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SPACE, SETTLEMENTS, TOWNS: THE INFLUENCE OF GEOGRAPHY AND  
MARKET ACCESS ON SETTLEMENT DISTRIBUTION AND URBANIZATION

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**Cities and Innovation**

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**ABSTRACT:** The spatial distribution of economic activity is strongly linked to the structure of the urban system. The origin and development of the spatial pattern of this system is separated into two stages, the diffusion of settlements and their potential transition to urban status. The theoretical framework incorporates the influence of geographic characteristics and location interdependence as central mechanisms in both stages. Their relative importance for both is tested empirically with the historical settlement pattern in Saxony as a case study. After investigating with a spatial point process approach how geographic endowments and location interdependence shape the spatial distribution of all settlements within the state, I apply a spatial probit estimation to determine how these endowments and interdependence, which resembles a market access effect, influence the likelihood that a settlement transitioned to a town. The results indicate that geographic factors are the primary influence on the spatial distribution and urbanization of settlements, while the spatial relationship has a significant but small clustering impact. Furthermore the determinants of the spatial distribution of size based and institutional towns are compared, demonstrating that the influence of location interdependence is quite close, while there are some significant differences in the influence of physical geography.

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## 1. Introduction

Towns as population centres are closely connected to the location, size and growth of economic activity. The economics and economic history literatures have recently used this relationship to investigate the impact of various geographic, institutional and other factors on economic growth through determining the impact on town size and growth.<sup>1</sup> These analyses however usually presuppose an existing urban system, focusing on changes within the system. The origins of the system and the factors behind its spatial shape are usually not taken into account. This paper focuses on the creation of the system by investigating the mechanisms underlying the distribution of all settlements as well as the transition of certain settlements to urban status. This approach shows how geography and location interdependence shaped the foundations of the urban system.

Conceptually I separate the development of an urban system into three steps, first the settlement location decision, secondly the move from village to town and thirdly the development of an urban hierarchy. The third step, the urban hierarchy, focuses on the relative importance of towns, usually measured by size or function. There is a very extensive literature on this stage; one strand is concerned with size and is centered around Zipf's law (Zipf, 1949), the empirical regularity of the town size distribution, while another strand is concerned with the functional structure of the urban system

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<sup>1</sup>Examples are De Long and Shleifer (1993) and Acemoglu et al. (2005).

as epitomized by Christaller's Central Place theory (Christaller, 1933). Both of these literatures however usually take the set of towns as given and do not take its determinants and characteristics into account. This analysis focuses therefore on the first two steps which explain the locations of towns, the foundations on which the urban hierarchies developed.

The first stage contains the diffusion of settlements over the geographical area in question. Settlements are not randomly distributed over space, for example, settlements in Saxony, the setting of the empirical analysis, are shown to exhibit a clustering pattern. Hudson's theory of rural settlements, which provides a theoretical framework for this stage, distinguishes two potential mechanisms explaining this pattern (Hudson, 1969). The first is the nature of the geographical area to be settled, its endowments, suitability for agriculture and other characteristics. The second is a potential interdependence between settlements as a result of diffusion and competition effects. Since I take the set of all settlements as the set of possible town locations, the investigation in this stage reveals the main mechanisms underlying the step from the whole geographic area to a number of specific locations by identifying the relative probability that a particular site becomes settled

The second stage starts with the set of all settlements as a starting point for the selection process underlying a separation into towns and villages. Setting this analysis in a time frame before the industrial revolution I utilize a town definition based on identifying a threshold size such that agriculture is no longer the central income source above it. There are essentially two pro-

cesses for the evolution of towns. The first starts with location characteristics and postulates that settlements become towns due to the ability to diversify their production away from agriculture. The other stresses the importance of trade and in particular a settlements ability to focus trade and market exchange in its location. These two processes are not mutually exclusive, in the contrary non-agricultural production and trade are strong complements. Similar to the first stage one of mechanisms stresses the importance of location characteristics, while the other emphasizes the relationship between locations.

The relative importance of the two factors, endowments and interdependence, within each of these two stages is tested empirically. The geographical setting for this test is Saxony, a historically important state in central Europe, that became part of the German Empire. I utilize data from the early 19th century, in particular the year 1834, when Saxony was in the early phase of the industrial revolution.

The long persistence of the area in question under Saxon rule, which went back for centuries, implies that the settlement and especially the urbanization process proceeded without strong political borders within the area or major institutional differences between different regions. This territorial consistency makes the state a good setting to investigate the outcome of a long term development process. This is reinforced through the geographic conditions, the area has a number of different physical patterns, from a mountain range along the southern border, a major river crossing through quite flat land to

rather hilly regions in the west. The diversity of patterns however did not lead to important natural barriers within the state, which was historically recognized as a single region.

The use of historical data has also advantages for the identification of locations. In modern settings political or administrative location boundaries do not always correspond very well with actual economic or settlement locations. Historically the identification is much closer, in some cases settlement boundaries are even physical, for example city walls. This identification also benefits from historically less fragmentation between work and housing. The combination of these two in the same location implies that there was no distinction between residential settlements and the location of economic activity. People lived and worked in the same place. This implies that the underlying forces affecting the spatial distribution of the population, through the location of settlements as well as urbanization, are not differentiated along this dimension.

The choice of setting is also based on the existence of a town classification scheme. Ploeckl (2011b) uses the same setting, Saxony in the middle of the 19th century, as the empirical example of a new town definition approach. The main, underlying idea is a differentiation of settlements along the main income source; a size threshold is chosen such that settlements below have agriculture as their main income source, while those above the threshold are based on non-agricultural income sources. This approach to classifying settlements is consistent with the conceptual idea underlying the urbanization

stage. The empirical analysis of this stage is therefore based on the set of towns taken from Ploeckl (2011b).

This classification approach looks at towns from an economic perspective, there is however another approach based on institutional, usually legal, characteristics. This particular historical setting allows a comparison due to the existence of such a legal town classification. Based on historical institutional developments the Saxon Government formalized the classification of all settlements into towns and villages in the early 19th century. Conducting the empirical analysis with this set of towns reveals the determinants behind the geographical distribution of institutions. This allows the comparison of the underlying mechanisms for the development of population based urban system with the principles underlying the institutional system of town rights. This illustrates whether towns as economic institutions followed the same logic as the legal and institutional development.

