Space, Settlements, Towns: The Influence of Geography and Market Access on Settlement Distribution and Urbanization

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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.

1 Introduction

Towns as population centers 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 their impact on town size and growth.[1] These analyses however usually presuppose an existing urban system, focusing on changes with 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 shape the foundations of the urban system.

The underlying theoretical framework separates 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; the strand concerned with size 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 as epitomized by Christaller's (1933) Central place theory. 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,

[1] Examples are De Long and Shleifer (1993) and Acemoglu, Johnson and Robinson (2005).

the foundations of the urban system.

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, exhibit a clustering pattern. Following Hudson's (1969) theory of rural settlements, which I use as the theoretical framework for this stage, there are two potential mechanisms explaining this pattern. The first is the nature of the geographical area in questions, its endowments, suitability for agriculture and other characteristics. The second is a potential interdependence between settlements, the result of a diffusion and competition effect. 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.

The second stage starts with the set of settlements and contains the selection process underlying the separation into towns and villages. Setting this analysis in a time frame before the industrial revolution towns are defined as settlements for which agriculture is no longer the central income source already. The theoretical framework describes two processes 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 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 is 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 consistence makes the state a good setting to investigate the 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 boundaries do not correspond very well with economic or settlement locations, at least for a number of cases. Historically the identification is much closer, in same 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 (2011) uses the same setting, Saxony in the middle of the 19th century, as a practical example of a new classification scheme. 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 theory underlying the urbanization stage. The empirical analysis of this stage is therefore based on the set of towns taken from Ploeckl (2011).

This historical setting has another beneficial characteristic, namely the existence of a legal town classification. Based on historical institutional developments the Saxon Government formally classified all settlements into towns and villages in the early 19th century. Conducting the empirical analysis with this set of towns reveals 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.

Both town classifications are explained in more detailed with the underlying data in section 3, which follows the explanation of theoretical framework in section 2. Following this framework, which splits the process into different stages, the empirical tests are conducted separately for each of these stages.

Section 4 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 in a multiplicative way, while the influence of other locations is specified in a functional form that allows to make it conditional on distance between sites. This implies that the estimated coefficients show the relative impact size of the various 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 5 investigates the mechanisms underlying the urbanization process. The main hypothesis tested is whether geographic factors and interdependence influence which settlement becomes 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. 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 mechanisms between institutional and population based spatial distributions, results show that the influence of location interdependence is very similar, where there are some differences in the influence of specific geographic factors.

2 Theoretical framework

How can we explain the process underlying the spatial distribution of towns ? The set of urban settlements within a geographical area is interpreted here as the outcome of a two step process, namely settlement and urbanization. Settlement is the process which selects a particular number of sites within the area in question. These sites represent the set of potential town sites. This is then followed by the second step, urbanization, during which actual towns are determined. A number of the potential sites resulting from the settlement step evolve further into towns while the rest remain villages. The major assumption here is the sequential order of events, first the determination of all potential sites and second the their classification into towns and villages. Geographic characteristics and location interdependence have a potential influence on the outcome of both steps. The first step, the settlement phase, will be interpreted the the theory of rural settlement developed by Hudson (1969). The step contains three stages, namely colonization, spread and competition.

Colonization describes the initial settlement process, where the settlers arrive in an uninhabited area and select the initial settlement sites based on the suitability of the location to support the settlement. This implies that the distribution of initial settlements is determined by the area's underlying geographic characteristics. In the spread phase the existing settlements have grown large enough that it becomes beneficial for a number of inhabitants to leave the existing settlements and found new ones. The creation of these off-shot settlements leads to a clustering of locations, including old and new settlements. This phase leads into the third one, labeled the competition phase. The growing villages begin to compete for resources, for example farm land, since no free land remains to be settled after the spread phase. As a result a number of settlements will loose out and become deserted in favor of their neighbouring rivals. This process leads to a more regular spaced pattern of settlement locations.

The predictions of this model postulate a higher density of settlements in favorable geographical areas and allow for clustering or regular spacing of settlements due to location interdependence. These two points resemble the usual formulation about the influence of ecological conditions, usually referred to as first nature geography, and the relationship between locations, the second nature geography, in the literature on the spatial location of economic activity (Krugman, 1993). I test these predictions empirically. The relative importance of physical geography and location interdependence is determined with a spatial point pattern approach, which shows how these factors influence the likelihood of a particular site to be the location of settlement. The revealed nature of the location interdependence effect consequently illustrates whether the clustering effect of the spread phase or the spacing impact of the competition phase is dominant.

