Borders, Market Size and Urban growth, the case of Saxon Towns and the Zollverein in the 19th century

Florian Ploeckl*

Yale University

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Abstract

Changes in trade institutions, like abolishment of tariff barriers, have a potentially strong impact on economic development. The Zollverein, the 1834 customs union between German states, erased borders in much of central Europe. This paper investigates the Zollverein's economic impact through a study of urban population and its growth in the German state of Saxony. A model of the effect of market access on urban growth is combined with an extensive data set on town populations in Saxony and its neighbors as well as an improved distance measure based on GIS techniques, which take into account elevation patterns, roads and rivers. The results show that Zollverein membership led to significantly higher growth for towns close to the border with fellow Zollverein member Thuringia. They also illustrate that natural resources affect town size but not the growth pattern after the Zollverein. Changes in market access had second-order effects through their impact on market access in other towns as well as a stronger direct effect on larger towns. Migration was the predominant source of the differential growth pattern.

*E-mail: florian.ploeckl@yale.edu

Yale University, Department of Economics, 28 Hillhouse Avenue, New Haven, CT 06511

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1 Introduction

The Napoleonic wars engulfed a Germany which consisted of more than three hundred independent territories and set it on a path of unification which culminated in the founding of the German Empire in 1871. However before Germany saw political unification, it also experienced an economic unification, especially the creation of a common market. The institutional centerpiece which swept away most trade barriers between German states was the Zollverein, a customs union founded in 1834.

C.F.Nebenius, a public offcial in Baden and vocal advocate of the Zollverein, saw for regions close to internal German borders the major benefits of this customs union in moral improvement. He envisioned an reduction in the temptation to smuggle, and more peaceful relations with neighboring regions, due to less potential for conflict (Nebenius, 1835). However he doesn't address the differential economic impact, so what about the effects on growth in regions close and far from the borders ?

The Zollverein is one of the first major customs unions in Europe and represents a historical case of peaceful border reduction, where economic unification predates the political development. This customs union fostered economic integration in Germany through the reduction of many transaction costs, harmonizing measures, weights, currencies, and laws and especially through eliminating internal tariff borders. This creation of a unified market led to an increase in the number and size of markets traders could access to sell their goods and to receive goods from. My project analyses the effects of the Zollverein on local and regional development utilizing the differential effects this customs union had on the market access of towns, focusing on one particular state, Saxony.

Urban size is a good indicator for the level of economic activity for the historical time period. Urban growth, serving then as an indicator for economic growth, is used to identify effects on local and regional levels on a finer geographical level than possible with alternative measures like GDP data or trade flows which also require data not available for the time period in question. I also establish that there is a connection between urban size and market access. The later is not only determined by the size of each market, but also by the trade costs between locations. Plain great-circle distance is often used as a proxy for these costs. This approach neglects geographic factors and infrastructure which influence the relationship between two markets. I use Geographic information systems to incorporate location specific information into the calculation of a cost distance measure and show that this improved distance measure is a better proxy for trade costs.

Saxony shares borders mainly with three neighbors, Prussia, Thuringia, and Bohemia, and each of these borders experiences a different change due to Saxony's entry into the Zollverein. This variation allows the identification of specific sets of towns which market access is predominantly affected by a particular trade barrier change. The liberalization with Thuringia had a strong positive effect on the affected towns, the liberalization with Prussia restored the conditions prior to the imposition of that border in 1815 and the increase of barriers in Bohemia had a negative, but insignificant effect on the towns in question.

The paper begins with an outline of the historical context of the liberalization before the theoretical framework, I apply a New Economic Geography model recently developed by Redding and Sturm (2008), for the analysis is explained. After detailing the actual changes through the Zollverein and the implications of the model I describe the data used in the empirical analysis, including the distance measurement calculation. The main empirical analysis is then followed by a series of extensions looking at various additional implications of Saxony's entry into the Zollverein.

2 Historical Context

Saxony existed as a political entity for centuries within the Holy Roman Empire of German nation. It was one of the larger German powers at the time of the Napoleonic wars, located between Prussia and the Austrian province Bohemia (Keller, 2002). Its central location within continental Europe, which had made it to a center of trade, also made it to one of the major battlefields of the Napoleonic wars. Saxony emerged from the wars with substantial territorial losses to Prussia but only minor economic and political institutional changes.

By this time Saxony was a region with one of the highest population densities as well as urbanization rates within Germany (Kiesewetter, 2007); most towns in Saxony had already been established between the 11th and the 16th century (Blaschke, 1967). These medieval roots gave rise to a development of institutional details, which saw settlements gradually acquire certain rights, like court rights or political representation. So over time a set of towns developed which were recognized as such, for example, with regard to excise tax regulations. In 1832 the Saxon government reformed the relevant laws about municipal administration and governance and introduced the *Staedteordnung*, which clearly outlined a uniform set of administrative rules for towns. This also led to a clear political institutional separation between towns and villages and implied a strong stability of the set of towns in the period around the Zollverein (Blaschke, 1967).

At the Congress of Vienna Saxony became a member of the *Deutsche Bund*, a political institution established at the congress by the German states.[1] Although its original charter contained the mandate to work for a customs and economic union, no significant further attempts were made by the *Deutsche Bund* to achieve these goals (Henderson, 1984; Ploeckl, 2008). When some German states began to form customs unions, starting in 1828 with the Bavarian-Wuerttemberg union and the treaty between Prussia and Hesse-Darmstadt, Saxony became one of the main initiators of the *Mitteldeutscher Handelsverein*, a defensive agreement between most of the remaining German states.[2] Although some of the architects of the *Mitteldeutscher Handelsverein* had hoped that it could serve as a vehicle for negotiations with other customs unions about a common union for all of Germany, Prussia refused any such advances. Further developments, like the impending merger of the two existing customs unions, led Saxony to fear Prussian dominance of its trade routes with other nations and possible complete exclusion from German and foreign markets. Negotiations between Prussia and Saxony were opened up and after the merger agreement between the already existing German customs successfully concluded. The Zollverein, now a customs union encompassing a significant number of German states, came officially into being with the start of the year 1834(Henderson, 1984; Ploeckl, 2008).

This institution lifted all internal tariff barriers, instituted a common external customs system and applied a distribution system for tariff revenues based on member states' population. Policies were set by a regular congress of its member states, where each member had veto power due to an unanimity requirement. The Zollverein specified administrative regulations but the actual policing and legal enforcement

[1]This organization had predominantly security related powers through the creation of a military structure to coordinate the armed forces of its members states as well as common policies to quell any domestic political unrest (Angelow, 2003; Mueller, 2006)

[2]Its specific aims were to prevent the further expansion of the other customs unions through a commitment of its members states not to join any of them, not to raise tariffs or impede existing trade roads against each other as well as the coordination of further infrastructure development.

was still the prerogative of each member state individually. The customs union showed considerable institutional persistence, remaining virtually unchanged for over 30 years. Prussia forced changes in the institutional structure in the wake of the Prussian-Austrian war of 1866 [3] and incorporated it into the political structure of the German Empire of 1871 (Hahn, 1984; Henderson, 1984).

This sudden change of trade barriers, the complete liberalization between Saxony, Prussia and Thuringia and the increase of barriers with Bohemia allow the empirical identification of the effects of the Zollverein. The main effect of this customs union for Saxon towns is a change in market access, so I utilize a New Economic geography model, which builds upon this concept, as the the theoretical framework to derive the implications of Saxony's Zollverein entry. Differential changes in trade barriers with Saxony's neigbors provide a source of variation to identify the effects of changes in market access even more clearly. These trade barriers were asymmetrical, a feature which the theoretical framework can incorporate through the specification of asymetric trade costs. The trade cost component of the framework will also be estimated with a cost distance measure, which includes geography and infrastructure through GIS methods. The differences between the results using plain great circle distance and the cost distance measure show how the incorporation of this additional information improves the use of distance as a trade cost proxy.

3 Theoretical Framework

Saxon towns were clearly defined centers of economic activity as well as trade and any framework to investigate the impact of tariff liberalization on population growth needs to take this into account.Helpman (1998) develops a theoretical model incorporating production and trade between two locations to explain mechanisms leading to regional differentiation with regard to the size of each region. Redding and Sturm (2008) take up his framework and extend it to a multi-region setting, which can be interpreted as a system of individual towns, using it to investigate the effects of the German separation after World War II. This paper uses their model as the theoretical framework to investigate Saxony's urban structure and the effects of the Zollverein.

This approach utilizes modeling elements of the New Economic Geography to

[3] Prussia annexed a number of other member states, abolished the congress and its unanimity rules and instituted a customs parliament which was dominated by its Prussian members.

incorporate two opposite forces that shape the distribution of economic activity and population. The first is a combination of factors which lead to agglomeration, especially increasing returns and transportation costs. This is balanced by factors which act as a force for dispersion, modeled primarily through the introduction of an immobile, non-traded resource or amenity existing in each location. The equilibrium outcome is then a population distribution which achieves a balance of these two forces.

The model incorporates Saxony's population as a mass of representative consumers, labeled L, and has each consumer living in a specific location c. There is complete labor mobility between all locations. The set of locations $\{1, \ldots, C\}$ contains all towns in Saxony, a fixed number. As described above, the set of towns is very stable, which justifies keeping the number of locations constant. Each consumer is endowed with a single unit of labor and receives a location specific nominal wage w_c. Labor is supplied inelastically for production within the specific location and is the sole factor of production. The production process results in a range of horizontally differentiated manufacturing goods with the differentiation of these varieties based on the Dixit-Stiglitz form, which implies a constant elasticity of substitution σ between the varieties. The production process for each variety has a fixed cost, F, and a constant marginal cost, both in terms of labor. All varieties are produced under monopolistic competition and are completely tradable between locations. Trading requires a cost for shipping, which is modeled as the standard iceberg trading cost. So $T_{ic} > 1$ units of the goods have to be shipped from location i such that exactly one unit arrives in location c.[4] Besides functioning as the site of production each location is also endowed with a stock of a non-tradable amenity H_c, which level is exogenously given for each location.[5] The amenity is supplied perfectly inelastic for consumption by consumers at the location. The utility function of each consumer has Cobb-Douglas form with an index of manufacturing varieties and the amenity as the two consumption inputs. This leads each consumer to allocate a share μ, with $0 < \mu < 1$ of her income to purchase manufacturing goods and a share of $1 - \mu$ for

[4]Von Thuenen (1826) in the exposition of his model of land use and transportation costs gives an example from the 1826 about the cost of transporting grain to the market which resembles the iceberg analogy fairly well. He calculates the costs as the share of grain consumed by the horses required for pulling the cart loaded with grains.

[5]Helpman gives housing as a motivating example for this modeling choice.

the local amenity. The complete expenditure on the amenity at a given location is redistributed to all consumers at that location. The local price of the amenity, P_c^H, depends on the stock available in the location as well as the total expenditure by all consumers there. The price index for manufacturing goods, P_c^M, at location c depends on the price in each production location which exports to this location, the transport costs from these places to c as well as the number of varieties traded.

The expenditure formulation and love of variety of manufacturing goods by consumers of a specific location make it possible to derive their demand for the products imported from any other location. The demand in location i for the products of location c is a function the total expenditure, which equals total income $w_i L_i$, adjusted by the price level for manufactured goods in location i, P_i^M as well as the transportation costs between the two locations. Formally the size of the market in location i for goods from location c is $(w_i L_i)(P_i^M)^{\sigma-1}(T_{ci})^{(1-\sigma)}$. The demand from all locations for goods from location c, which is the total market size for these goods, is then summarized as firm market access:

$$FMA_c \equiv \sum_i (w_i L_i)(P_i^M)^{\sigma-1}(T_{ci})^{(1-\sigma)}$$

Consumers exhibit a love of variety as modeled in the utility function. The supply of varieties from location i to location c depends on the number of varieties produced in location i, n_i, as well as the production price there and transportation costs between i and c. Since the number of varieties in a location is a function of the local amount of labor, represented by the population L_i, as well as the fixed cost parameter F and the elasticity of substitution σ, it is possible to define this total supply of varieties in location c formally as consumer market access:

$$CMA_c \equiv \sum_i \frac{L_i}{F\sigma}(p_i T_{ic})^{(1-\sigma)}$$

P_c^M, the price index of tradeable goods, is a direct function of this supply, the larger the supply the lower the price paid for manufacturing goods in that location.