Both town classifications are explained in more detailed with the underlying data in the following section. Section 3 addresses the mechanisms behind the spatial distribution of settlements. The main hypothesis tested is that geographic characteristics and location interdependence affect the spatial distribution of settlements. Using spatial point process tests I first establish that the spatial settlement pattern is not random, but exhibits clustering. The main test then shows whether geographic factors and location interdependence affect the likelihood that a particular point in the area is the site of a settlement. Geographic factors affect this probability multiplicatively,

while the influence of other locations is specified in a functional form that is conditional on the distance between sites. This implies that the estimated coefficients show the relative size of the impact through endowment factors and other locations.

Results show that quite a number of geographic characteristics, for example agricultural land quality, elevation, and water access, have a considerable impact on the likelihood that a site is the location of a settlement. Location interdependence also matters, the magnitude of the estimated impact is sizeable but fairly in line with the individual impact of the more important geographic covariates.

Section 4 investigates the mechanisms underlying the urbanization process. The main hypothesis tested is whether geographic factors and interdependence influence which settlement develops into a town. Taking all settlements as the set of observations, I apply a spatial probit estimation to determine the factors influencing the probability that a settlement had reached urban status by the industrial revolution. The specification includes the geographic factors as regular covariates and a spatial term which contains the outcome of all other locations combined with a weighting matrix. The specification of this weight matrix based on the distance between locations allows to investigate the shape of the potential interdependence effect. Results show that geographic factors also dominate the emergence of urban settlements, with a small clustering effect due to market access. I repeat the estimation with the legal town status as outcome to compare the underlying

ing mechanisms between institutional and population based spatial distributions, results show that the influence of location interdependence is similar, though there are some differences in the influence of specific geographic factors pointing to the different determinants for population based towns and the institutional spatial landscape.

## 2. Setting

The empirical analysis is set in Saxony, an historically important, central European state, which is nowadays a part of Germany. The actual data point used for the empirical analysis is based on settlement and urban systems in the year 1834, which is right at the beginning of the industrial revolution in the area (Kiesewetter, 2007; Forberger, 1982). The settlement system had been stable for a number of centuries at this point, which allows the use of the observed towns and villages as the final realization of the settlement process. An additional advantage of this area is its history as a consistent region without major internal borders and a common government over the settlement periods, which minimizes a number of distorting effects, in particular borders (Redding and Sturm, 2008; Ploeckl, 2010a).

The actual data is taken from Ploeckl (2011b), which bases the set of settlements on information from historical census counts of the Saxon governments. These were introduced in 1834 because of Saxony's entry into the Zollverein, the German customs union (Ploeckl, 2010b; Henderson, 1984). The data, which lists the number of inhabitants for 140 legal towns and 3417

villages<sup>2</sup>, is described by Waechter (1901) and Lommatzsch (1905). Each location is referenced with geographic coordinates<sup>3</sup> which allow a link between settlements and a number of geographic location characteristics.

Available characteristics<sup>4</sup> for the whole area, and therefore all location sites, are the suitability of the site for farming as well as pasture purposes, the vicinity to flowing surface water, average rainfall and temperature, elevation above sea level and ruggedness, and the distance to coal mines. The suitability for farming and pasture is measured by an index value between 0 and 100. The number is based on extensive geographical surveys conducted by the Saxon government in the middle of the 20th century. The respective index value combines a number of input factors like soil type, water and climatic conditions. The data is reported as average values for late 20th century political parishes which implies about 1600 distinct values. A modern parish and the associated value cover therefore the local conditions for approximately two settlements in the data set. Elevation is measured as meters above sea level at the particular location. The elevation values are also the basis for the measure of ruggedness, which is calculated as the standard deviation of elevation levels in a two kilometer radius around the settlement

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<sup>2</sup>The number of villages is slightly higher in the original lists, however a small number of places are enclaves within another state and get therefore dropped from the sample.

<sup>3</sup>These are either official coordinates from the Saxon *Landesvermessungsamt* or from a historical place register (Blaschke and Baudisch, 2006), and usually represent a central position within the settlement.

<sup>4</sup>Ploeckl (2011b) describes the characteristics in more detail and provides sources.

location.<sup>5</sup> The presence of flowing water is measured with a dummy. It indicates whether the the location is within a kilometer of any water that could potentially serve as a source of energy and easy access to water taking into account the complete Saxon river system. Technically the measurement is based on modern geographic data, but the differences between historic and current water flows are minimal, especially since there was no real canal building activity in Saxony. Additionally the distance to the river Elbe, the only major navigable river, is included as a variable. The geographic surveys underlying the farming and pasture suitability also include explicit climatic conditions. In particular I use two of these, namely rain fall and temperature. Rain fall is measured in average yearly amount of rain while temperature is again turned into a index value between 0 and 100 based on agricultural criteria. While all of these variables are clearly exogeneous, some specifications also include information about a location's distance to major and minor roads. The resulting endogeneity problems will be discussed in connection with the estimation results.

### *2.1. Definition of Towns and Villages*

This focus on the set of towns rather than the size hierarchy leads to the use of a binary classification of settlements into villages and towns. The second step, the urbanization phase, requires therefore a definition of township.

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<sup>5</sup>The high resolution of the elevation data makes the standard measure, as used by Nunn and Puga (2009), too focused on an extremely small area.

The postulated two mechanisms at work during this step center around the emergence of non-agricultural income sources for the settlement population. The share of non-agricultural income is one of the four criteria for town status listed in the definition developed by DeVries (1984). The other three are the population size, economic diversity, and population density. The utilization of these mechanisms implies that the theoretical framework uses a production based, economic approach for the definition of township rather than an institutional or sociological approach.

Ploeckl (2011b) demonstrates that the applied town definition matters for the results drawn from urban data, for example the inference about the location of towns and the relationship to villages is strongly influenced. These results are based on a new classification of settlements into towns and villages based on a population threshold that is derived from data rather than the ad hoc approach used by most studies based on data by DeVries (1984) or Bairoch et al. (1988). This classification is based on the relevance of agricultural endowments for location size, towns are settlements larger than a threshold such that the income structure is not dependent on local agriculture any more. Since this definition corresponds to the postulated mechanisms above, I will utilize it in the analysis of the emergence of towns.