The second step, the urbanization phase, has two main mechanisms that turn settlements into towns. The first is production specialization; a settlement has due to specific location characteristics the ability to become the site of non-agricultural production. This production can be either manufacturing, for example mining or textiles, or also service based, for example strategic military points or religious sites (Weber, 1920). In both cases the emergence of non-agricultural income sources for the local population is triggered by a specific location endowment. The other possibility is the emergence of towns as coordination sites for trade. Certain settlements become the site of organized exchange and developed into market towns with the consequence that agriculture loses its relevance as source of income. Again the model allows for clustering as well as regular spacing of towns to emerge. If the emergence of a market town is predominantly due to the trade between the town and villages in the hinterland other settlements in the vicinity are deterred from becoming towns due to the higher costs necessary to divert trade from the existing market place. This biases the pattern of towns towards a more regular pattern. If a town emerges due to coordination of regional and long-distance trade, it can be part of a cluster of towns due to the gains available from more trading activities.

Again, the model allows for the influence of specific geographic factors as well as the relationship between locations to influence the likelihood that a particular settlements becomes a town. While the first step, the emergence of settlements, looks at the whole area in question, the second step, the emergence of towns, only takes existing settlement locations into account. This is based on the development process of settlements, they usually start out as villages before they become towns.[2] This assumption also allows to overcome one of the major problems for the analysis of the development of the urban system, namely the identification of the set of potential town sites. The empirical test of this step applies a discrete choice framework including spatial autocorrelation on the outcome whether a settlement emerges as a town. The inclusion of geographic variables tests the influence of the specialization mechanism, while the incorporated spatial relationship reveals the influence

[2]There are a number of counterexamples, where the settlement is conceived as a town from the beginning, but there are only a small number of these and it is mostly a modern phenomenon.

and nature of the location interdependence mechanism

This theoretical framework addresses the seeds of the urban system, the potential and realized sites of urban settlements. It does not address the emergence of a town hierarchy. There are a considerable literatures on the structure of urban systems, most notably Christaller's 1933 central place theory, and the shape of the population distribution, centered around the empirical regularity of town size noted by Zipf (1949). While this literature is able to provide explanations for the emergence of the observed hierarchy, it usually does not address the mechanisms underlying the actual spatial distribution of towns. One exception is Bosker and Buringh (2010), which focuses on large cities and utilizes a set of potential locations based on historical bishop seats. Though even this is based on a large scale and does neither address the location of all settlements nor the emergence of small urban settlements of local and regional importance.

3 Data

The empirical analysis is set in Saxony, an historically central European state, which is now part of Germany. The actual data point is based on the situation in the year 1834, which is right at the beginning of the industrial revolution in the area (Kiesewetter, 2007; Forberger, 1982). The settlement system was stable for a number of centuries at this point, which allows to use the observed towns and villages as the realization of the above described model of settlement formation. 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 disturbing effects, in particular borders (Redding and Sturm, 2008; Ploeckl, 2010*a*).

The actual data is taken from Ploeckl (2011*b*), 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, 2010*b*; Henderson, 1984). The data, which lists the number of inhabitants for 140 legal towns and 3417 villages[3], is described by Waechter (1901) and Lommatzsch (1905). Each location is referenced with geographic coordinates. 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. These geographical references allow a link between settlements and a number of geographic characteristics of their locations.

Included characteristics[4] 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 value for late 20th century political parishes. These implies that there are about 1600 observations, one of them covers therefore the local condition for approximately two villages. Elevation is measured as meter above sea level at the particular location. The elevation values are also the basis for the measure of ruggedness, which

[3]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 s

[4]Ploeckl (2011*b*) describes the characteristics in more detail and provides sources.

is calculated as the standard deviation of elevation levels in a two kilometer radius around the settlement location. 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. Additionally, some specifications also include information a locations distance to major and minor roads.

3.1 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, nevertheless requires a definition of township. 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 described in DeVries (1984). The other three are the population size, economic diversity, and population density. The use 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 (2011*b*) demonstrates that the applied town definition matters for the results drawn from urban data. In particular it is shown that inference about the location of towns and the relationship to villages is strongly influenced. These results are based on a classification of settlements into towns and villages based on a population threshold that is derived from data rather than ad hoc. This threshold is based on the relevance of agricultural endowments for location size, defining towns as settlements whose income structure is not dependent on local agriculture. Since this definition corresponds to the postulated mechanisms above, I will utilize it in the analysis of the emergence of towns.