As introduced above the model assumes complete labor mobility. Consumers use the price indices for manufacturing goods and the local amenity as well as the nominal wage to compare real wage levels and to select a location based on real wage differentials. Given labor mobility this adjustement process leads to the equalization of real wages at all locations. The outcome of the equalization process determines the equilibrium distribution of consumers over all locations. Formally the equation for the real wage equalization can be rewritten to link the population distribution with the defined market access measures and the stock of the local amenity in the following way:

$$L_c = \chi (FMA_c)^{\frac{\mu}{\sigma(1-\mu)}} (CMA_c)^{\frac{\mu}{(1-\mu)(\sigma-1)}} H_c$$

where χ is a collection of model parameters.

3.1 Testable Implications

The equilibrium equation provides the theoretical link between population size and the idea of agglomeration economies, represented as market access, as well as the importance of location fundamentals, modeled as the local amenity. Taking the log on both sides of the equation results in:

$$\ln L_c = \ln \chi + \frac{\mu}{\sigma(1-\mu)} \ln FMA_c + \frac{\mu}{(1-\mu)(\sigma-1)} \ln CMA_c + \ln H_c$$

The positive scalars on the three elements, which in case of the market access measures are based on the consumption share of non-tradeables and the elasticity of substitution, show that the model implies a positive correlation between urban size and both market access measures as well as local characteristics. This positive link between the factors will be empirically verified, using an empirical representation of market access and a set of geographical location characteristics. These two factors represent two of the three main strands of explanation used in the vast literature on city size (Davis and Weinstein, 2002). The third approach, random growth, focuses on a statistical explanation of the properties of the city size distribution, especially on Zipf's law.[6], as the outcome of a random growth process (Gabaix, 1999). The theoretical framework focuses on the other two but testing these theories is not focus of this paper. Beeson, DeJong, and Troesken (2001) give a short description of the differences between the location fundamentals and the agglomeration approach. The first sees productivity as exogenous, with differences stemming from differences in resource endowments. Unequal population growth is then the adjustment to a steady state. The second sees productivity as endogenous. While initial differences

[6] Zipf's law describes the occurrence of a power law in the distribution of city size such that the size of the s-th largest town is $\frac{1}{s}$times the size of the largest town overall. This relationship implies that a plot of the log of the rank versus the log of the size exhibits slope of -1 .

might be due to natural advantages, further growth is then driven by agglomeration economics including economies of scale. The model fits both explanations, the first sees any changes due to changes in local amenity H, the second assumes H to be fixed and any change is due to market access changes.

The model provides therefore a basis for inference about urban growth processes. The equilibrium equation implies that differential growth between towns can be caused by changes in three different factors. An increase in firm market access implies a higher demand for local products which lead to a higher nominal wage. The rise in nominal wages leads to a rise in the real wage, which attracts labor from other towns. This inmigration leads to a higher price of the non-traded amenity until this price increase equalizes the real wage again and ends the inmigration. Similarly an increase in consumer market access implies a decrease in the price paid for manufacturing varieties and equals therefore a rise in the real wage. The resulting inmigration of labor leads again to a price increase of the non-traded amenity until the real wage is equalized and the population distribution is again in equalibrium. A direct increase of the local non-traded amenity results in a price drop of the amenity and therefore an increase in the real wage. Again an increase in population at this location raises the price of the amenity and leads to the equilibrium real wage equalization.

The impact on the equilibrium population distribution through these three channels, Firm Market access, Consumer Market access and location characteristics, is summarized in the following equation. X is the equilibrium before any change, Y is the resulting equilibrium outcome after the change.

$$\ln(\frac{L_Y}{L_X}) = \frac{\mu}{\sigma(1-\mu)}\ln(\frac{FMA_Y}{FMA_X}) + \frac{\mu}{(1-\mu)(\sigma-1)}\ln(\frac{CMA_Y}{CMA_X}) + \ln(\frac{H_Y}{H_X})$$

So population growth should increase when Firm Market access, Consumer Market access or the location characteristics increase.

The effect on growth is a function of the relative change in market access which has implications for the strength of the effect for small and large towns. Total market access is the sum of individual market access in other locations as well as the town itself. If now two towns have the same market access in other locations then the larger town has a higher total market access due to the larger home market, $FMA_{LargeX} > FMA_{SmallX}$. A change in trade barriers increases market access for both by the same absolute amount, $FMA_{\Delta} = FMA_{LargeY} - FMA_{LargeX} = FMA_{SmallY} - FMA_{SmallX}$, which implies that the relative change is higher for the small town $\frac{FMA_{\Delta}+FMA_{SmallX}}{FMA_{SmallX}} > \frac{FMA_{\Delta}+FMA_{LargeX}}{FMA_{LargeX}}$. Since the relationship between market access growth and population growth is positive this relative higher change in market access implies a stronger relative growth effect for smaller towns.[7]

Another implication of the model is the reinforcement of a shock to market access through the impact on markets in the proximity. If a town experiences a sudden increase in market access abroad, then other towns closeby will also experience the shock and grow faster as a result. This positive growth in proximate towns will then cause additional growth in the first town beyond the immediate effect of the shock. Similar a negative shock will be reinforced

4 Tariff barriers

Changes to market access were the main impact the Zollverein had through altering tariff barriers between Saxony and its neighbor states; its precise impact on Saxon towns is therefore dependent on the tariff systems before the customs union as well as the newly introduced regulations.

Prior to the Zollverein Saxony had no external border tariff system but levied excise taxes. Although there existed such a tax on a few imports its extent and height was very minor (Ulbricht, 2001). The main element of the taxation system was a general excise tax, the so-called *General-Konsumtions-Akzise* [8] (Reuschel, 1930). This tax was levied on almost all commercial transactions; some of its regulations also resembled land or income taxes. Its main focus was trading and production within towns. The excise was levied on any good entering the town with immediate payment required at the town gate and therefore resembled a tariff barrier around each town.

Although the administration of this tax was relatively simple in principle the actual implementation became quite bureaucratic and mired by a large number of details. For example the list of tariffs contained specific regulations for more than

[7] This also holds for Consumer Market access.

[8] It had been instituted during the first decade of the 18th century when it replaced a head tax. The existence of this tax was a success of Prince Friedrich August I over the Saxon estates, since their members, who had far reaching tax exemption privileges under the previous system, were liable to pay this tax, making it fairly universal. Despite this success Saxon rulers never attained far reaching control over the tax system and so this excise tax coexisted with a slew of other related taxes, like taxes on land, meat or milling.

1200 different goods, some taxed based on value and some with a specific tariff. In general the tariff rates were relatively low, only in exceptional cases reaching just a few percent. Besides the good itself the tariffs depended on the origin of the goods as well as the trader. Goods from certain foreign states as well as those traded by certain foreign traders had to pay higher tariffs. But these protectionist rules were very weak and only limited in reach.

The entry into the Zollverein in 1834 forced a complete overhaul of the tax system including the abolishment of the main excise tax. Although there were still a few indirect taxes, especially production and consumption taxes on consumer goods like beer, wine and meat, the system saw a major shift towards direct taxes, a personal and commercial tax on income were introduced in 1834 and a new property tax was established in 1843 (Zei, 1858).

Facing huge war debts after the Napoleonic wars many German states had turned to tariffs. Saxon traders encountered therefore substantial tariff barriers for exports to neighbor states. Prussia, bordering Saxony in the North, had reformed its tariff system in 1818, abolishing over 50 internal tariff lines, establishing an external tariff system and simplifying the tariff structure. Although the initial intentions were tariff rates of about 10%, the actual rates grew considerably higher than that, predominantly due to the tariff being specific and not value based (Ohnishi, 1973). Additionally the Prussian system levied the highest rates on finished goods while there were almost no barriers for raw materials, a feature which was later retained in the Zollverein tariff structure (Dumke, 1994). At the same time Bavaria, Saxony's neighbor in the Southwest, introduced an external tariff system with relative high tariff rates (Alber, 1919). Saxony's neighbor to the South, the Austrian province of Bohemia, had a prohibitive tariff system, constraining trade between the two states significantly (Kiesewetter, 2007). However the geography of this border, the mountain range of the *Erzgebirge*, posed problems for border enforcement, especially since Saxony itself did not even have a border system. Prior to Saxony's entry into the Zollverein there was considerable smuggling activity along the border. The introduction of the Zollverein regulations led to a severe crackdown on the contraband trade (Kiesewetter, 2007). The Thuringian principalities, which are referred to in their entirety as Thuringia, had neither the size nor administrative capacity to run external tariff systems (Dumke, 1994). Their main tariff revenues were transit tolls on the main east-west trade routes connecting the major trade fairs of Leipzig and Frankfurt. Tolls, multiple routes and bad road conditions however kept these revenues down.

The Zollverein of 1834 created a common external tariff, abolished internal tariffs and lowered transaction costs through measurement and currency harmonization. The tariff rates and some of the administrative regulations were based predominantly on Prussian tariff rules. This led to moderate to high tariffs, especially on finished as well as consumption goods, and to the introduction of considerably more rigorous controls on most borders.

In the case of Saxony the Zollverein regulations completely dropped barriers with Prussia, Bavaria and the Thuringian principalities, while it raised barriers for traders from Bohemia, affecting the supply relationships of Saxon towns(Dumke, 1994; Henderson, 1984).

5 Data and Estimation

Before outlining the specifications of the empirical tests of the Zollverein effects I detail data and variables used for the three main factors, urban size and growth, market access measures and location characteristics. The discussion of the calculations leading to the GIS-based distance measure is also included.

The size and growth of cities and towns, next to population density and the extent of urbanization, have been linked to economic development Bairoch (1988); Acemoglu, Johnson, and Robinson (2002). This connection allows their use as outcome variables to investigate economic growth patterns and to test explanatory factors for differential growth (Acemoglu, Johnson, and Robinson, 2005; De Long and Shleifer, 1993). Advantages of this approach are in the case of the Zollverein and Saxon towns the possibility to focus on regional development on a very disaggregated level, the availability of sufficient data as well as the avoidance of arbitrary borders. Saxon towns at the onset of the industrial revolution had still quite clear boundaries, in some cases literally physical walls. Their population based on administrative boundaries represents the size of the local economies therefore quite well [9] Blaschke (1967). These boundaries see almost no change during the time period in

[9]This feature of Saxon towns solves the problem to delineate appropriate urban areas, since especially in the 20th century administrative boundaries no longer coincide with meaningful economic units (Blaschke, 1967; Hohenberg and Lees, 1985).

question, the extent of incorporation of villages into towns is negligible before the late 19th century and the data has been corrected for any changes (Waechter, 1901). Most papers apply a size-based approach to identify towns, either based on absolute or on relative size (Bairoch, 1988). I use a legal definition and include all settlements which had the legal status as a town according to the law of 1832. This creates an institutionally homogeneous set, which is very stable and contains 140 towns.[10] This institutional homogeneity avoids problems due to the economic effects of different legal environments between towns and other settlements.

The population data set contains the years 1815,1830,1834, every third year following till 1867 and concludes with 1871. There is a systematic difference between the first two years, 1815 and 1830, and the rest of the data due to the method underlying the data creation. The first two counts are based on tax rolls; while the others are results of population censuses held every three years.[11] The actual numbers show a significant discrepancy between the 1830 and 1834 numbers, with 1830 exhibiting a considerable undercounting. I use the 1815/1830 numbers only to calculate the growth rate for this period, but not in combination with any other year. The population data is primarily taken from an overview article in the 1901 issue of the *Zeitschrift des K.Saechsischen Statistischen Buereaus*, a periodical of the Saxon Statistical office, as well as from other publications by the Statistical office.[12]

Since the set of Saxon towns is defined by legal characteristics the size of some of these places is smaller than what is commonly seen as an urban area. For example the smallest town in 1834 has less than 500 inhabitants and the median is just over 2000.[13] Figure 1 shows log(Size) plotted against log(Rank), which is usually used to illustrate Zipf's Law. At the lower end of the tail it is clearly visible that the set contains a number of settlements, which are significantly smaller than what would

[10] In 1848 Saxony receives a town, Schirgiswalde, through a land swap with Austria and in the second half of the 19the century two more villages are granted town rights. At the moment I do not include them as towns in the analysis but their population is used in calculating the size of rural markets

[11] These censuses were required for the revenue distribution scheme of the Zollverein (Waechter, 1901)

[12] One complicating factor is the presence of military personnel, which obviously does not necessarily follow economic incentives based on local wage levels in their location decision. I, therefore, exclude such personnel from the population counts, but do use information about the relative size of their presence as an independent variable.