## *2.2. Legal Institution*

Although the common definition of towns is based on population we usually associate towns also with specific institutional characteristics. The par-

ticular nature of these characteristics varies widely, from governance regulations to tax privileges to security installations. Such a formal approach has a long precedent, going back at least to Roman times for the European case. In Saxony over time a set of legal towns emerged and by the early 19th century their institutional characteristics were finally completely harmonized and fully codified by the Saxon government (Blaschke, 1967). There is a strong correlation between the sets of legal and population based towns on both ends of the settlement spectrum, i.e. usually very large settlements are consistently classified as towns and very small ones as villages, but there is a substantial difference around the thresholds. Repeating the analysis with the set of legal towns illustrates how the diffusion in the two cases differs. This demonstrates whether the rise of town institutions is linked to the same factors as the emergence of population-based towns, especially whether geographic endowments have the same influence for the spatial pattern of institutions.

### **3. Location**

The process of location choice and settlement is not only a spatial but also an inherently temporal phenomenon. Focussing on settlement patterns in historically settled areas like Europe however usually implies a lack of sufficient information about historical developments. This leads to an approach which starts with the postulation of an underlying process of settlement and the derivation of implications for the resulting spatial outcome pattern. These

implications are then tested using cross-sectional data from the empirically observed spatial distribution. Here the theoretical framework incorporates geographic conditions as a starting point for the distribution of locations and then location interdependence as a further mechanism that either adds or removes locations. It will consequently be investigated whether physical geography and location interdependence had an influence on the urban system through the rural distribution of settlements.

The investigation is carried out using a spatial point pattern approach, which starts out with a set of locations, irregularly distributed within a region, like settlements within a country, and assumes it to be generated by some unknown random mechanism (Diggle, 2003). Here the observed pattern of settlements, labelled  $x$ , will be treated as the realization of a random point process, labelled  $X$ , where the number of points - settlements- as well as the point - settlement- locations in the two-dimensional region  $W$ , here the state of Saxony, are random (Baddeley and Turner, 2006). The interest is then into the parameters of the process  $X$  including the effect of explanatory variables. Of particular interest is the *intensity* of the point process, which is the expected number of points per unit area, the settlement density.<sup>6</sup>  $\lambda(u)$  is the *intensity function*, which satisfies  $E[N(X \cap B)] = \int_B \lambda(u) du$  for all regions  $B$ , assuming that  $\lambda(u) du$  is equal to the expected number of points

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<sup>6</sup>If the intensity is constant over all of  $W$  it is referred to as uniform or homogeneous, while it is labelled inhomogeneous if it varies from location to location (Baddeley and Turner, 2006).

falling in a small region with area  $du$  around a location  $u$  (Baddeley and Turner, 2006).

### 3.1. Pattern Characteristics

The first step is to demonstrate that the observed pattern itself is not purely random. Baddeley and Turner (2006) states that the usual reference model of a point process is the uniform Poisson point process in the plane with constant intensity  $\lambda$ , which is usually referred to as *Complete Spatial Randomness (CSR)*. They lists the basic properties as

- the number of points in any region  $A \in W$  has a Poisson distribution with mean  $\lambda|A|$
- the locations of points inside region  $A$  are i.i.d and uniformly distributed within  $A$
- the contents of two disjoint regions  $A$  and  $B$  are independent

If the hypothesis of CSR is not rejected, it essentially implies that none of the two mechanisms introduced above, local endowment characteristics and systematic interaction or dependency between the settlements, mattered and influenced the spatial distribution of settlements. The hypothesis can be tested with a number of tests, for example with a  $\chi^2$  based test of quadrant counts or a Kolmogorow-Smirnow test. Although both tests reject CSR,<sup>7</sup> it

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<sup>7</sup>The quadrat count test has a p-value below 0.01, similar the KS-tests using the y coordinate or the sum of the x and y coordinates. The KS-test based on the x coordinate only does not reject CSR.

cannot be deduced which of the listed properties is violated. This implies the test does not allow to deduce whether there is an underlying inhomogeneity or whether there is dependence between the locations.

Some more information can be deduced by using the information about the distances between locations and their respective nearest neighbour locations. In particular they can be used to deduce whether the pattern of locations shows signs of regularity, locations are more evenly spaced over the area, or clustering, locations are more densely clustered. The results of the test, usually referred to as Ripley's  $K$ , is shown in figure 1. A graph below the theoretical curve implies a regular pattern while values above indicate clustering. As is evident, settlement locations in Saxony exhibit a clustering pattern, which might be caused by either spatial factors influencing the distribution or by an attraction process between locations.

### *3.2. Absolute Influence*

The next step is to investigate whether geographic conditions shape the spatial distribution of settlement locations. If they do not, then the likelihood that a point within the area in question is the site of settlement should not be influenced by the endowments and geographic characteristics of the site. This will be tested by including the effect of explanatory variables through the use of spatial covariates. This implies that the assumption of a homogeneous intensity function is dropped, while the independence of the settlements from each other is maintained.

The first stage of the theoretical framework begins with the colonization of the space, postulating a contingency on the environmental conditions. Agriculture represents the central source of nutrition, once hunter and gatherers had become sedentary. The necessity of a basic food supply obviously had an influence on the process of pre-historical settlement with agriculture becoming the main source of income and employment. Geographic endowments obviously go beyond just agricultural conditions. They potentially influenced the location of settlements through their impact on a series of non-agricultural factors like security, living amenities and access to sources of energy and other natural resources. A third factor is the access to transport routes, which can be either land or water based. Travel requires services, for examples housing, food or security, which implies that there is a demand for labor along important trade routes. This might influence the location decision of settlements towards locations in the vicinity of major roads or rivers.