3.2 Legal Institution

Although the common definition of towns is based on population we usually associate towns with specific institutional characteristics. The specific 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 to Roman times. In the case of Saxony over time a set of legal towns emerged, their institutional characteristics were finally completely harmonized and fully codified by the early 19th century.(Blaschke, 1967) There is a strong correlation between the sets of legal and population based towns on both ends, i.e. usually very large and very small settlements are consistently classified in the two definitions, but there is a substantial difference around the thresholds. Repeating the analysis with this set of towns illustrates how the diffusion of the two sets differ, so is the rise of town institutions linked to the same geographic and interdependence factors as the emergence of population towns ?

4 Location

Classifying locations into towns and villages relies on the spatial distribution of settlements. The nature and structure of actual locations of villages and towns have been of interest for quite some time. The new economy geography also addresses this issue and looks at factors influencing the relative position of locations. One central idea, increasing returns, uses market access in other locations, which extends the idea of agglomeration beyond just individual settlements and into the relationship between different locations (Fujita, Krugman and Venables, 1999).

The processes of settlement and urbanization are not only spatial but also inherently temporal phenomenons. Focussing on settlement patterns in historically settled areas like Europe however usually lacks sufficient temporal information about the sequence of events. This leads to an approach where an underlying process of settlement and urban creation is postulated and used to derive implications for the resulting spatial pattern. These implications are then tested using cross-sectional data from the observed spatial distribution. The theoretical framework incorporates geographic conditions as a starting point for the distribution of all locations and then consequently see whether physical geography and location interdependence had an influence on the urban system through the rural distribution of settlements and the emergence of urban 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). The observed pattern x will be treated as the realization of a random point process X, where the number of point as well as the point locations in the two-dimensional region W 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.[5] $\lambda(u)$ 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 the equal to the expected number of points falling in a small region of area du around a location u (Baddeley and Turner, 2006).

4.1 Pattern Characteristics

The first step is to demonstrate that the 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 λ, which is usually referred to as *Complete Spatial Randomness (CSR)*. He 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 local endowment characteristics do not matter for the spatial distribution of set-

[5] 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).

tlements, nor is there a systematic interaction or dependency between the settlements. The hypothesis can be tested with a number of tests, for example with a χ^2 based test of quadrant counts or a Kolmogorow-Smirnow test. Although both tests reject CSR,[6] it 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.

4.2 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 in-

[6]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.

tensity function is dropped, while the independence of the settlements from each other is maintained.

Agriculture represents the central source of nutrition, once hunter and gatherers had become sedentary. The necessity of a basic food supply obviously already had an influence on the process of pre-historical settlement and agriculture became the main source of income and employment. This dominant role of the primary sector remained during the middle ages, so it might have played a role in Saxony's main settlement process. Geographic endowments go beyond agricultural conditions. They influence settlements through their impact on security, amenity, energy or 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 used in the previous section. The quality of the local land for farming and pasture purposes might not only influence the size of settlements, but also their spatial distribution. These factors are combined with a number of additional site conditions, in particular elevation above sea levels, the ruggedness of the surrounding land, the proximity to surface water, as well as climatic conditions like rain and temperature. A third set consists of the distance of a location from the Elbe, the only major navigable river, major roads, as well as minor roads.[7]

[7]The data and their sources are described in more detail in the appendix.

This impact of local characteristics is modeled 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 θ, which leads to the following log-likelihood for θ:

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

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 θ, 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 α is a constant and Z is a vector of spatial covariates. The first specification concerning the pattern of all settlement locations will include the 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 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 not only for size also 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 roads during the 1830's. 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 influence by natural and geographic factors, but they are determined by human activity. Since roads usually connect settlements, there is a possible endogeneity issue with including 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.

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 seem to have a quite strong impact, which is likely caused by 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.

4.3 Interdependence

The pattern of all settlement locations in Saxony is not random, as shown above. Although these tests cannot distinguish whether the violation of randomness is due to an underlying inhomogeneous intensity function or interdependence between settlements. In the previous section I demonstrated that agriculture, geography and trade routes influence the spatial distribution. This however does not preclude that there is also an interdependence between locations. The following section starts with the influence of location characteristics and incorporates a mechanism for a possible interaction process between settlements.