[13] More detailed summary statistics are given in table 1

be expected under this regularity (Gabaix and Ioannides, 2004); there did exist a number of villages which had attained a size considerable larger than smaller towns (Blaschke, 1967).

Saxony had for most of the 19th century the highest population density of German states [14], in 1830 the number was 93.5 inhabitants per km^2 (Kiesewetter, 2007). This high density is also connected to a high degree of urbanization. Using the legal definition of a town the urbanization rate in Saxony in 1834 was 32.8%, though the urban distribution was dominated by small towns.[15] This degree of urbanization shows that towns were the main centers of economic activity within Saxony.

The model characterizes towns through the specification of an exogenously given, non-traded amenity H_c. Since there is no single one characteristic which explains urban size I interpret this variable as a combination of location characteristics, which influence the location decision of population. I broadly categorize these characteristics in two classes, one being natural endowments and the other being institutional factors.

The first category contains variables which indicate natural characteristics of a town location. These are geographic factors such as the elevation of the town [16], the ruggedness of the surrounding area, which is measured as the standard deviation of the elevation within a 2km radius around the town, access to flowing water, as measured by having a river within a kilometer of the town, and specifically whether the town is located on the Elbe, the only major navigable river in Saxony; all of these are based on contemporary data from modern Geographic Information systems. Another set are natural and climatic factors like rain, temperature and the quality of the soil for pasture and farming; all of which come from extensive geological and climatic surveys conducted during the middle of 20th century.[17] This is complemented by natural resource variables, specifically the distance to the nearest coal mines and the share of public mining authority employees in the town population, which is related to the extent of other mining activity around the town. Together with information

[14]This excludes any of the free cities, which by their nature as city-states had obviously a much higher population density

[15]Using settlement size of 2000 inhabitants results in 32.66% and a limit of 5000 people gives 16.93%. The difference between the two rates show the dominance of small towns.

[16]Elevation is measured in meters above sea level.

[17]The surveys classify each location on a scale between 0 and 100 with higher values indicating better suitability for agricultural purposes.

on military personal these are the location characteristics used in the estimation of town size since they are clearly not endogenous in that regard.

Besides these quite unchanging location characteristics I also include a set of variables representing institutional factors, which are for the most part related to but not necessarily causally given by the specific geographic location. These factors include information about transportation, for example whether the town had a post office and later on a railroad station. Another set relates to the idea of human capital, measured by the presence of regular publishing of a newspaper or magazine, the number of children per school as well as per teacher in each town, and the presence of other higher education institutions.[18] This is complemented by information on whether trade fairs for general goods, textiles or animals were held in each town as well as the stock of housing.[19] These characteristics are used together with the first set as the representation of the local amenity in specifications investigating growth patterns. A more detailed description of each characteristic, as well as the sources and variable specifications are given in the appendix.

The third factor required to derive empirical specifications for the model implications is market access. In the context of this paper urban and rural markets in Saxony as well as urban markets abroad are used as the relevant markets, their size being determined by the respective population.

- *Urban Market in Saxony* This set contains all towns within Saxony, which have in 1834 officially 523563 inhabitants. The model includes the town itself as part of its market access, which leads to the differential impact of market access changes based on town size.

- *Foreign urban markets* Although the legal regulations differ towns are centers of economic activity in Saxony's neighbor states as well and represent therefore the relevant foreign markets for Saxon towns. Due to data limitations the set consists of towns within a 100km radius around Saxony. The total market abroad can also be split into individual parts according to country, which results in variables indicating markets in Prussia, Thuringia, Bavaria and Bohemia

[18]This could be a university, a seminary or a teacher college

[19]The plain number of houses in each town, which were counted simultaneously with population in 1834 and reported in the same sources, is explained by a polynomial of town size, the resulting residual is then used as an independent variable

respectively.

- *Rural Markets in Saxony* Each town has a "hinterland", a set of villages which are in a close economic relationship with a specific town (Blaschke 1967). To determine the size of this market, I assign each village in Saxony to its nearest town neighbor.[20] The rural market size for each town is then the sum of the population of all villages for which this town is the nearest town neighbor.[21]

Some of the empirical specifications will make use of an empirical market potential variable, which is conceptually close to the Firm and Consumer market access variables. Hanson (2005)among others uses in his work on the impact of NAFTA market potential as the empirical proxy for market access following the approach pioneered by Harris (1954), who calculated this measure as the distance weighted sum of all accessible markets, $MPot_c = \sum_i \frac{M_i}{d_{ci}}$, where M_i signifies a measure of the size of the market [22] and d_{ci} is the distance to this market.[23]

My approach to distance measurement is related to the use of either road distance, travel time or transportation cost (Brakman, Garretsen, and Schramm, 2004; Harris, 1954), Harris 1954), measures which implicitly include some cost factors.[24] There are no comprehensive historical travel time or transportation cost measures for Sax-

[20]Depending on the empirical specification this assignment is based on either plain distance or my cost measure.

[21]This sum is not weighted by distance since the nature of the economic relationship between town and countryside outweighs the importance of the relatively short distances between towns and the surrounding villages.

[22]There are various market size measures used in the literature, Harris took retail sales, Hanson uses income as measured by GDP,De Vries (1984) uses population in his investigation of European urbanization

[23]Another problem for distance measurement is the issue of specifying respective end points for distance measurement especially if the underlying units of observation, for example regions or countries, cover extended areas(Head and Mayer, 2002). Historical towns covered a relatively limited area, so the intra-town transport costs paled in contrast to inter-town costs(Barker, Gerhold, and Society., 1995), which makes the issue moot in this context.

[24]Bosker and Garretsen (2007) survey varying functional specifications to include cost factors and show that trade costs are either modeled as direct function of the measured distance, or as two step estimation, which uses other trade data, especially trade flows, to back out cost factors, like border effects or being landlocked, and combines those with distance measurements. Given the absence of trade flow data I follow a direct approach specifying the trade cost function as a power function of distance.

ony and its neighboring regions and historical transportation technology depended strongly on geographical factors.

I calculate a cost measure using GIS methods to incorporate various cost modifiers to account for this dependence. The main elements included are transportation infrastructure, predominantly roads and river shipping, as well as elevation, which increases distance traveled and causes higher transportation costs through the obstacles associated with slopes. The calculation, which is described in more detail in the appendix, separates the surface into a fine raster and derives for each cell a cost value for the travel over this particular cell. The optimization process finds the least costly path between two grid locations, where the cost of crossing raster cells between the two locations is associated with the respective cost value and elevation level of each cell. The parameters for these costs are explained in the appendix as well. The outcome value is a relative distance measure where the benchmark is travel on flat highest quality roads. So a distance cost value of 50km between town A and B implies that traveling from A to B is as expensive as traveling 50km on a completely flat and straight road of the highest contemporary quality.

In most cases the cost value is higher than the plain distance value between two points and it is asymmetric due to cost asymmetries associated with differences in the elevation and slope of the two travel directions between the two points. The magnitude of this effect of geography is relatively small, since it depends on the existence of significant elevation differences between the two towns. A possible significant source for these differences in the case of Saxony and its neighbors is the *Erzgebirge*, the range of mountains in the south of Saxony, along the border with Bohemia. However the relatively low height of these mountains and the small number of affected towns make these differences relatively small. A major source of asymmetry, which is however not directly included in the calculation, are differential trade barriers between two towns. The differences in trading regimes between Saxony and its neighbors, as described above, are such barriers. They affect obviously only trade with foreign states but not domestic markets.

The asymmetry of the distance measure, $d_{ic} \neq d_{ci}$, implies asymmetric transportation costs in the model, since these are uniquely determined by the distance and travel direction. Absent trade barriers between the two locations the extent of asymmetry is however such that the two trade costs between the locations are highly correlated.[25]

The effectiveness of this new distance measure is investigated by comparing it to the regular plain distance. This is done by estimating empirical specifications which use a distance measure with my measure as well as the plain distance.[26]

5.1 Empirical specifications

The main empirical question asks what impact the Zollverein had on urban population growth patterns through its effect on towns' market access. Saxony's entry into the Zollverein had multiple effects, it caused an increase in firm market access through removing trade barriers for Saxon exporters to the neighboring states of Prussia, Bavaria and the Thuringian principalities. It reduced consumer market access by introducing stronger barriers against imports from Bohemia. This implies that towns more directly affected by the liberalization of borders with fellow Zollverein members should see stronger growth, while towns more affected by the imposition of barriers against Bohemia should see the opposite.

The theoretical model assumes each town to be affected through these changes to a different extent. The main empirical specification however models the effect of the Zollverein as a discrete effect, a town is either affected or it is not. The choice of this discreet approach is due to data limitations. Specifying a continuous effect requires a consistent and precise estimation of the change in market access due to the Zollverein. The calculation of such a change would require assumptions about the exact height of trade barriers between Saxony and its neighbors. Although the tariff policy of Saxony's neighbors is detailed above the data available are not sufficient to make a more precise quantitative estimation of the trade barriers. The effect of the Zollverein is therefore estimated predominantly in this discrete way, selecting towns based on a criterium correlated with the extent of the change. The treatment group is chosen based on geographical proximity to a specific border, in particular Saxony's border with other states joining the Zollverein. This assumes

[25] This implies that some empirical specifications utilizing distance, especially those using market potential, will be specified with only one market access measure and not separate firm and customer access measures.

[26] Distance measures are used in the calculation of market potential, the treatment thresholds in the difference-in-difference specification described below, the distance to coal mines variables and in the weighting matrices in the spatial econometrics extension.

that proximity to a border is correlated with a larger increase in market access when that particular border is opened up.[27] This selection mechanism allows not only to investigate the impact of the whole Zollverein, but also the effect of changes in the barriers between Saxony and individual neighbor states by specifying proximity to different border parts as separate treatments. The assumption about a correlation between the size of change and distance to border implies that the size of the effect should monotonically decrease with a higher distance selection threshold. This will be tested by repeating the estimation for varying distances to border.[28]

Sturm and Redding establish the correlation between the size of the change and distance to border through a simulation exercise, which requires more data than available for the case of the Zollverein. They are then investigating the actual effect in a discreet way estimating a difference in difference specification with a distance to border threshold derived from their simulation. My main specification will differ in two ways, first I investigate multiple border parts, specifically the borders with Prussia, Thuringia and Bohemia, through the inclusion of separate treatment categories and second I select the distance thresholds based on a grid search.[29] This leads to the following formal specification:

$$Growth_{ct} = \sum_{l} \beta_l Treatment_{lc} + \sum_{l} \gamma_l (Treatment_{lc} * Zollverein_t) + \delta_t + \mu_r + \epsilon_{ct}$$

where the subscript c denotes a town, subscript t denotes a time period, *Treatment* is a dummy which indicates whether town c is assumed to be treated through the Zollverein, and *Zollverein* indicates whether Saxony was a member of the Zollverein during period t. Subscript l indicates a specific border segment, either Prussia,

[27] Table 2 shows the average market potential in the respective markets conditional on the difference-in-difference treatment groups. The numbers show that distance to border is correlated with the market potential in the specific market.