These three points are addressed by a number of specific site conditions which are included as independent variables to test for the potential influence on the distribution of settlements. The first set of factors are the agricultural endowments, in particular the quality of the local land for farming and pasture purposes. Another category includes site conditions like elevation above sea levels, the ruggedness of the surrounding land, the proximity to surface water, as well as climatic conditions like rain and temperature. The third set consists of the distance of a location from the Elbe, the only major navigable

river, major roads, as well as minor roads.<sup>8</sup>

This impact of local characteristics is modelled through the influence of covariates on the intensity function, These covariates are based on spatial functions  $Z(u)$  that are potentially observable at every spatial location  $u \in W$ . The intensity function  $\lambda_\theta(u)$  now depends on a parameter  $\theta$ , which leads to the following log-likelihood for  $\theta$ :

$$\log L(\theta, x) = \sum_{i=1}^n \log \lambda_\theta(x_i) - \int_W \lambda_\theta(u) du$$

which is a well-behaved likelihood, but the MLE  $\hat{\theta}$  is not analytically tractable and requires a numerical solution (Baddeley and Turner, 2006). Berman and Turner (1992) develop an algorithm that uses a formal similarity between the Poisson log-likelihood and that of a loglinear Poisson regression. This requires that the intensity function  $\lambda_\theta(u)$  is loglinear in the parameter  $\theta$ , formally  $\log \lambda_\theta(u) = \theta * S(u)$ , where  $S(u)$  is a real-valued or vector-valued function of location  $u$ . In particular  $S(u)$  can be a function of observed spatial covariates. This leads to the use of the following form of the intensity function:

$$\lambda(u) = \exp(\alpha + Z\beta)$$

where  $\alpha$  is a constant and  $Z$  is a vector of spatial covariates. The first specification concerning the pattern of all settlement locations will include the

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<sup>8</sup>The data and their sources are described in more detail in the appendix.

agricultural endowments used above as covariates, this will be followed with the inclusion of other geographic factors and concludes with the inclusion of infrastructure covariates.

The first specification builds on the intensity function  $\log(\lambda(u)) = \alpha + \beta_f * Farm + \beta_p * Pasture + \beta_{fp} Farm * Pasture$ , which includes the quality of a location for farming purposes (*Farm*), pasture purposes (*Pasture*) and their interaction as a test of the influence of agricultural endowments on the spatial distribution of settlement locations. The results in table 1 show that these endowments matter for the spatial distribution of population settlements. Although the direct effect of farm land quality is statistically insignificant, it does have a significant effect through the interaction term. The positive sign of the interaction implies that better farmland increases the likelihood for a location to be settled. In particular if the quality is above 29, which holds for 88% of all settled locations, then also the effect of pasture quality becomes positive. So both farm and pasture land quality increase the likelihood in this case, which shows that better agricultural endowments influence the spatial distribution of settlements and lead to a higher density of said locations.

The next step is to incorporate other geographic factors, which leads to the following intensity function:

$$\log(\lambda(u)) = \alpha + \beta_f * Farm + \beta_p * Pasture + \beta_{fp} + \mu_e * Elevation + \mu_{rg} * Ruggedness + \mu_t * Temperature + \mu_r * Rain + \mu_{tr} * Temperature * Rain + \mu_w * River$$

Table 1 shows the results when these variables are added to the intensity

function. The agricultural endowment variables are now all statistically significant and both, farming and pasture quality have each a positive marginal effect once the other is above a low minimum value. The geographic variables all exhibit statistical significance as well. Elevation has a negative effect, higher locations have a lower likelihood to be settled. In contrast to this, a more rugged neighbourhood actually increases the density of settlements. Rain and Temperature have a negative marginal impact as long as the other is below a relative high value. The coefficient on the presence of a river is highly significant, surface water in the vicinity increases the likelihood for a location to be settled.

The third step is to include information about trade routes. In particular I include the distance to the Elbe river, which was the major navigable river in Saxony, as well as the distance to major and minor historical roads. This implies the following intensity function:

$$\log(\lambda(u)) = \alpha + \beta_f * Farm + \beta_p * Pasture + \beta_{fp} + \mu_e * Elevation + \mu_{rg} * Ruggedness + \mu_t * Temperature + \mu_r Rain + \mu_{tr} Temperature * Rain + \mu_w * River + \delta_E * RiverElbe + \delta_s * MajorRoad + \delta_{ss} * Road$$

In contrast to all other factors roads are not exogenously given. They might be influenced by natural and geographic factors, but they are determined by human activity. Since roads usually connect settlements, there is a possible endogeneity issue concerning the distance from such roads in the estimation. However as the results in table 1 show the effect of roads is not

statistically significant or even negative. Distance to the Elbe in contrast does have a significant effect, whose sign goes against expectation. Locations are likelier to be settled if they are further away from this river. This is likely due to the positive correlation of the Elbe with land quality values, which are linked to a higher density.

Based on the average and standard deviation the change in likelihood from a one standard deviation increase in each of the spatial covariates is calculated, the resulting values are given in the impact column in table 1. A location with a one standard deviation higher farm land quality has a 22.1% higher likelihood to be settled than an otherwise identical location, conditional that the pasture quality for both is equal to the average value. The similar effect for a higher pasture value is 11.38%. The effect of elevation levels is considerably stronger, a higher situated location has its likelihood lowered by 39.7%, while an increase in ruggedness raises the likelihood by 33.6%. Climactic differences have relatively small effect, a higher temperature reduces the likelihood by 15.5%, more rain increases it by 3.6%. If a location is in the vicinity of flowing water, explicitly within one km of it, then the likelihood is 24.4% higher. Locations further away from the Elbe have a 11.7% higher chance of being the site of a settlement. The numbers show that agricultural quality has a considerable influence on the settlement, other geographic feature have an even stronger influence. Especially elevation patterns have a quite strong impact, which reflects the impact of the mountain range along the southern border, similar water as source of food,

irrigation and the site of transportation routes makes settlements much more likely in its vicinity.

### 3.3. Interdependence

The pattern of all settlement locations in Saxony is not random, as shown above. These tests however cannot distinguish whether the violation of randomness is due to an underlying inhomogeneous intensity function or interdependence between settlements. In the previous section I demonstrate that agriculture, geography and trade routes influence the spatial distribution. This however does omit the second postulated mechanism, location interdependence. This section therefore extends the analysis to include this mechanism and quantifies their relative importance.