This interaction 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 γ. 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 threshold varies from 500 meters to 10 kilometers. 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 with 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 γ 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 might matter in a very close as well as further afar distance, while there is a strong competition effect at around a kilometer 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.

5 Towns and Villages

The final section combines the ideas from both previous sections. It takes up the influence of geography as well as interdependence between locations and focuses them towards the determination of urban status. If local geography and the presence of other settlements matter for the location of all settlements, does this also apply 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 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 as derived 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.

5.1 Legal vs Size

The analysis until now is based on a set of towns defined by population size. The major alternative is to conduct the same analysis based on towns defined by institutional criteria. A comparison of the results for the two definitions 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.

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 the two sets of results 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. 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.

6 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 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 (2011*a*) have shown, market access matters for town size and growth by the start of the industrial revolution, while this study demonstrate that the emergence of urban settlements is predominantly driven 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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7 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	0.18	0.74	1.66	2.95	4.62	6.65	11.82	18.46	41.54	73.85
Locations increased by 50%	0.28	1.11	2.49	4.43	6.92	9.97	17.72	27.70	62.31	110.78
Combined effect of expected locations	1.03	1.00	0.96	1.00	1.18	1.18	1.30	1.30	1.25	1.16
Combined effect of increased locations	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.

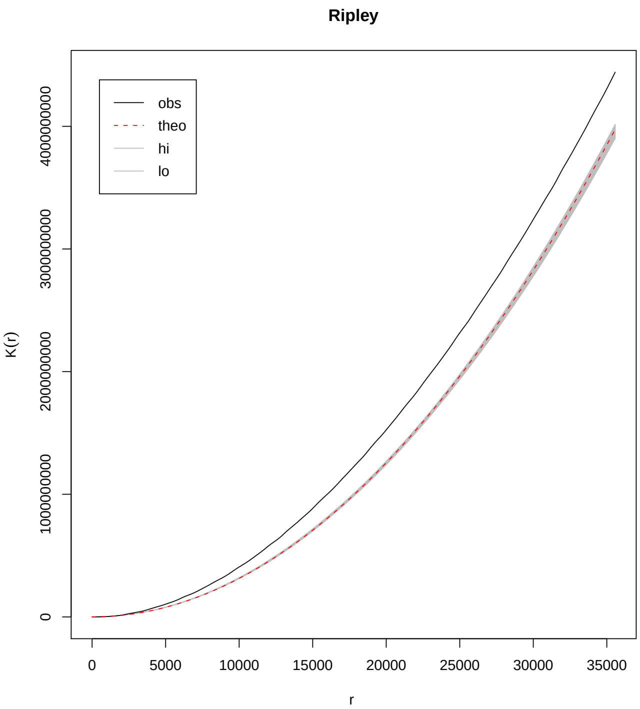
Table 4: Determinants of Urban status

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

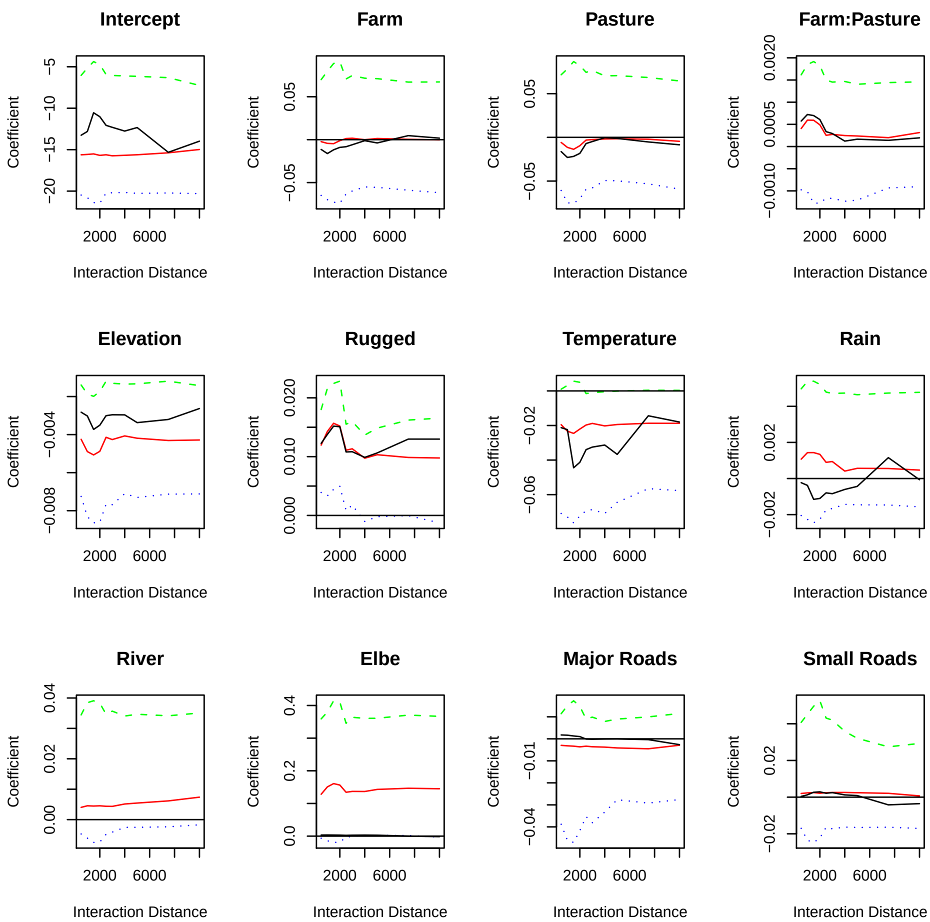
8 Figures

Figure 1: Ripley's K for all locations



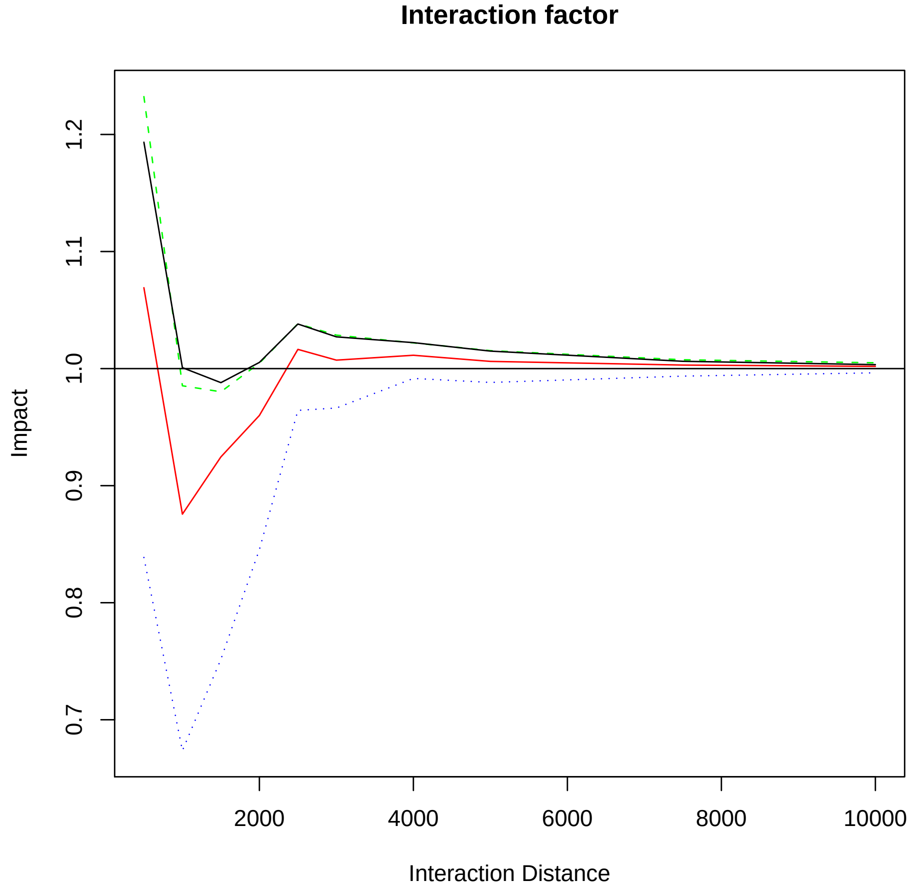
The graph plots the observed Ripley's K measure as well as the theoretical value implied by complete spatial randomness within confidence intervals.

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.