[28] This will be done using a single treatment with the distance to border liberalized by the Zollverein as selection threshold

[29] For this search I use threshold values between 5km and 35km for the plain distance to border and between 10km and 70km for the cost measure, which will be introduced in the data section. The doubling of the values for the cost measure is due the relation between the average distances of both measures, which is somewhat over 2. The upper bound is slightly below half of the threshold value Sturm and Redding finds for the effect of the German separation. This reduction is justified by the improvements of transportation technology between the Zollverein and the German separation a century later as demonstrated byShiue (2005) who found the border effect of the Zollverein magnitudes smaller than contemporary effects. The selection criterion is the adjusted R^2

Thuringia or Bohemia. δ_t are time dummies, μ_r denotes regional dummies and $\epsilon_c t$ are stochastic errors. γ_l, the coefficients on the interaction of the treatments and membership in the Zollverein, are the main coefficients of interest since they measures the effect of the Zollverein. The initial investigation uses two time periods, 1815-1830 before the Zollverein and 1834-1849 after the entry. A direct follow-up is an investigation of the adjustment path over time, which uses the base specification but includes multiple treatment periods to follow the development of the effect over time.

This base specification focuses on growth solely due to a change in market access. The model however implies that differential population growth can also be the outcome of changes in the local amenity. To test whether this is the case for Saxony's entry into the Zollverein I include the full set of location fundamentals as controls into the main specification. These are also interacted with an indicator for Saxony's entry into the Zollverein to investigate whether the impact of a certain location characteristic changes between the periods.

As described above, town size has specific implications for the effect of market access changes. First I verify the link between town size, market access and location characteristics and investigate then the relationship between growth, size and market access. The equilibrium of the model is determined by a system of equations with seven unknowns [30], so using the population distribution given by the actual town sizes in a particular year allows the derivation of all equilibrium values. This also includes the implied location amenity values $\hat{H}_c$. A comparison between the amenity values and the actual town sizes shows whether market access has any influence on the actual distribution. The derived amenity values also allow to demonstrate the impact of geographic location characteristics. Estimating

$$\hat{H}_c = \alpha + \sum_j \gamma_j H_{cj} + \varepsilon_c$$

with each H_{cj} being one element of a set of selected location characteristics, establishes whether geographic factors play a relevant role in determining town size. Since most of the institutional characteristics are endogenous with regard to size I only include the natural endowment variables into this estimation.

[30] Population, number of varieties produced, sales price, real wage, amenity price level, manufacturing price level, Total expenditure

The first specification regarding the connection between size, growth and market access is as follows

$$\ln L_c = \alpha + \beta \ln \sum_k Market_{ck} + \sum_j \gamma_j H_{cj} + \varepsilon_c$$

where $Market_{ck}$ is the market potential of Saxon town c within the different markets k, and is estimated with quantile regression estimation to investigate the importance of market access along the conditional town size distribution. Additionally the above described baseline difference-in-difference specification is estimated with quantile regressions, which allow inference about the importance of market access along the conditional growth distribution. The final specification to investigate the link between growth, size and market access is an estimation of the difference-in-difference specification with subsamples selected based on town size.

A spatial econometrics regression with an error autocorrelation specification is used to investigate more deeply the nature of the spatial interaction between the towns beyond aggregate market access (Anselin, 1988). First I look at the influence of agglomeration on size of towns by using the following Spatial rror autocorrelation specification which is estimated using Maximum Likelihood.

$$\ln L_c = \alpha + \beta \ln \sum_k Market_{ck} + \sum_j \gamma_j H_{cj} + \lambda W \varepsilon + \varepsilon_c$$

where λ is the coefficient on the spatial term and W a spatial weight matrix.

Moving from size to growth, the analysis allows investigating the second-order effect of the changes in market access through the Zollverein. When towns grow faster due to an exogenous increase in market access the model predicts that this additional growth has also a positive effect on growth in related locations. To investigate this I specify a Spatial Lag specification, again estimated with Maximum Likelihood,

$$Growth_c = \rho W Growth + \sum_k \beta_k \ln(Market_{ck}) + \sum_j \gamma_j H_{cj} + \varepsilon_c$$

where $Growth_c$ is the annualized growth rate, H_j is an element of the set of geographic and institutional variables and W is again a spatial weight matrix. This is done for three periods, one before the Zollverein, two afterwards, to see whether these second order effects are visible besides the first order effect of the border liberalizations.

The analysis concludes with an investigation of the adjust mechanisms, an issue which is not addressed in the theoretical model. For the time period 1834 - 1852 data about the sources of population growth, migration or natural increase, is available. These numbers are then used in a Seemingly Unrelated Regression approach to determine which channel changes in market access by the Zollverein worked through to cause differential growth patterns. The formal specification is

$$Growth_{ac} = \alpha_a + \sum_k \beta_{ak} Market_{akc} + \sum_i \gamma_i H_{aic} + \varepsilon_{ac}$$

where $Growth_{ac}$ is the annualized growth rate of town c in the period 1834 to 1852 due to mechanism a, which is either migration or demographic change. $Market_k$ is the market potential in the relevant state and H_i are location characteristics. This set of location characteristics contains an additional set of demographic variables besides the geographic and institutional variables detailed above. The additions are the birth and death rate in the town in 1834, the share of youth in the total population, the share of widowed persons as well as the gender ratio. The coefficients on these variables are restricted to be zero for the equation estimating the growth due to migration.

6 Empirical Results

6.1 Urban Growth

The main specification investigates three separate effects of the Zollverein, identified by differential changes to the trade barriers with Saxony's three main neighbor states. As described above I use a grid search over possible distance to border values to determine the necessary thresholds for both distance measures. The resulting distances [31] exhibit a further reach for the effect connected with the Prussian borders, which is approximately two day trips deep. The corresponding values for the effect of the Thuringian and Bohemian border correspond to about one day travel into Saxony. [32] Using these border thresholds I estimate the base specification, outlined above, with treatment groups based on either my cost measure or plain distance. Columns 1 and 3 in table 3 show the resulting regression results. Columns 2 and 4 show the

[31] Plain Measure: Prussia 26km,Thuringia 10km, Bohemia 17km; Cost Measure: Prussia 62km, Thuringia 29km, Bohemia 31km

[32] Map 2 and 3 show the actual geographical location of the thresholds.

results when I estimate the specification with the same thresholds but correct for the influence of location characteristics.

The estimation results exhibit distinct effects for the three different borders. For the case of towns affected by the liberalization with Prussia, the following general pattern emerges from all four results. During the period 1815 to 1830 there is a considerable higher growth of towns close the Prussian border than for towns in the control group, the effect is basically identical for both base specifications with an annual growth rate that is 0.5% higher. Introducing location characteristics leads to a strengthening of the effect to 0.9% for the cost measure, while for the plain measure the magnitude stays the same but turns statistically insignificant. The results for the period after Saxony's entry into the Zollverein however indicate that the growth of towns close to this border is not different from growth of towns in central Saxony in any significant way. At first glance, these numbers are completely opposed to the model predictions, which imply a higher growth after the Zollverein but not before. This discrepancy might be due to the issue that this border was actually imposed in 1815, when Prussia annexed considerable parts of northern Saxony. In a later section I will investigate the impact of this separation and reconcile the observed results with the theoretical implications of the Zollverein.

The growth of towns close to the Thuringian border exhibits a pattern in accordance with the model predictions. The reduction of tolls and tariffs, some of them newly imposed in the aftermath of the Napoleonic wars, led to an increase in market access for Saxon towns close to that border. Before the Zollverein these actually do grow slightly slower, though statistically insignificant so, than control towns. The trade liberalization through the entry of Saxony and the Thuringian principalities causes a significant and strong increase in the growth rate for locations close to the border. The size of the effect, approximately 0.72% higher annual growth for the baseline specifications under both distance measures, is robust for the inclusion of location characteristics, it even increases slightly for the cost measure.

The third investigated border ran between Saxony and its southern neighbor Bohemia, which as part of the Austrian Empire did not join the Zollverein. Saxony's adoption of the Zollverein external tariff system, a considerable change from its prior free trade policy, led to an increase in trade barriers between the two states. Such an increase in barriers implies a reduction in market access, in the above described theoretical framework in particular a decrease in customer market access. The empirical results seem to correspond with that prediction. Both baseline specifications show no significant different growth before the Zollverein, a small decrease in the growth rate afterwards, even turning statistically significant negative for the cost measure. Introducing the location characteristics however changes the results considerably. The regression using cost measure indicates that location characteristics can explain the negative growth after the Zollverein, showing that the effect shown in the baseline specification is not primarily due to a change in market access. A more detailed discussion about this is given in the context of the extension that looks at the adjustment path of the effects. The results for the introduction of location characteristics into the regression using the plain distance measure however appear non-sensical, especially for the period before the Zollverein. There is no indication why these towns should grow so significantly faster and why this effect does not appear in any of the other regressions.

In summary the Zollverein and its impact on the market access of Saxon towns led to stronger growth close to the neighboring region of Thuringia, as implied by the model. The effects of the new markets in Prussia, a return from higher growth to an insignificant difference, seem contradictory to the model prediction. The raise of barriers against Bohemia had the expected negative effect, though insignificantly so. In general the Zollverein and its changes in market access lead to a significant change in the regional growth pattern of urban population within Saxony.[33]

[33] Robustness checks include the assumption of a discreet change in the specification and the assumption that the effect is correlated with distance to border. I apply a difference in difference estimation of the effect of the Zollverein as a whole and the results for the repeated estimations with varying distance thresholds are illustrated in figure 2. The effect shows a considerable increase of the growth rate close to the border; using the plain measure the annual growth rate is around 0.3-0.4 percent higher within 20km from the border, using the cost measure the effect is even stronger with up to 0.7 percent. Especially the results for the estimation using cost measure thresholds show a decreasing effect with further distance from the border, which corresponds well with the implications of the assumption that the change in market access is correlated with distance from the border. The next checks concern the robustness of the results with regard to the estimation method. I conduct a median regression of the main specification as well as a fixed effects specification, the obtained results are consistent with the regular OLS estimation.

6.2 Extensions

6.2.1 Adjustment Path

As mentioned above, this extension investigates the adjustment paths of the effects after the entry into the Zollverein. This is achieved by including multiple treatment periods in to the baseline specification. The reduction of the length of the treatment periods to nine years [34] allows the incorporation of four periods until 1871, while still keeping the periods long enough to adjust for the impact of short-term fluctuations.[35] The results are represented graphically in figure 3 to illustrate the development over time more clearly. The numbers follow the results of the baseline specification detailed above very well.

The positive effect close to the Prussian border is again visible for the time period before the Zollverein. The treatment coefficients for the Zollverein entry illustrate that there was no significant difference for town growth between towns in the vicinity of the border and the control group. The development of this coefficient demonstrates that the trade liberalization with Prussia returned the situation to prior 1815, which will be discussed more extensively in the next extension.

Towns close to the Thuringian border exhibit again no significant different growth before the Zollverein and a strong positive effect afterwards. The development over time indicates that the effect grew stronger over time before dropping back considerably during the 1860's. The magnitude of the additional growth after the increase in market access begins with 0.6% in the first decade and then raises to about 0.9% over the next two periods. During the 1860's the effect drops considerably to around 0.4% and becomes statistically insignificant. The model does not make any predictions about the adjustment process, only specifies a new equilibrium as the outcome of the process. One possible explanation for the observed path of the adjustment path, a strengthening over time until a sudden drop, can be the nature of the adjustment mechanisms, migration and natural increase. Another possible reason is the Prussian-Austrian war of 1866, which saw some of the Thuringian principalities on the side of Prussia, while Saxony allied itself with Austria.

The above discussion about the effect of the Bohemian border shows that the inclusion of location characteristics led to a disappearance of a significant effect. The

[34] The last period, 1861-1871 contains ten years

[35] The period before the Zollverein remains at 15 years due to data limitations.

adjustment path sheds further light on this issue. While the treatment coefficients are generally negative, the effect in the cost measure specification for the 1843-1852 period is considerably stronger and statistically significant. Saxony, and Germany as a whole, experienced a series of bad harvests during these years. The location characteristics introduced into the baseline specification contain controls, especially of geographic nature, that take out the differential effect of these harvest failures due to underlying structural differences. The border between Saxony and Bohemia runs along the *Erzgebirge*, a mountainous range with less favorable agricultural conditions. Towns in the vicinity are therefore harder hit by widespread harvest failures due a strong dependency on grain imports. The timing of these failures corresponds well with the shape of the adjustment path, which implies that this effect is not primarily due to the changes in market access by the Zollverein.