This interaction between settlements is modeled as a pairwise interaction process, which focusses on the direct, symmetric interaction between points. The conditional intensity function  $\lambda(u, X) = b(u) \prod_{i=1}^{n(x)} c(u, x_i)$  combines the previously included function of spatial covariates,  $b(u)$ , with the interaction process  $c(u, x_i)$ . This formulation implies that the conditional intensity function  $\log \lambda_\theta(u, x) = \eta * S(u) + \varphi * V(u, x)$  is comprised of fully separate terms for the covariate effect and the interpoint interaction (Baddeley and Turner, 2006).

I use a so-called *Geyer* saturation process to model the interaction process, which allows for clustering as well as regularity. Formally, the conditional intensity is  $\lambda(u, X) = b(u) \gamma^{m.in}(s, t(u, X))$ , where  $s$  is a saturation

threshold and  $t(u, X)$  denotes the number of settlements within a given neighbourhood around the location. This implies that an additional settlement within a specific distance from the location modifies the likelihood of a settlement by the factor  $\gamma$ . If  $\gamma > 1$ , then the process has a clustering effect, while  $\gamma < 1$  results in a more regular pattern. The effect is multiplicative for additional settlements until their number reaches a saturation threshold  $s$  after which additional settlements do not have any further effect. Although this formulation contains therefore an upper bound for the number of interactions with other settlements within the specified distance, I use a parameter  $s$  high enough, such that the upper bound will not be binding.

This leaves the parameter for the distance range for the appropriate neighbourhood to be selected. There is no prior information about the range of interaction, therefore I will repeat the estimation for a number of different distance parameters. The selected distance thresholds vary from 500 meters to 10 kilometres. The choice of threshold also has computational reasons, since larger values become problematic due to necessary correction for border areas. Similar there are a number of issues preventing the calculation of standard errors (Baddeley and Turner, 2005), therefore I approach this in a different way. In particular, I repeat the calculation for a number of randomly chosen subsamples, each containing an circle area with a radius of 40km. The effect of factors influencing the intensity function is therefore reported in table 2 without standard errors, but figure 2 shows relevant information derived from the repeated regional sampling.

The coefficients of geographic factors remain fairly unchanged when the interdependence process with a small interaction distance threshold is introduced. When the interaction distance is increased, the effect of elevation strengthens, while the impact of ruggedness and water weakens. The development of the effect of agricultural and climatic variables is more variable, in a few cases it even changes signs. Compared to the median values derived from regional sampling, the variability is slightly higher, though is considerably lower than the variation between the different regional values. The displayed summary statistics, mean, median, 5th and 95th percentile, remain fairly stable when the interaction distance is increased. A number of them show that they are not distributed around zero, especially geographic factors like elevation, ruggedness and water, while for the agricultural, climatic and road mean and median appear relative close to zero.

The estimated coefficients  $\gamma$  underlying the interaction process between locations also move from a positive, clustering, to a negative, regular spacing, effect and back. This change in impact shows that market access matters on very short as well as further afar distances, while there is a strong competition effect peaking around a kilometre distance.

Table 3 and Figure 3 also shows the magnitude of the implied coefficient, as well as the resulting impact on the settlement likelihood if the number of locations within the interaction neighbour is equal to statewide average. The magnitude of the estimated impact is sizeable but fairly in line with the individual impact of the more important spatial covariates. This implies

that while interaction processes are relevant and influential for the spatial distribution of settlements, local endowments in their totality appear to be considerably more important in explaining the resulting pattern of settlement locations.

#### 4. Towns and Villages

Local geography and the presence of other settlements are shown to matter for the location of where people choose to settle, but does this also hold for the emergence of towns? This is closely related to the question about the relative role of endowments and agglomeration for urban size, but focuses on their role for the creation of towns rather than for a particular characteristic of their persistence.

The specification utilized to investigate the importance of market access and geographic endowments is a spatial probit regression (LeSage and Pace, 2009). This approach builds upon a Spatial Autoregressive model to incorporate the spatial interaction process between location. The central part of the specification is therefore

$$y = \rho W y + X\beta + \varepsilon$$

The specification has three main components, the set of local geographic endowments  $X$ , a market access term that combines the urban status of all settlements with a specific interaction process,  $\rho W y$ , and the urban status

of settlements as the binary outcome variable,  $y$ .

The set of geographic factors I utilize here is the same as the one introduced above to investigate the distribution of all settlements. This will show whether the same factors influence distribution and status or whether there is a change in the relative importance for the two issues.

The market access factor requires two main components, the urban status of all locations and a specification for the interaction process. The first component is simply the same as the outcome variable. The interaction process, as embodied in the matrix  $W$ , is specified in two distinct ways. The first method uses the presence of other settlements within a particular distance from the settlement for the determination of the interaction. The result is a binary matrix with element  $ij$  equal one if location  $j$  is within a specified distance. This method takes up the underlying idea about the interaction process utilized in the previous section. The applied interaction distance thresholds are 10km and 25km. The second method presumes that there is an interaction between all settlements, however its strength is dependent on the distance between the two. This dependence on distance is modeled through a decay function, where the strength of the effect decreases the further two settlements are apart. Formally the decay function is specified defining  $W = \frac{1}{d_{ij}^2}$ , where  $d_{ij}$  is the distance between locations  $i$  and  $j$ . If the spatial effect has a positive effect, it implies that towns are clustering and that urban market access leads to agglomeration and the emergence of towns. If the effect is negative the existence of other towns has a competitive

effect which reduces the emergence of towns, shifting the pattern to be more regular spaced.

The third required element is the outcome variable. The specifications use the set of towns based on the production based size threshold introduced above. Additionally I estimate the specifications also with the set of legal towns as the outcome variable. The use of the size based definition and the legal definition allows to compare the evolvement of an urban system characterized by the population distribution with the evolvement of an explicitly institutional system of towns defined by their legal status. This demonstrates whether the factors underlying the spatial distribution of institutions have the same influence as those underlying population distribution.

