in the distance bands.

A.3 Changing the city definition

In addition to assessing the sensitivity of our results to possible measurement error (see column 9 in Table 3), we also looked at the sensitivity of our results with respect to our city definition based on an *absolute* population cutoff of having at least 5,000 inhabitants. Table A8 below shows the results when using a different absolute cutoff, or a time-varying population cutoff instead. Note, that in each column we also change the definition of a competitor potential location accordingly (when e.g. increasing our size criterion to 6,000 inhabitants we also consider all locations that, at *t-1*, have fewer than 6,000 inhabitants as competitor potential city locations).

In columns 2 and 3, we lower our absolute population criterion to 3,000 and 4,000 inhabitants respectively. Bairoch et al. (1988) only provide these population numbers for a very limited set of city locations, stressing that these numbers are subject to a much greater margin of error than those larger or equal than 5,000 inhabitants (see also our discussion of the results in column 3 of Table 2). However, when taking this data seriously in columns 2 and 3, we find that doing this leaves our baseline results unchanged.

This is not the case when raising our population cutoff. When increasing our population cutoff to 6,000 inhabitants, our main results still come through. However, when increasing it to 7,000 inhabitants, we find a slight change to our 2nd nature geography results that is further exacerbated when increasing the population cutoff to 10,000 inhabitants. In particular, we find that the positive effect of having an already existing city at medium distance disappears when raising our city criterion. The positive effect is still there at 20 – 50km and at 50 – 100km when raising the criterion to 6,000 inhabitants. When raising it to 7,000 inhabitants the effect only remains in the farther 50 – 100 km range. Raising it even further to 10,000 inhabitants, the positive effect disappears entirely. However, this result does not necessarily invalidate our baseline results. In combination with our baseline findings in column 1 of Table 3, the results in columns 2 – 5 show a consistent pattern: the positive effect of an already existing city at medium distances gradually disappears when raising the absolute size criterion used to define a city. Having an existing city at medium range may significantly

Table A8. Sensitivity to the choice of city definition

P(city t | no city t-1)	>= 3,000	>= 4,000	>= 6,000	>= 7,000	>= 10,000	step-wise
sea < 1600	0.021**	0.021***	0.011*	0.008	0.008	0.009
	[0.013]	[0.008]	[0.090]	[0.187]	[0.121]	[0.204]
sea >= 1600	-0.023	-0.003	0.027	0.016	0.045***	0.045**
	[0.340]	[0.883]	[0.207]	[0.407]	[0.003]	[0.012]
river < 1600	0.058***	0.052***	0.041***	0.037***	0.028***	0.047***
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
river >= 1600	0.107***	0.099***	0.065***	0.061***	0.060***	0.058***
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
hub < 1600	0.042***	0.042***	0.029***	0.029***	0.018***	0.033***
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
hub >= 1600	-0.088***	-0.090***	-0.024	-0.013	-0.014	-0.014
	[0.000]	[0.000]	[0.225]	[0.479]	[0.272]	[0.395]
ruggedness < 1600	-0.010***	-0.010***	-0.008***	-0.007***	-0.005***	-0.009***
	[0.000]	[0.000]	[0.000]	[0.000]	[0.001]	[0.000]
ruggedness >= 1600	-0.008	-0.003	-0.010	-0.006	-0.013***	-0.011**
	[0.317]	[0.699]	[0.143]	[0.320]	[0.005]	[0.047]
roman road	-0.011*	-0.011*	-0.003	-0.001	0.008*	0.003
	[0.081]	[0.061]	[0.634]	[0.839]	[0.061]	[0.536]
ln elevation	0.004*	0.004	0.002	-0.001	-0.003*	0.000
	[0.091]	[0.127]	[0.461]	[0.540]	[0.099]	[0.862]
P(cultivation)	0.116***	0.117***	0.099***	0.095***	0.071***	0.102***
	[0.004]	[0.002]	[0.003]	[0.002]	[0.003]	[0.002]
P(cultivation) * trend	-0.013***	-0.013***	-0.011***	-0.011***	-0.007***	-0.013***
	[0.008]	[0.005]	[0.003]	[0.003]	[0.008]	[0.002]
city >= 10k? (t-1)			**0 - 20 km**			
< 1600	-0.037***	-0.031***	-0.015	-0.008	-0.006	-0.025**
	[0.004]	[0.008]	[0.104]	[0.306]	[0.454]	[0.021]
>= 1600	0.027	0.022	0.015	0.024	0.018	0.015
	[0.206]	[0.266]	[0.400]	[0.153]	[0.145]	[0.349]
city >= 10k? (t-1)			**20 - 50 km**			
< 1600	-0.005	-0.009	-0.001	0.000	0.002	-0.004
	[0.398]	[0.123]	[0.761]	[0.955]	[0.657]	[0.412]
>= 1600	0.041***	0.044***	0.023*	0.018	-0.001	0.011
	[0.007]	[0.002]	[0.087]	[0.147]	[0.928]	[0.335]
city >= 10k? (t-1)			**50 - 100 km**			
< 1600	-0.005	-0.006	0.002	0.000	-0.002	-0.005
	[0.324]	[0.228]	[0.585]	[0.952]	[0.498]	[0.237]
>= 1600	0.071***	0.063***	0.037**	0.045***	0.017	0.037***
	[0.000]	[0.001]	[0.025]	[0.004]	[0.143]	[0.007]
competitor potential city location? (t-1)			**0 - 20 km**			
< 1600	-0.012**	-0.011**	-0.011**	-0.009**	-0.006*	-0.012**
	[0.031]	[0.029]	[0.013]	[0.029]	[0.057]	[0.017]
>= 1600	-0.027*	-0.032**	-0.014	-0.007	0.011	0.004
	[0.089]	[0.032]	[0.294]	[0.577]	[0.241]	[0.717]
competitor potential city location? (t-1)			**20 - 50 km**			
< 1600	-0.019*	-0.013	-0.001	0.002	0.006	-0.010
	[0.052]	[0.132]	[0.863]	[0.816]	[0.352]	[0.263]
>= 1600	0.016	-0.003	-0.006	0.003	-0.014	-0.019
	[0.582]	[0.907]	[0.803]	[0.893]	[0.445]	[0.368]
competitor potential city location? (t-1)			**50 - 100 km**			
< 1600	-0.011	-0.018	-0.013	-0.011	-0.023	-0.022
	[0.658]	[0.45]	[0.547]	[0.529]	[0.128]	[0.355]
>= 1600	-0.037	-0.102*	-0.036	-0.077	-0.001	-0.033
	[0.568]	[0.096]	[0.548]	[0.147]	[0.972]	[0.51]
country/century FE	yes	yes	yes	yes	yes	yes
nr observations	12814	13139	13828	14084	13832	13370