6.3 Prussian Migration

All previous results indicate that there was a significantly higher population growth close to the Prussian border prior to the Zollverein and no significant negative growth afterwards. This result is contrary to the expectations which imply a positive growth due to market liberalization by the Zollverein.

The empirical results are likely due to the impact of the changes caused by the Congress of Vienna in 1815. Although Saxony was one of the latecomers as an ally for France, it stayed longer on its side than most other German states. As a result Prussia was given the right to annex substantial parts of Northern Saxony, leading to the imposition of a rather arbitrarily drawn new border between Prussia and Saxony (Kohlschmidt, 1930; Keller, 2002). The official annexation agreement contained also a provision which let people migrate freely from the newly annexed Prussian territories into the remaining Saxon state. There are no records available for the actual size of this migration but Kiesewetter (2007) calculates estimates for the total net migration between Saxony and abroad in three years intervals for the time period between 1815 and 1830.

I investigate whether a conjectured magnitude of the migration from Prussia to Saxony based on these numbers can explain the observed effect. These conjectures are used to derive a counterfactual population distribution for the year 1830. The main assumptions are that all migrants move from a Prussian town which was formerly

Saxon into a town on the Saxon side of this border; I use towns in the Prussian border treatment group as destination towns. The magnitude of a particular flow between two towns is estimated by $(\frac{L_p L_s}{d_{ps}^2} / \sum_{ps \in PxS} \frac{L_p L_s}{d_{ps}^2}) * Migrants$, where p and s index the sets of origin towns within Prussia and destination towns within Saxony, L is the respective town size, d is the distance between the two towns and $Migrants$ is the total number of migrants. Summing up all flows into one particular town allows to calculate its counterfactual population in 1830 and the implied growth rate between 1815 and 1830.

Estimating the main difference in difference specification with the counterfactual growth rate results in a counterfactual treatment coefficient for the Prussian border. I use the specification with my cost measure and included location characteristics and estimate it repeatedly, varying the distance threshold for the selection of the treatment group affected by the Prussian border.[36] Figure 4 shows the resulting treatment coefficients for the Prussian border before the Zollverein for distance thresholds ranging from 20km to 70km.

The three panels show the effects of different assumed migration flows from Prussia, starting with thousand, then eleven thousand and finishing with twenty thousand people moving. There are two main results visible from the results, one is that under fairly strong assumptions about the size of the migration flow connected with the border imposition of 1815 the seemingly positive treatment effect can be reduced to insignificance and even a negative effect. This brings the results much more in line with model predictions, which imply that the imposition of the border and its impact on market access should lead to a slower growth of stronger affected towns. The counterfactual results show another interesting aspect of the treatment effect itself and the impact of the counterfactual migration flows, namely their spatial dimension. The original structure of the effect was strongly positive very close to the border, than a range of distances for which the effect was weaker and even negative, followed by a range which reverses the direction of the effect again and results in the found positive effect of the border imposition. When the counterfactual results take out the positive effect very close to the border, the results indicate that the effect on growth was not in the aggregate, between towns in the treatment and control group, but a shift within the treatment group. The reduction in market access shifted ac-

[36] I keep the thresholds connected with the other two borders fixed.

tivity from towns very close to the new Prussian border towards towns closer to the markets in the remaining Saxon territories.

6.4 Size effects

As detailed in the discussion of the theoretical framework the size of a town matters for the magnitude of the effect of changes in market access. Before I test this implication I verify the postulated link between size, market access and location characteristics empirically.

The population distribution in any given year together with the distance values allow the calculation of the implied value for the location amenity. The results of a comparison between these implied values and town size will be between two extremes, complete equality between population and amenity values, which implies that market access has no influence, and no correlation at all, which implies that the complete shape of the population distribution is driven by market access. I use the population distribution of 1834 and estimate multiple configurations, based on both distance measures as well as different markets.[37] The R^2 of regressing the population on the derived amenity values are 0.8 (Saxon towns) and 0.84 (all towns) for the cost measure as well as 0.85 (Saxon towns) and 0.92 (all towns) for the plain distance. These results demonstrate that market access influences the town size distribution and imply therefore that changes in market access can have a substantial differential impact on the growth of towns. A further revealing connection is the correlation between the location value and the size of the related rural population, 0.44 for values based on the plain measure and 0.56 based on my distance measure. These numbers imply that there is a strong positive linkage between urban and rural markets, however further research is necessary about the direction of the linkage. The next step is to verify that actual town characteristics explain the implied location amenity value. Table 4 shows the result of regressing the implied location amenity values on the set of geographic location characteristics.[38] Especially ruggedness as well as the distances to coal mines have a significant effect. Introducing additionally variables indicating the strength of military and public mining presence shows that

[37]The two market configurations are only Saxon towns, 140 observations, and inclusive of all neighbor towns, 479 observations.

[38]I don't include the institutional variables for endogeneity reasons

especially armed forces have an impact on the local population.

Market access affects the size of a town, but size might also influence the effect of market access changes on growth. To investigate this potentially differential impact I estimate the base difference-in-difference specification with subsamples based on size. Figure 6 shows the effect of the liberalization of the Thuringian border as well as that of the Prussian border before the Zollverein based on samples which subsequently drop either the largest or the smallest towns. Dropping small towns does not affect the treatment coefficients, taking out large towns however results in a considerably weakening of the effect for the Thuringian border. Contrary to model predictions, which imply a stronger effect for smaller places, larger places grew faster due to the increase in market access. A possible explanation is the existence of a threshold effect such that very small places don't see any effect of market access changes at all.

Additional information about the importance of size is derived from the application of quantile regression methods (Buchinsky, 1998; Koenker, 2005). As described above I estimate a specification with the size as dependent variable and market potential measure as well as location characteristics as independent variables.[39] Figure 4 shows the graph for the market access coefficient which exhibits a clear upward trend with a slight reverse at the highest percentiles. This indicates that market access becomes more important the larger the town is conditional on the market access level.

So if growth is stronger for large towns and market access is more important for the size of conditionally larger places then market access should also be a strong factor to explain conditionally higher growth rates. To explore this connection the main growth difference in difference specification is estimated with quantile regressions to look at the effects along the conditional growth distribution.[40] Figure 7 shows the results for a selected number of coefficients. The plots indicate that the effect of enlargening the market access plays a considerably more positive role for explaining growth in the higher percentiles of the growth distribution.

6.4.1 Spatial effects

Spatial econometrics is applied to look at additional spatial effects influencing size and growth of towns. First I investigate the link between town size and market ac-

[39] Quantile regressions are conducted for the 10th-90th percentiles in steps of 5 percentiles

[40] Quantile regressions are conducted for the 10th-90th percentiles in steps of 5 percentiles

cessto see whether there is any spatial connection beyond the single market potential variable. To do so I use two weight matrices, one contains a regular decay function, $W_{ci} = \frac{1}{d_{ci}}$, and the other a population weighted decay function, $W_{ci} = \frac{L_i}{d_{ci}}$. The first matrix models a geographic interaction process, where geographic proximity matters to explain influence patterns. The second matrix combines geographic proximity with the relative size of the market. The results of this specification in table 5 show that λ, the coefficient on the spatial error term, is only statistically significant using the population weighted distance matrix. Its negative value implies a stronger effect of concentration. So if a neighboring town is larger than predicted by market access and location characteristics the town itself is smaller than predicted and the effect is stronger the larger the neighboring town. This indicates that agglomeration effects have an even stronger role for determining town size than identified by the market access variable

The second part investigates spatial effects in growth patterns before and after the Zollverein. These spatial patterns reveal second order effects of the changes in market access. The Zollverein caused an exogenous shock to market access of Saxon towns by opening markets in neighbor states, this direct increase led to higher growth. That higher growth of each Saxon town however increases the market access of other Saxon towns additionally. To investigate whether this additional growth mechanism was at work following the liberalization of the Zollverein I apply a spatial lag specification as described above. The growth transmission mechanism is modeled by the inclusion of a weighted sum of the dependent variables of all observations, $\rho W y$, as a dependent variable into the specification, which is again estimated using maximum likelihood. The same two weight matrices as above are used for the spatial term. The empirical specification is estimated for each of the three periods separately [41] and incorporates the effect of markets in other states by including these individual market variables in the specification.

The estimated values, as shown in table 6, for the coefficient on the spatial term follow a specific pattern for both weight matrix specifications, namely a negative, though statistically insignificant, value before the Zollverein, which turns positive and statistically significant for the period after the access and reverts again to a negative, insignificant effect in the later time period. These numbers show the pos-

[41] The used time periods are 1815-1830 before the Zollverein, 1834-1849 and 1849-1864 after Saxony's entry

tulated second order effect very clearly, population growth, and therefore market size, in neighboring towns influences growth in a significant positive way. The first order effect of the Zollverein, namely the increase in market access abroad, again is statistically significant and confirms the results of the main difference-in-difference specification.

One decisive factor for market access is infrastructure and a few years after the Zollverein railroads begin to be built in Germany. Saxony's first main track between Dresden and Leipzig was opened in 1839, the start of a considerable extension over the next decades. Railroads and their forward as well backward linkages are a main factor in Germany's industrialization during the second half of the 19th century (Fremdling, 1977). Introducing information about the presence of railroads in Saxon towns to control for their differential impact on urban growth shows that the effect clearly lags the effect of the Zollverein. The controls show no significant effect in the difference-in-difference specifications and the spatial growth regressions show that the effect is not significant for the initial period after the Zollverein, but strongly positive for the late period after 1849. Railroads clearly had an effect on urban growth, though the timing indicates that the impact lags the changes in market access through the Zollverein for quite some time.

6.5 Migration and Demographic change

The empirical analysis concludes with an investigation of the population adjustment mechanism. The model incorporates full labor mobility as the only mechanism to reallocate population. Besides migration demographic factors can also cause differential growth between locations. Crozet (2004) shows that market potential explains part of the contemporary regional migration pattern within European states. Demographic pattern, births and deaths, are also influenced by economic factors. The Saxon statistical office published data on the population change of towns between 1834 and 1852, separating the total growth into natural increase and net migration. The demographic component is defined as the difference between all births and deaths during the time. Using that number and the total change in population the office then calculated net migration as the difference between these two since migration was not observed separately. The resulting number indicates the net population change caused by migration for each town but not migration flows between individual towns. Using these numbers for migration and natural increase I estimate the above described seemingly unrelated regression specification.

Table 7 shows the results. I focus the discussion on three main results sets, namely the effect of market access, the influence of demographic variables and the role of human capital. The results for the market access variables reflect the results of the main difference-in-difference specification very well. The coefficients on the market potential in Thuringia show a significantly positive effect for migration as well as natural increase. Market potential in Prussia shows again no significant effect after the entry into the Zollverein. Market potential in Bohemia has a significant negative effect on migration behavior but not demographic change. This selective effect of Bohemia confirms that this effect is due to the shock of bad harvests in the last few years before the end of the investigated period. The effect of market potential in Thuringia shows that the Zollverein had a sustained impact on the economic landscape in Saxony. It shifted population into the stronger affected regions, indicating that the change in market access through the Zollverein caused a shift in the economic situations of these regions. The positive effect on the demographic development shows that the effect was not just a one-off shift but had a sustained impact over more than one and a half decades.

The coefficients on the demographic variables show a significant positive effect on growth due to natural increase. A higher birth rate has a positive effect and a higher death rate has a negative effect, both as expected. A higher share of widowed people leads to lower demographic growth, which is likely due to a lower number of marriages as well as a higher share of older people. The last point is confirmed by the significant positive effect of a higher share of young people. The male/female gender ratio has also a significantly positive effect. Although these demographical variables indicate that differences in the demographic characteristics of towns at the entry into the Zollverein have an impact on growth the statistical significance of the Thuringia market access variable implies that the effect of the change in market access has a general positive effect on natural increase.

The third interesting set of results concerns the coefficients on human capital variables. They exhibit a significantly positive effect for growth due to migration, which indicates that human capital has an importance for the growth of towns. Since the coefficients are insignificant, in one case even negative, for natural increase this implies that the effect of human capital is more of a redistributive effect towards places with higher levels.