Table 4 reports in columns 1 to 3 the results for the regressions using size-based towns, individual columns show the results for the different spatial interaction processes. The results for size-based towns illustrate that a number of geographic factors had a statistical significant influence on the likelihood that a particular settlement became a town. The major factors were water, climate and elevation. The numbers show that the presence of a river raises the probability by 62%. Similarly the climatic environment did significantly influence the process. The final factor is elevation, the higher up a settlement is located, the lower is the probability that it emerged as a town by the 19th century. A one standard deviation increase in elevation reduces the probability by 51%. Given the elevation profile of the area in question this effect is predominantly caused by the influence of mountain

range along the southern border. An interesting result is the non-effect of direct agricultural factors. The quality of the land around the settlement did not influence whether the settlement became a town.

The other tested hypothesis was the influence of market access on the emergence of towns. Did the emergence of a town in the vicinity raise, decrease or have no influence on the probability that the settlement became a town ? The results show that in two of three tested specifications market access had a statistically significant positive effect on this probability. The differences between the results reveal that this effect was local. The two specifications modeling the interaction process in an area directly around the town show significant interaction effects, while the use of a state-wide specification shows no impact. The two local specifications further show that the effect was stronger the tighter the area around the town is. The emergence of another town within 10km raised the probability by 0.2%, while a town within a 25km radius had an effect of 0.1%. The numbers indicate that similar to the influence on locations, the impact of location interdependence on urbanization is quite minor in comparison to the impact of geography.

#### *4.1. Legal vs Size*

The comparison of the above results with those from a repeat of the analysis with the legal town set reveals whether the processes underlying the spatial distribution of people, and therefore economic activity, resemble those underlying the spatial pattern of the emergence of institutions. Towns

not only have economic functions, which predominantly are linked to the population distribution, but also a potential administrative function not only for the location itself but also the area surrounding it. Although these two functions potentially converged historically, for example the administrative center also organized the local trade fair, the two functions might explain a differential importance of the underlying distribution mechanisms.

Columns 4 to 6 in table 4 show the results for the analysis of the emergence of urban settlements repeated with the set of legal towns as outcome. The major similarity between these results and the set of population towns is the influence of interdependence between the different locations. This indicates that the influence of market access and spatial relationships on the spread of legal institutions follows the same logic as the diffusion of production and trade based settlement characteristics. There are however differences regarding the influence of geographic factors on the emergence of urban characteristics. One such difference is the role of elevation. While it has a significantly negative influence on the emergence of population based towns, the influence on legal towns is not statistically significant. The explanation behind these results is the role of *Bergstaedte*, mountain settlements that received town rights in connection with their mining activities but did not develop into larger population centers. Comparing the results more general geographical endowments play a more important role for population based towns since more of them show a statistically significant influence on the urbanization process.

In summary, institutions and population follow the same logic with regard to the influence of location interdependence, but they react in different ways to the underlying geographical circumstances. The absence of an impact of a number of characteristics for legal towns point towards a role of institutions in control of the wider space around them rather than just the individual location itself.

## 5. Conclusion

The underlying principles used to explain the location of economic activity also influence the spatial distribution of settlements. Geographic factors, in particular agricultural endowments, influence the distribution of all settlements. The inclusion of an interaction process, which models the interdependence of locations, shows that there exists a positive, therefore clustering, impact of neighbouring locations at very short or somewhat further distances, while there also seems to be a competition effect within the near vicinity. The magnitude of these interdependence effects are sizable but considerably smaller than the combined effects of geographic location characteristics. A very similar picture emerges for the transition from rural to urban settlements, market access plays a role but pales in comparison to the impact of geographic factors.

Bosker and Buringh (2010) and Ploeckl (2011a) have shown that market access matters for town size and growth already by the start of the industrial revolution, while this study demonstrates that the emergence of urban settle-

ments is predominantly driven by geographic factors. This points towards a shift in relative importance during the formation of the urban hierarchy in the centuries between initial colonization and the the industrial revolution. Further research into the characteristics and determinants for this particular shift will enhance our understanding of the temporal and spatial development of population and economic activity.

The results quantify and demonstrate new and revealing characteristics of the urbanization process in historically settled areas. This further opens the door to new research in other areas. First, it might be possible to link the shift from geography to location interdependence to the emergence of increasing returns in towns. What is the size a settlement has to reach to begin to profit from increasing returns and how does that threshold change over time? And second, whether and if so how did and does the spatial distribution of settlements interact with the development of other institutional characteristics, for example the size of land holdings. The obtained results show that geography matters directly for the emergence of spatial patterns of institutional characteristics, but the differences to the determinants for distribution of people open up the possibility for an indirect mechanism from local characteristics through population to other economically and socially relevant institutions.

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## 6. Tables

Table 1: Influence of Spatial Covariates on Settlement Probability

	Agriculture	Geography	All	Impact
Intercept	-15.8233 *	-13.4908 *	-14.1519 *	
	0.2118	0.4178	0.4674	
Farmland Quality	0.0048	-0.0144 *	-0.0113	22.10%
	0.0051	0.0059	0.0062	
Pastureland Quality	-0.0111 *	-0.0181 *	-0.0147 *	11.38%
	0.0054	0.0067	0.0068	
Farm X Pasture	0.0004 *	0.0006 *	0.0006 *	
	0.0001	0.0001	0.0001	
Elevation		-0.0022 *	-0.0027 *	-39.68%
		0.0003	0.0003	
Ruggedness		0.0116 *	0.0131 *	33.63%
		0.0014	0.0015	
Temperature		-0.0163 *	-0.0146 *	-15.47%
		0.0037	0.0038	
Rain		-0.0002	0.0003	3.64%
		0.0003	0.0004	
Rivers		0.2320 *	0.2218 *	24.38%
		0.0366	0.0367	
River Elbe			0.0031 *	11.67%
			0.0007	
Major Roads			0.0002	0.37%
			0.0049	
Minor Roads			-0.0123	-17.44%
			0.0073	

\* significant at 5%-level

The results are based on a Spatial Point Pattern analysis, which investigates the influence of local characteristics on the intensity function.