TABLE A8 CONTINUED	*p-value H0: pre 1600 = post 1600*					
sea	[0.014]**	[0.051]**	[0.775]	[0.717]	[0.297]	[0.258]
river	[0.151]	[0.111]	[0.001]***	[0.001]***	[0.073]*	[0.015]**
hub	[0.000]***	[0.000]***	[0.000]***	[0.000]***	[0.000]***	[0.000]***
ruggedness	[0.083]*	[0.006]***	[0.049]**	[0.023]**	[0.826]	[0.189]
city >= 10k? (t-1)						
0 - 20 km	[0.002]***	[0.005]***	[0.066]*	[0.106]	[0.176]	[0.015]
20 - 50 km	[0.012]**	[0.001]***	[0.177]	[0.327]	[0.691]	[0.205]
50 - 100 km	[0.000]***	[0.001]***	[0.163]	[0.024]**	[0.120]	[0.004]***
competitor? (t-1)						
0 - 20 km	[0.902]	[0.902]	[0.289]	[0.229]	[0.029]**	[0.065]*
20 - 50 km	[0.094]*	[0.367]	[0.962]	[0.935]	[0.229]	[0.968]
50 - 100 km	[0.927]	[0.529]	[0.953]	[0.635]	[0.271]	[0.859]

Notes: the last column shows the results when employing a step-wise city definition, i.e. from 800 – 1500 the size criterion is >= 5,000 inhabitants, from 1600 – 1700 it is >= 6,000, and in 1800 it is >= 10,000. p-values, based on robust standard errors, between square brackets. *, **, *** denotes significance at the 10%, 5%, 1% respectively. Instead of the estimated coefficients in (2), 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 coefficients and their standard errors.

improve a location's probability of becoming a city of 5,000 or 6,000 inhabitants, it becomes increasingly difficult to grow larger in the shadow of an already existing urban centre. An existing city as it were does only tolerate moderately sized new cities to appear in its immediate backyard.

Note that when raising the absolute size criterion to 10,000 inhabitants we also find two additional changes in the post-1600 period results. First, location at sea starts to exert a positive influence on locations' urban chances. Second, ruggedness does not lose its negative influence on city location. The former confirms the notion that location at sea becomes increasingly important in order to attract larger numbers of inhabitants (see e.g. the results in Acemoglu et al. (2005) that find that location at sea (and at Atlantic shores in particular) has strong effects on city size when focussing on a sample of cities with more than 10,000 inhabitants. The latter is an indication that locations in more rugged areas find it more difficult to host larger urban populations.

Finally, column 7 shows results when using a time-varying population cutoff to define a city. We employ the following step-wise increasing population cutoff: 5,000 inhabitants before 1600, 6,000 in 1600 and 1700, and 10,000 in 1800. We choose this particular stepwise increase as this leaves the unconditional probability of becoming a city in any century around 11% in the period 1500 – 1800 (instead of increasing substantially over this period when using our absolute 5,000 inhabitants cutoff). As discussed in section 3.2 using such a time-varying definition is in itself not without difficulties. In particular, given that we condition on not already being a city in *t-1* and include our three 'competitor potential city location'-dummies one century lagged (i.e. in *t-1*), one has to choose which definition to use when constructing these variables (i.e. the 'new' definition in period *t* or the 'old' definition in period *t-1*). To give an example, say we increase our city definition in period *t* from 5,000 to 6,000 inhabitants. Should we, in period *t*, look at the probability of a location becoming a city (at least 6,000 inhabitants) given that it was not a city in period *t-1* according to its new definition in period *t* (at least 6,000 inhabitants) or to its old definition in period *t-1* (at least 5,000 inhabitants)? Similarly, should we define competitor potential city locations in period *t-1* as locations with less than 5,000 or less than 6,000 inhabitants?

In column 7 we use the city definition in period *t-1* to construct all our one-century lagged variables and our conditioning variable (i.e. was there a city in period *t-1*)[70]. The results show that our main findings are again generally robust to using this time-varying city-definition. Only the effect of an already existing city within 20 - 50 km is no longer significant (similar to our results when using an absolute cutoff of 7,000 inhabitants), and location at sea and ruggedness remain are both significant determinants of city location in the post-1600 period (echoing the results when using an absolute cutoff of 10,000 inhabitants).

[70] This choice is arbitrary however. The results are also robust to using the city definition in period *t* instead. Also using a different 'step-wise' city definition (i.e. 5,000 before 1800 and 10,000 in 1800) all our baseline results come through. These results are available upon request.