7 Distance Measure comparison

The empirical specifications use distance measures in three distinct ways. The first is with regard to location characteristics, in this case distance to an active coal mine. The second application is to delineate relevant geographical areas, i.e. which towns are affected by border liberalization and what is the appropriate rural hinterland of a town. The third use is to calculate a town's market potential. Comparing the results for these three applications shows the improvements through introducing geography and infrastructure into distance calculation. Regarding the impact on location characteristics, the results for the regression of the local amenity on actual characteristics show that the robust significance of the influence of brown coal mines using the cost distance measure in contrast to no significance using the plain measures. Two specifications use distances to select a specific group of locations, one is the selection of treatments groups for the difference-in-difference specification and the other is the creation of the rural market variable, delineating the relationship of towns on villages. Table 3 shows the result for the dif-in-dif estimation, the main difference between the two results is the significant positive coefficient on Bohemia before the Zollverein when controls are introduced. Since there is no other regression showing this nor any other reason why that should be the case, the selection based on cost measure appears to be more robust. The correlation between the implied amenity value and the rural market is considerably stronger using the cost measure to denote the area of influence.[42] Both examples demonstrate that cost distance measure performs better in delineating appropriate geographical areas. The third use of the distance measure is the calculation of market potential variables, which were especially used in the spatial analysis. The AIC results show that using the cost measure improves the model fit. Similarly the SUR regression results show more robust results for the market access variables. In summary, incorporating geography and infrastructure into the calculation of distances between markets improves the precision, robustness and fit of distance as proxy for transportation cost.

[42]This holds regardless which distance measure is used to derive the amenity values.

8 Conclusion

Distances are commonly used as a proxy for trade costs within the international trade literature. My empirical results show that the choice of distance measure matters for the quality of the analysis. Neglecting geographical factors and infrastructure results in a loss of information which impacts the precision, robustness and fit of the empirical model. This is not limited to the use of distance as a direct proxy, but also in applications which implicitly use such a measure. For example the delineating of the extent of a relevant market, as used for the calculation of the rural market for towns, represents such an application.

This paper uses distance to investigate the role of market access in the changes caused by the Zollverein to regional economic activity as represented by the size of towns. Market access is a major determinant of town size as are geographic factors like natural resources. This link between market access and urban size allows the identification of the effects of a reduction or increase in trade barriers between markets.

The opening of new markets through the Zollverein led to an increase in population growth closer to those new markets, especially in the west of Saxony close to Thuringia. In the case of Saxony and Prussia trade liberalization reopened markets closed through the imposition of a border and reversed economic effects of that imposition. The effect shows persistence for more than two decades, shaping the spatial dimension of the population distribution and economic activity in a significant way.

The results in general indicate that the idea of agglomeration played an important role in determining the geographical distribution and growth of population and economic activity already at the onset of the Industrial Revolution. Further research into the interaction of agglomeration, natural endowments and geography will be a useful undertaking to illuminate how these various forces interact and how they together shaped and will shape economic geography.

References

(1858): "Die indirecten Steuern im Koenigreich Sachsen," *Zeitschrift des Statistischen Bureaus des Koenigl. Saechs. Ministeriums des Inneren*, 1858(8).

ACEMOGLU, D., S. JOHNSON, AND J. ROBINSON (2005): "The Rise of Europe: Atlantic Trade, Institutional Change and Growth," *American Economic Review*, 95(3), 546–579.

ACEMOGLU, D., S. JOHNSON, AND J. A. ROBINSON (2002): "Reversal of Fortune: Geography and Institutions in the Making of the Modern World Income Distribution*," *Quarterly Journal of Economics*, 117(4), 1231–1294.

ALBER, G. (1919): *Zollverwaltung und Zollertraegnisse in Bayern seit dem Jahre 1819*. Limmer, Muenchen.

ANGELOW, J. (2003): *Der Deutsche Bund*. Wissenschaftliche Buchgesellschaft, Darmstadt.

ANSELIN, L. (1988): *Spatial econometrics : methods and models*, Studies in operational regional science ; 4. Kluwer Academic Publishers, Dordrecht ; Boston.

BAIROCH, P. (1988): *Cities and economic development : from the dawn of history to the present*. University of Chicago Press, Chicago.

BARKER, T. C., D. GERHOLD, AND E. H. SOCIETY. (1995): *The rise and rise of road transport, 1700-1900*, New studies in economic and social history. Cambridge University Press, Cambridge ; New York, NY, USA, 1st cambridge university press edn.

BEESON, P. E., D. N. DEJONG, AND W. TROESKEN (2001): "Population growth in U.S. counties, 1840-1990," *Regional Science and Urban Economics*, 31(6), 669–699.

BLASCHKE, K. (1967): *Bevoelkerungsgeschichte von Sachsen bis zur industriellen Revolution*. Boehlau, Weimar,.

BOSKER, M., AND H. GARRETSEN (2007): "Trade Costs," *Market Access and Economic Geography: Why the Empirical Specification of Trade Costs Matters, August*.

BRAKMAN, S., H. GARRETSEN, AND M. SCHRAMM (2004): "The Spatial Distribution of Wages: Estimating the Helpman-Hanson Model for Germany," *Journal of Regional Science*, 44(3), 437–466.

Buchinsky, M. (1998): "Recent Advances in Quantile Regression Models: A Practical Guideline for Empirical Research," *Journal of Human Resources*, 33(1), 88–126.

Crozet, M. (2004): "Do migrants follow market potentials? An estimation of a new economic geography model," *J Econ Geogr*, 4(4), 439–458.

Davis, D. R., and D. E. Weinstein (2002): "Bones, bombs, and break points: The geography of economic activity," *American Economic Review*, 92(5), 1269–1289.

De Long, J. B., and A. Shleifer (1993): "Princes and Merchants: City Growth Before the Industrial Revolution," *Journal of Law and Economics*, 36(2), 671–702.

De Vries, J. (1984): *European urbanization, 1500-1800*, Harvard studies in urban history. Harvard University Press, Cambridge, Mass.

Dumke, R. H. (1994): *German economic unification in the 19th century : the political economy of the Zollverein*. Institut fuer Volkswirtschaftslehre, Universitaet der Bundeswehr Muenchen, Muenchen.

Fremdling, R. (1977): "Railroads and German Economic Growth: A Leading Sector Analysis with a Comparison to the United States and Great Britain," *Journal of Economic History*, 37(3), 583–604.

Gabaix, X. (1999): "Zipf's Law and the Growth of Cities," *The American Economic Review*, 89(2), 129–132.

Gabaix, X., and Y. Ioannides (2004): "The Evolution of City Size Distributions," *Handbook of Regional and Urban Economics*, 4, 2341–2378.

Hahn, H.-W. (1984): *Geschichte des Deutschen Zollvereins*. Vandenhoeck und Ruprecht, Goettingen.

Hanson, G. H. (2005): "Market potential, increasing returns and geographic concentration," *Journal of International Economics*, 67(1), 1–24.

Harris, C. D. (1954): "The Market as a Factor in the Localization of Industry in the United States," *Annals of the Association of American Geographers*, 44(4), 315–348.

Head, K., and T. Mayer (2002): "Illusory Border Effects: Distance Mismeasurement Inflates Estimates of Home Bias in Trade," *Centre d'Edutes Prospectives et d'Informations Internationales Working Paper*, 1.

Helpman, E. (1998): "The Size of Regions," in *Topics in Public Economics*, ed. by D. Pines, E. Sadka, and I. Zilcha. Cambridge University Press, Cambridge.

Henderson, W. O. (1984): *The Zollverein*. F. Cass, London, Eng. ; Totowa, N.J., 3rd edn.

Hohenberg, P. M., and L. H. Lees (1985): *The making of urban Europe, 1000-1950*, Harvard studies in urban History. Harvard University Press, Cambridge.

Keller, K. (2002): *Landesgeschichte Sachsen*. E. Ulmer, Stuttgart.

Kiesewetter, H. (2007): *Die Industrialisierung Sachsens : ein regional-vergleichendes Erklaerungsmodell*, Regionale Industrialisierung ; Bd. 5. Franz Steiner Verlag, Stuttgart.

Koenker, R. (2005): *Quantile Regression*. Cambridge University Press.

Kohlschmidt, W. (1930): "Die saechsische Frage auf dem Wiener Kongress und die saechsische Diplomatie dieser Zeit," Thesis (ph. d.), W. und B.v. Baensch Stiftung, Universitaet Leipzig, 1930.

Mueller, J. (2006): *Der Deutsche Bund, 1815-1866*, Enzyklopaedie deutscher Geschichte ; Bd. 78. Oldenbourg, Muenchen.

Nebenius, C. F. (1835): *Der deutsche Zollverein, sein System und seine Zukunft*. Verlag der CF Müller'schen Hofbuchhandlung.

Ohnishi, T. (1973): *Zolltarifpolitik Preussens bis zur Gruendung des Deutschen Zollvereins : ein Beitrag zur Finanz- und Außenhandelspolitik Preußens*. Schwartz, Goettingen.

Ploeckl, F. (2008): "The Zollverein and the formation of a customs union," .

Redding, S. J., and D. M. Sturm (2008): "The Costs of Remoteness: Evidence from German Division and Reunification," *American Economic Review*.

Reuschel, A. (1930): "Die Einfuehrung der Generalkonsumtionsakzise in Kursachsen und ihre wirtschaftspolitische Bedeutung," Thesis, Helios-Druckerei Univ. Leipzig, 1930.

Shiue, C. (2005): "From Political Fragmentation towards a Customs Union: Border Effects of the German Zollverein," *European Review of Economic History*, 9(2), 129–62.

Ulbricht, G. (2001): *Finanzgeschichte Sachsens im Uebergang zum konstitutionellen Staat : (1763 bis 1843)*, Studien zur Wirtschafts- und Sozialgeschichte ; Bd. 23. Scripta Mercaturae, St. Katherinen.

von Thuenen, J. H. (1826): *Der isolierte Staat in Beziehung auf Landwirtschaft und Nationaloekonomie*. Perthes, Hamburg.

Waechter, G. (1901): "Die saechsischen Staedte im 19.Jahrhundert," *Zeitschrift des koeniglichen saechsischen statistischen Landesamtes*, 47(1), 179–232.

Appendix Tables

Table 1: Descriptive Statistics of Saxon Town size

	min	max	Mean	Median
Y1815	284	59217	2779	1510
Y1834	449	73614	3740	2112
Y1852	489	104199	5031	2762
Y1871	606	177089	7194	3198

The table reports summary statistics for the size of Saxon towns for four years, 1815, 1834, 1852 and 1871.

Table 2: Descriptive statistics of Market potential

	Sax. Urban	Sax. Rural	Prussia	Thuringia	Bohemia
Control group	5500	6339	2863	756	1372
Prussian Treatment	6274	10861	4157	886	1335
Thuringian Treatment	5661	6142	1260	1260	1223
Bohemian Treatment	3990	8907	532	532	1639

The table reports the average market potential for towns in the treatment and control groups at the time of the Zollverein, the selection of treatment groups is based on my cost measure.

Table 3: Difference-in-difference Results

	Plain Baseline	Plain Controls	Cost Baseline	Cost Controls
Prussia 1815-1830	0.5*	0.538	0.498**	0.912***
	(0.254)	(0.433)	(0.213)	(0.305)
Prussia Zollverein	0.069	0.233	-0.0551	0.0155
	(0.188)	(0.244)	(0.171)	(0.243)
Thuringia 1815-1830	-0.134	-0.233	-0.213	-0.359
	(0.284)	(0.352)	(0.269)	(0.321)
Thuringia Zollverein	0.73***	0.76***	0.725***	0.844***
	(0.256)	(0.290)	(0.234)	(0.258)
Bohemia 1815-1850	0.333	0.782*	-0.0744	0.210
	(0.232)	(0.435)	(0.225)	(0.309)
Bohemia Zollverein	-0.0693	0.284	-0.359**	-0.0914
	(0.118)	(0.188)	(0.148)	(0.207)
Time Controls	Yes	Yes	Yes	Yes
Regional Controls	Yes	Yes	Yes	Yes
Location Controls	No	Yes	No	Yes
Observations	280	280	280	280
R-squared	0.685	0.67	0.688	0.67

Significance Stars: *** significant at 1 % level, ** significant at 5 % level, * significant at 10% level

Standard errors are clustered on towns

Columns 1 and 2 report values for the use of treatment groups based on the plain distance measure

Columns 3 and 4 use treatment groups based on the cost measure

Columns 1 and 3 are estimated using the baseline difference-in-difference specification.