Table 2: Influence of Spatial Covariates with Interaction effect

Interaction Range	500	1000	1500	2000	2500	3000	4000	5000	7500	10000
Intercept	-13.2605	-12.807	-10.5484	-11.0245	-12.0666	-12.3059	-12.7583	-12.332	-15.3206	-13.9756
Farm	-0.0114	-0.01622	-0.01182	-0.00901	-0.00821	-0.00591	-0.00119	-0.00382	0.00469	0.00177
Pasture	-0.01628	-0.02302	-0.02177	-0.01831	-0.00708	-0.0048	-0.00037	-0.00122	-0.00526	-0.00851
Farm:Pasture	0.00057	0.00072	0.0007	0.00061	0.00034	0.00029	0.00012	0.00017	0.00014	0.0002
Elevation	-0.00282	-0.00302	-0.00373	-0.00351	-0.00301	-0.00296	-0.00296	-0.00337	-0.0032	-0.00263
Ruggedness	0.01226	0.01378	0.0152	0.01508	0.01079	0.01083	0.00987	0.01063	0.01298	0.01298
Temperature	-0.02126	-0.0224	-0.04447	-0.04129	-0.03396	-0.0325	-0.0313	-0.03671	-0.01438	-0.01801
Rain	-0.00023	-0.00038	-0.00115	-0.0011	-0.00079	-0.00084	-0.0006	-0.00044	0.00116	-0.00007
River	0.1953	0.22078	0.20141	0.17831	0.14079	0.14909	0.11199	0.11032	0.07912	0.0462
Elbe	0.00333	0.00351	0.00333	0.00307	0.00245	0.00294	0.00321	0.00288	0.00005	-0.00165
Major Roads	0.00176	0.00166	0.0013	0.00101	-0.00011	-0.00018	-0.00009	-0.00006	-0.00036	-0.00264
Small Roads	0.0004	0.00125	0.00266	0.00288	0.00212	0.00247	0.00122	0.00087	-0.0042	-0.00354

The results are based on Spatial Point Pattern analysis, which investigate the influence of local characteristics and the interdependence between locations on the intensity function. The table reports the coefficients on the local characteristics for specifications differing by the applied distance threshold for the interdependence effect.

Table 3: Size of Interaction effect

Interaction Distance	500	1000	1500	2000	2500	3000	4000	5000	7500	10000
Estimated Coefficient	0.1731	-0.0042	-0.0225	-0.0015	0.0351	0.0248	0.0219	0.0140	0.0054	0.0020
Implied Impact coefficient	1.1889	0.9958	0.9777	0.9985	1.0357	1.0251	1.0222	1.0141	1.0054	1.0020
Expected Number of neighbour locations Locations increased by 50%	0.18	0.74	1.66	2.95	4.62	6.65	11.82	18.46	41.54	73.85
Combined effect of expected locations Combined effect of increased locations	1.03	1.00	0.96	1.00	1.18	1.18	1.30	1.30	1.25	1.16
	1.05	1.00	0.95	0.99	1.28	1.28	1.47	1.47	1.40	1.25

The table reports the coefficients for the interdependence effect connected to the results reported in the previous table. Furthermore the size of the implied effect is quantified.

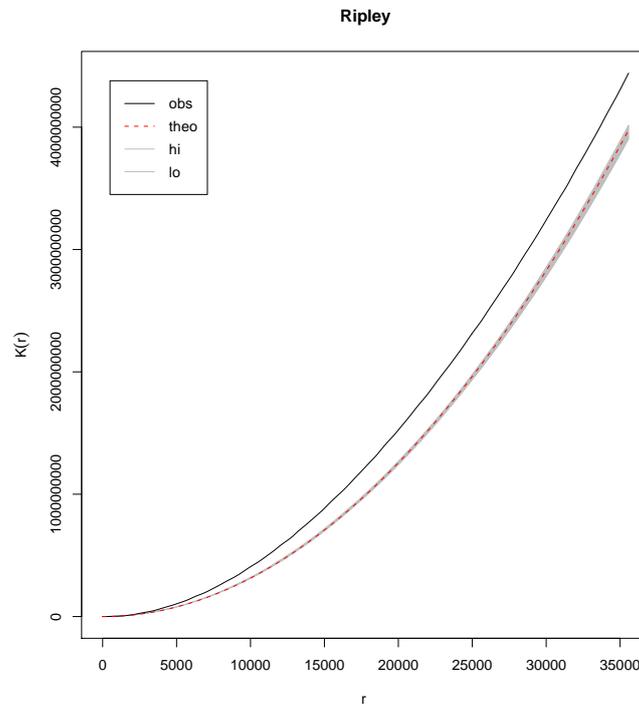
Table 4: Determinants of Urban status

Spatial Specification	Size Based Towns			Legal Towns		
	Decay	< 10KM	< 25KM	Decay	< 10KM	< 25KM
Constant	-2.032	-1.870	-1.833	-2.984	-2.907	-2.894
Farm quality	0.432	0.449	0.441	0.861	0.600	0.884
Pasture quality	4.591	1.879	3.132	20.541	19.993	23.019
Farm x Pasture	10.865	11.835	11.274	14.402	12.895	14.425
Elevation	5.160	0.504	-0.396	-20.673	-21.568	-19.348
Ruggedness	14.930	12.411	13.597	14.531	14.444	15.320
River	-0.146	-0.033	-0.044	-0.164	-0.120	-0.160
Elbe	0.225	0.225	0.226	0.263	0.248	0.278
Temperature	-2.103	-2.058	-1.982	-0.438	-0.429	-0.419
Rain	0.628	0.636	0.621	0.656	0.672	0.731
Spatial factor	0.731	0.778	-0.983	-2.206	-1.273	-2.346
	2.960	3.324	2.934	3.487	3.326	3.522
	222.034	233.674	239.045	447.123	456.276	465.741
	83.035	79.951	80.338	78.785	75.790	96.742
	119.143	104.264	82.314	65.920	63.397	49.405
	44.570	44.127	44.807	47.470	43.749	43.076
	-24.904	-23.938	-21.976	-2.219	-1.754	-2.736
	6.370	5.998	6.864	6.161	6.276	7.204
	2.888	2.818	2.859	1.981	1.865	1.965
	0.591	0.583	0.581	0.763	0.701	0.701
	0.322	0.792	0.300	0.191	0.710	0.282
	0.505	0.201	0.166	0.556	0.261	0.174

The results are based on a spatial probit analysis including local characteristics and the spatial component (rho).