Columns 2 and 4 additionally include the full set of control variables, once for both periods and once interacted with a treatment dummy for the Zollverein

Table 4: Implied Amenity value and actual location characteristics

	Plain	Plain	Cost	Cost
Elbe (Shipping)	19.2***	18.9***	18.2***	17.5***
	(5.74)	(5.47)	(5.71)	(5.45)
River	-3.55	-4.16*	-3.61	-4.48*
	(2.30)	(2.22)	(2.43)	(2.36)
Elevation	-0.00419	-0.00798	-0.0108	-0.0200
	(0.0246)	(0.0235)	(0.0277)	(0.0266)
Ruggedness	-0.242**	-0.239**	-0.193*	-0.198**
	(0.096)	(0.0915)	(0.0989)	(0.0943)
Temperature	0.352	0.182	0.221	0.062
	(0.466)	(0.448)	(0.476)	(0.457)
Rain	0.0235	0.0124	0.0258	0.0193
	(0.022)	(0.0216)	(0.0227)	(0.0222)
Farm quality	0.116	0.132	0.071	0.0963
	(0.18)	(0.173)	(0.182)	(0.176)
Pasture quality	-0.166	-0.202	-0.162	-0.178
	(0.271)	(0.261)	(0.278)	(0.268)
Stone Coal	-0.289	-0.33	-0.127	-0.164*
	(0.195)	(0.188)	(0.0934)	(0.0896)
Stone Coal squared	0.0045*	0.00431	0.000472	0.000617
	(0.00248)	(0.00237)	(0.000484)	(0.000463)
Brown Coal	-0.223	-0.21	-0.247**	-0.182*
	(0.241)	(0.23)	(0.0992)	(0.0964)
Brown Coal squared	0.00417	0.00415	0.00122**	0.00107**
	(0.0032)	(0.00306)	(0.000473)	(0.000454)
Public Mining authority		46.9		49*
		(28.5)		(28.3)
Military		67.4***		66.8***
		(21.4)		(21.7)
Observations	140	140	140	140
R^2	0.137	0.217	0.139	0.217

Significance Stars: *** significant at 1 % level, ** significant at 5 % level, * significant at 10% level

Column 1 and 2 are based on implied location amenity values where the plain measure is used to calibrate the model, Column 3 and 4 are based on values derived using the cost measure
The distance to coal mines variables (Brown Coal, Stone Coal) are measured with plain distance in 1 and 2 and with the cost measure in 3 and 4

Table 5: Spatial analysis of Town size

	Plain Geographic	Plain Pop. Weighted	Cost Geographic	Cost Pop.Weighted
Market Access	1.27***	1.34***	1.03***	1.03***
	(0.362)	(0.339)	(0.177)	(0.164)
Military	4.17***	4.06***	3.37***	3.49***
	(1.52)	(1.5)	(1.34)	(1.29)
Public Mining Authority	5.18***	4.82***	3.17**	3.36***
	(1.13)	(1.07)	(1.06)	(1.01)
Stone Coal	-0.0152	-0.00748	-0.00947**	-0.00515
	(0.00964)	(0.00834)	(0.00396)	(0.00372)
Stone Coal squared	0.0000907	0.00000779	0.0000263	0.00000371
	(0.000123)	(0.000107)	(0.0000208)	(0.0000197)
Brown Coal	-0.0178	-0.0119	-0.0055	-0.00597
	(0.0122)	(0.0107)	(0.00458)	(0.00434)
Brown Coal squared	0.000279*	0.000209	0.0000434**	0.0000425**
	(0.000159)	(0.000139)	(0.0000207)	(0.0000198)
Geographic Controls	Yes	Yes	Yes	Yes
Regional Controls	Yes	Yes	Yes	Yes
λ	-0.093	-0.000131	-0.435	-0.000173
p-value (λ)	0.623	0.000036	0.374	0.000233
Observations	140	140	140	140
AIC	284	267	252	240

Significance Stars: *** significant at 1 % level, ** significant at 5 % level, * significant at 10% level

Spatial Autocorrelation specification (Anselin 1988) of Town size on market access and location characteristics

Town size and market access variables are in logarithms.

Weight matrices are either a distance decay function (column 1,3) or a population weighted distance decay function (column 2,4)

Table 6: Spatial analysis of Urban Growth

Weight matrix	Geographic	Geographic	Geographic	Pop.Weighted	Pop.Weighted	Pop.Weighted
Time period	1815-1830	1834-1849	1849-1864	1815-1830	1834-1849	1849-1864
Town Market	-0.000226**	0.0000318	0.0000511	-0.000252***	0.000052	0.000043
	(0.000092)	(0.0000416)	(0.0000361)	(0.0000916)	(0.0000415)	(0.0000367)
Prussian Market	0.000818***	-0.000114	0.000114	0.000917***	-0.000233	0.000140
	(0.000251)	(0.000137)	(0.00016)	(0.000249)	(0.000145)	(0.000184)
Thuringian Market	-0.00109*	0.00136***	0.000686*	-0.00119*	0.00146***	0.00059
	(0.000633)	(0.000345)	(0.0004)	(0.000633)	(0.000342)	(0.000405)
Bohemian Market	-0.000386	-0.000369	-0.0005	-0.000364	-0.000437	-0.000478
	(0.000753)	(0.000407)	(0.000473)	(0.000753)	(0.000408)	(0.000480)
Rural Market	0.000000765	0.00000104	-0.00000483	0.00000100	0.000000816	-0.00000338
	(0.0000217)	(0.0000118)	(0.0000137)	(0.0000216)	(0.0000117)	(0.0000138)
Railroad	NA	0.0268	0.0439***	NA	0.0316	0.0435***
		(0.0293)	(0.0102		(0.0292)	(0.0103)
Geographic Controls	Yes	Yes	Yes	Yes	Yes	Yes
Institutional Controls	Yes	Yes	Yes	Yes	Yes	Yes
Regional Controls	Yes	Yes	Yes	Yes	Yes	Yes
ρ	-0.529	0.389	-0.489	-0.000135	0.0000783	-0.0000396
p-value (ρ)	0.158	0.0221	0.113	0.144	0.0107	0.253
Observations	140	140	140	140	140	140
AIC	462	290	331	462	289	332

Significance Stars: *** significant at 1 % level, ** significant at 5 % level, * significant at 10% level

Spatial lag specification relating annualized growth to market access and location variables.
The reported values are all based on the use of the Cost distance measure.

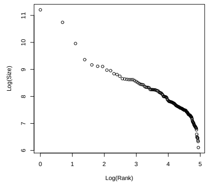
Table 7: SUR Migration and Demographic change

	Plain Migration	Plain Demographic	Cost Migration	Cost Demographic
Prussian Market	0.000270	0.0000319	-0.000054	-0.0000331
	(0.000254)	(0.000102)	(0.000179)	(0.000076)
Thuringian Market	0.000243	0.000201**	0.00092*	0.000493***
	(0.000226)	(0.000101)	(0.000466)	(0.000204)
Bohemian Market	0.000521	-0.0000512	-0.00116**	0.0000517
	(0.00038)	(0.000147)	(0.000547)	(0.000236)
Rural Market	-0.0000438***	0.000011	-0.0000218	0.00000454
	(0.0000156)	(0.00000697)	(0.0000154)	(0.00000658)
Railroad	0.0532*	0.0203	0.0501*	0.0258**
	(0.0283)	(0.0129)	(0.0283)	(0.0121)
Paper	0.648***	-0.244**	0.718***	-0.213**
	(0.229)	(0.100)	(0.236)	(0.101)
Multiple Papers	1.41***	-0.392	1.3**	-0.268
	(0.523)	(0.237)	(0.537)	(0.234)
Schools	0.000648*	-0.0000146	0.000713**	0.0000291
	(0.000345)	(0.000152)	(0.000353)	(0.000151)
Teacher	0.00385***	0.000295	0.00243*	0.000280
	(0.00138)	(0.000626)	(0.00146)	(0.00064)
Birthrate 1834		0.0107**		0.0118**
		(0.00512)		(0.00492)
Deathrate 1834		-0.00978**		-0.00953**
		(0.00476)		(0.00464)
Gender balance		1.56***		1.53***
		(0.574)		(0.567)
Widowed Share		-5.19*		-6.02*
		(3.48)		(3.41)
Youth Share		2.6*		2.55*
		(1.37)		(1.33)
Geographic Controls	Yes	Yes	Yes	Yes
Regional Controls	Yes	Yes	Yes	Yes
adjusted R^2	0.358	0.555	0.335	0.572

Significance Stars: *** significant at 1 % level, ** significant at 5 % level, * significant at 10% level

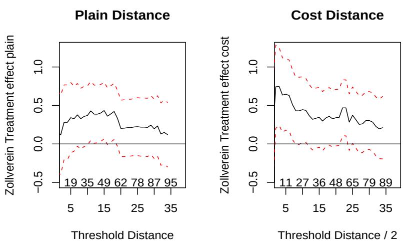
Appendix Figures

Figure 1: Log(Size)/Log(Rank)-Plot for 1834



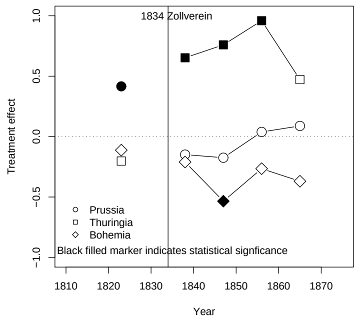
The graph plots the logarithm of town size against the logarithm of town size rank, which is the standard way to illustrate Zipf's law. Many studies about town sizes report a statistical regularity, namely that the resulting line has a slope of -1. In case of my sample the right tail drops sharply, implying that there are quite a few towns included which are smaller than they should be under the regularity (alternatively this can be the effect of not including villages that are larger than the smallest towns).

Figure 2: Treatment effect of the Zollverein with different selection thresholds



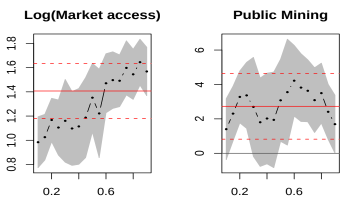
The graph plots the series of treatment effects of specifying a difference-in-difference estimations with one treatment group, namely towns close to Saxony's border with another Zollverein member. The selection of the treatment groups differ by the applied threshold distance from the border, which is plotted on the x-axis. The numbers above the X-axis indicate the number of towns in the treatment group for the corresponding distance threshold.

Figure 3: Adjustment path of all thre treatment effects



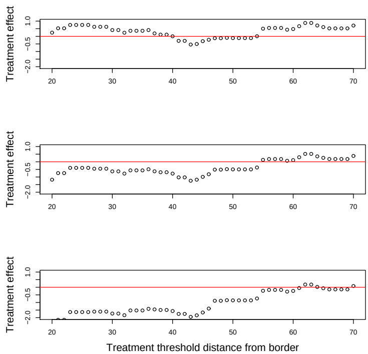
This graph shows the development of the three treatment effects over time, using the cost measure to determine the treatment group.

Figure 4: Size Quantile regression Coefficients on Market access



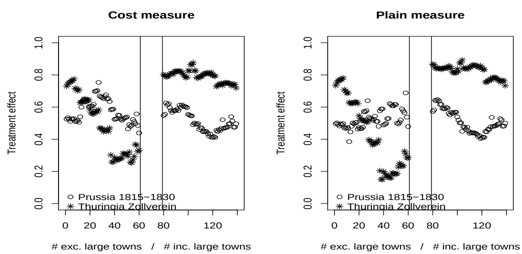
Each graph has the respective quantile on the x-axis and the resulting coefficient for that particular quantile on the y-axis. (black line are the coefficients, grey area are 90 percent confidence intervals, red solid line is the corresponding OLS coefficient, red dashed line are regular standard error.)