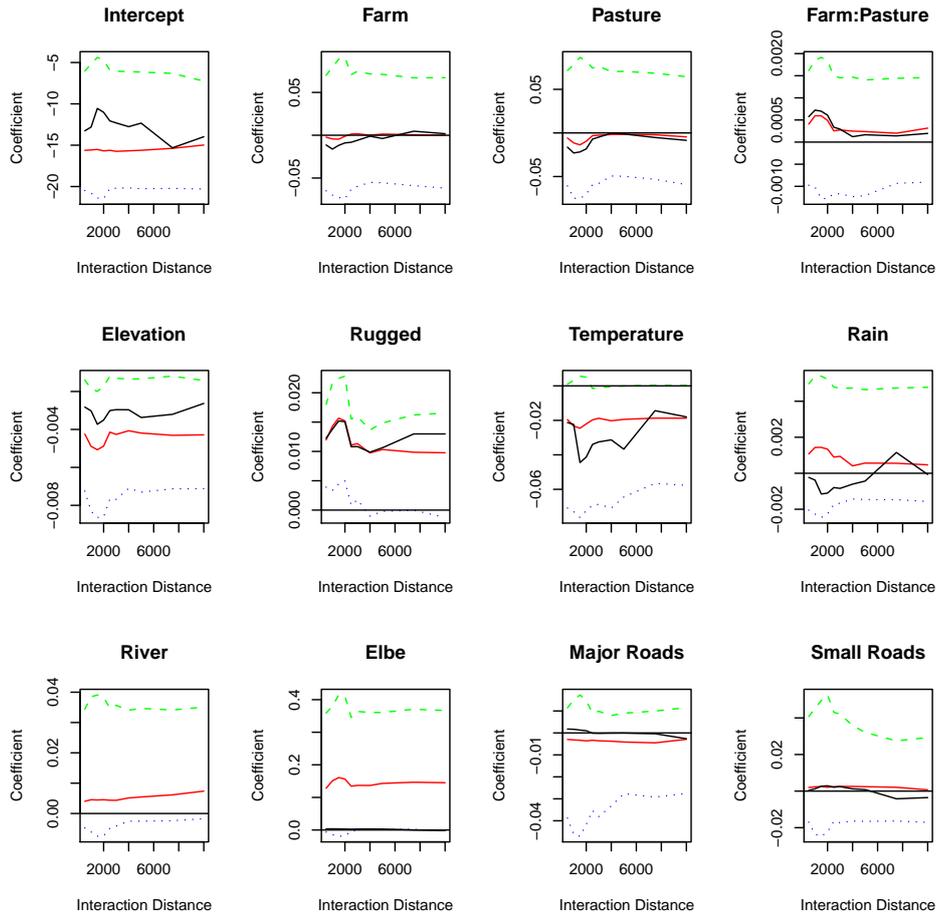
## 7. Figures

Figure 1: Ripley's K for all locations



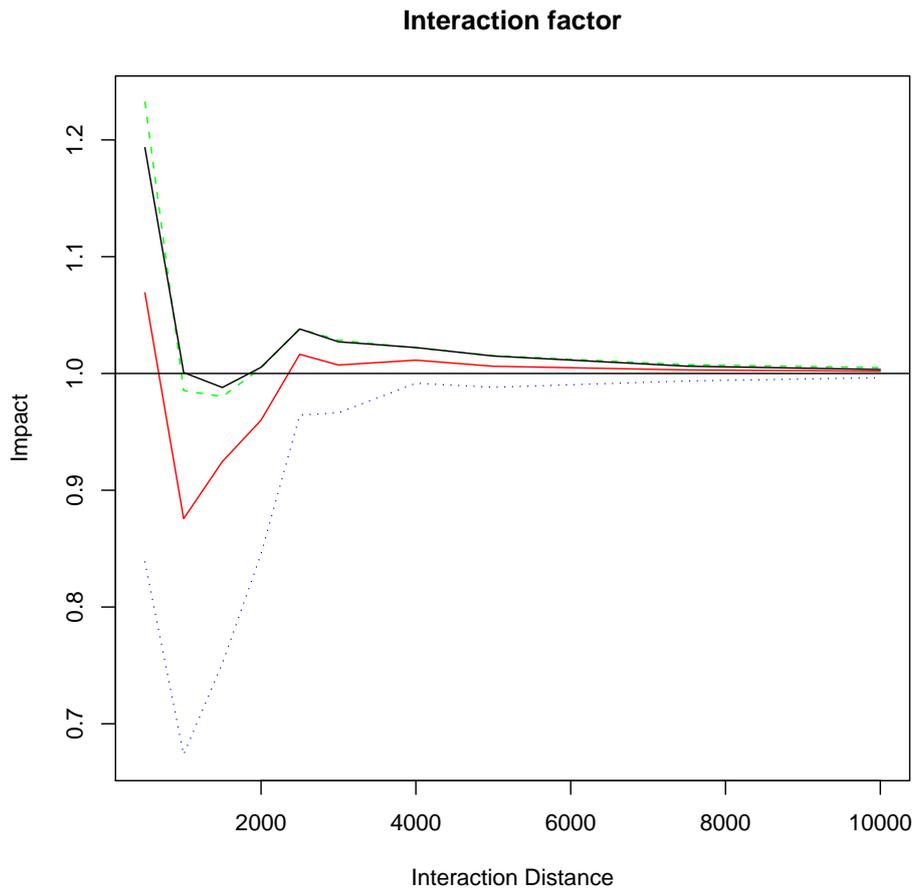
The graph plots the observed Ripley's K measure as well as the theoretical value implied by complete spatial randomness within confidence intervals.

Figure 2: Coefficients for the impact of geographic factors



Each panel depicts the coefficients for the impact of a specific geographic endowment on the settlement likelihood. The black line depicts the coefficient based on the full sample, the red is the median impact of the regional samples with the green and blue lines being the 5th and 95th percentile.

Figure 3: Impact of interaction effect



The black line depicts the interaction impact on the settlement likelihood based on the full sample, the red is the median impact of the regional samples with the green and blue lines being the 5th and 95th percentile.

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**2011**

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