Figure 5: Counterfactual effect of the Prussian border imposition in 1815



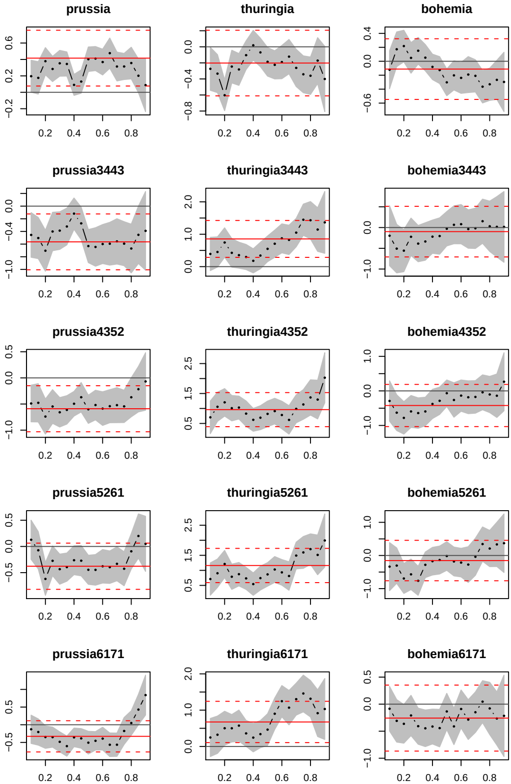
The three panels show the counterfactual treatment effect for the period 1815-1830 when the migration flow due to the Prussian border imposition in 1815 is assumed to be 1000,11000 or 20000 (from top to bottom) and 1830 town sizes are adjusted accordingly. Each panel shows the development of the effect for changing the distance threshold for the treatment group, using the cost distance measure (the plain measure result look very similar).

Figure 6: Thuringian / Prussian treatment effect for subsamples selected on size



The panel shows the treatment effects of the Prussian border for 1815-1830 and for the Thuringian border after the Zollverein.

Figure 7: Quantile Regression for specification with multiple treatment periods



The panels show the results of quantile regressions for the treatment effects for the differenc-in-difference specification with multiple periods

Appendix Data sources

Printed Sources

Saxony	Statistische Mitteilungen aus dem Koenigreich Sachsen (1831 - 1849,1851 - 1855) Statistisches Jahrbuch Sachsen (1871-1938) Zeitschrift des Sächsischen Statistischen Landesamtes (1855-1945) Historisches Ortsverzeichnis Sachsen, 2006 Historischer Atlas von Sachsen , Karte und Beiheft A 9 ,B II 6, F IV 1, H 16
Prussia	Hoffmann, J.G., "Die Bevoelkerung des Preussischen Staates", Nicolaische Buchhandlung, Berlin 1839 Tabellen und amtliche Nachrichten ueber den Preussischen Staat fuer das Jahr 1852 (Herausgegeben von dem statistischen Bureau zu Berlin Druck und Verlag von A.W.Hayn 1855)
Bavaria	Beitraege zur Statistik des Koenigreichs Bayern Nr 1, 13
Thuringia	Statistik Thueringens, Mitteilungen des Statistischen Vereins Vereinigter Thueringischer Staaten Beitraege zur Statistik des Grossherzogtums Sachsen-Weimar-Eisenach
Bohemia	Statistisches Handbuch des Koenigreichs Boehmen, 1913

Maps

Bayerische Landesbibliothek, Muenchen
Ref: VIII 21, VIII 23c , VIII 46, XII 118

Saechsisches Hauptstaatsarchiv, Dresden
Ref: 11345/15, 11345/16, 12884, R926

Electronic data

HGIS Germany (IEG Mainz ,i3mainz Fachhochschule Mainz) www.hgis-germany.de

Saechsisches Ministerium fuer Umwelt und Landwirtschaft:
-GEMDAT-LABO, Akademie der Landwirtschaft der DDR, Muencheberg-Eberswalde
-Gewässerdurchgaengigkeitsprogramm (Oberflaechengewaesser)

TOP 50 Sachsen, CD-ROM,Landesvermessungsamt Sachsen
U.S.Geological Survey ,National Elevation Data

Appendix Location characteristics

Natural endowment

Elevation This variable indicates the elevation over sea level measured in meters, the data is from current Digital elevation models.

Ruggedness This variable indicates how flat the area immediately surrounding the town is. The elevation profile of an area influences agricultural suitability as well as ease of transportation. I specify this as the standard deviation of all elevation values within a two kilometer radius of the town location.

Farm land quality This variable indicates the quality of the soil with respect to farming purposes, based on public geological surveys during the middle of the 20th century. The surveys are based on thousands of measurements and report average values for about 1600 parishes covering all of Saxony. The classification scheme uses a scale of 0-100, which is also the specification used for the empirical analysis.

Pasture quality This variable indicates the quality of the soil with respect to pasture purposes. The data is based on the same surveys as the farm land quality and the variable is specified in the same way.)

Brown Coal [43] This variable indicates distance to Brown Coal mines active in the late 1830's and early 1840's. The data about active mining locations come from the Historical Atlas of Saxony. The distance is specified in km either measure

[43] The terminology about coal varieties is not uniform, so I follow the convention used by Saxon statistical officials and distinguish between "Braunkohle" and "Steinkohle". Braunkohle is literally translated as brown coal, while Steinkohle is stone coal

as plain distance or with introduced cost measure and enters quadratically into the regressions.

Stone Coal This variable indicates distance to hard coal mines active in the late 1830's and early 1840's, the data is also from the Historical Atlas of Saxony. It is specificed in the same way as brown coal.

Rivers This variable indicated whether there is flowing water body within a kilometer of the town location, which is specified as a simple dummery variable.

Institution and Infrastructure

Elbe One of the major means of transportation in the early 19th century was shipping, especially also on rivers. In Saxony only the Elbe offered this possibility, no other river was navigable. Rivers also have other effects, for example as a source of energy, this variable however captures the effect shipping since most Saxon towns were located at rivers. The variable is dummy indicating whether the Elbe flows through the town.

Postal service This variable indicates whether the town had a regular postal service in a given year. The Data is taken from a compilation accompanying the Historical Atlas of Saxony.

Rail service This variable indicates whether and how long the town had a railway station within the investigated period. It's specified as the number of years the station was operating during this time period. The data is from the same source as the information about the Postal service.

Newspapers These dummy variables indicate whether a newspaper or similar publication was published in the town in 1832, with the second variable indicating at least two publications present. The data is taken from the 1833 issue of*Mittheilungen des statistischen Vereins fuer das Koenigreich Sachsen*, a regular publication of the Saxon Statistical Office.

Trade fairs These are dummy variables for the existence of trade fairs in 1836 with fairs classified in three categories, general goods, animals and textiles. The information comes from the 1835 issue of the *Mittheilungen des statistischen Vereins fuer das Koenigreich Sachsen*

Housing This is a variable indicating the stock of housing in each town in 1834. The stock is specified in number of houses without any regard to size or quality. Since larger towns tend to have larger houses, the variable is the residual not explained by a polynomial of the town population. The data was collected simultaneously with the census numbers and published in the same location.

Education These variables indicate the level of educational activity in each town. Gym indicates whether there is any school beyond regular schools, for example a university,seminary or teacher college, Teacher indicates the number of students per teacher in this town, School indicates the number of students per school in the town. The numbers are taken from an overview by the Statistical office published in 1833.

Appendix GIS calculation

The description of the GIS functionalities in this section are predominantly based on the ArcGis program documentation.

Basic Data Concepts

Geographical Information systems know two distinct concepts to conceptualize and map data, a Raster and a Vector system.

The raster approach uses information as a digital image, where a map is a grid of cells with each cell having x,y and z coordinates. The x and y coordinates give the location within the grid, the z coordinate contains specific numerical information. Possible examples for z are the elevation value of this cell, a measure of distance to a specific point or a category value indicating a specific surface (e.g 0 indicates empty land, 1 indicates a road, 2 indicates a river, etc).

The vector approach uses information as geometrical objects. The basic object shape is a point, which requires geographic (x,y) coordinates. It is possible to assign for each point a table of information (e.g a point can represent a town, where the table stores the name, population, etc). This information does not have to be numeric. Connecting points results in two more relevant shape forms, called polyline and polygon. The connecting lines can be straight or curved. Similar to points information can be assigned to each object. In the case of polygons this information is assigned to the area enclosed by the polygon as well. An example for a polyline is a river or a road, an example for a polygon is the territory of a state.

It is possible to transform data from one approach into the other. For example I have information about rivers in Saxony given in vector form, which I transform into a grid to combine it with other raster data.

The relative positions (x,y-coordinates) in both approaches can be connected to geographic reference positions, which allows linking multiple data sources. In the case of raster data this georeferencing also allows the inference of other cell properties, for example cell size. The elevation raster I use for Saxony has the property that each grid cell represents a surface area of about 100 by 100 meters.

It is possible to perform mathematical operations on geographical data, especially on raster data. The transformation usually operates on each cell individually, so it's for example feasible to add or multiply each grid cell with a constant. It is also possible to multiply two or more layers where the resulting layer contains the product of the corresponding grid cells. Transformations can also be executed on selected cells, for example all cells with negative values could be set to zero or all cells within a certain distance to specified source cells could be set to a constant.

Cost layer

I apply mathematical transformations to combine source layers into one cost layer, which is used in the distance measurement procedure described below. The goal is to create a layer whose z-value indicates the cost of crossing this cell. The distance calculation takes elevation patterns separately into account, so the cost layer combines roads and rivers. The relative cost factor are parameter values which can be changed relatively easy, however each change in the cost layer requires the distance calculation described below to be run again.

Roads The data for roads are based on information from three historical maps. Two maps drawn in 1834 show the network of major trade routes spanning Saxony and its neighbors, the road classifications are quite consistent between the two. As the benchmark transportation cost I use major trade routes, to which I assign all major roads which either saw service by *Eilwagen*, regular priority people transportation, or were chauseed. Small roads are all other marked important road connections. The exact routes within Saxony are based on a detailed 1852 Saxony road map. Major roads have a cost factor of one, small roads of two and for areas off one these roads I assign a cost factor of five.How this cost factor translates into distance will be explained in the description of the distance measurement.

Rivers I have information from the Saxon Landesvermessungsamt about the network of rivers in Saxony. As mentioned above the main navigable river within Saxony is the Elbe, which saw considerable commercial shipping during this time. Therefore I assign a cost factor of 0.4 to the Elbe, while for all other rivers, as well as the middle of the Elbe, I assign a cost factor of 25 to model the cost of crossing a river not on a major trade route. Naturally rivers and roads cross and given the assumption of existing bridges and furts the road cost value is used for that particular cell.

Elevation As described below elevation enters slightly different into the calculation then roads and rivers. One is the increase in actual travelled distance and the second way is the inclusion of costs due to the slope, which is described under the vertical factor heading below. I choose that slopes steeper than +-10 degrees cannot be followed and the slope costs are a multiplicative factor based on an inverse linear function $VF = \frac{1}{1-0.1*Slope}$

Pathdistance function

The objective of the PathDistance cost functions is for each cell location in the grid to determine the least costly path to reach this cell from the least costly source. Each cell will need to determine the least accumulative cost path from a source, the source that allows for the least cost path, and the least cost path itself. The formula used by PathDistance to calculate the total cost from cell a to cell b is:

$$Costdistance = Surfacedistance * Verticalfactor$$

Source cells All cost functions require a source raster. A source raster may contain single or multiple zones. These zones may or may not be connected. The original values assigned to the source cells are retained. There is no limit to the number of source cells within the source raster. As a practical example one class of source cells are the cells in which towns are located. These are usually single unconnected cells. An example for a zone of connected cells is a border line. Source cells can either be selected cells in a raster or vector based objects like points (e.g each town is represented by a point)

Cost layer The cost raster can be a single raster, which is generally the result of combining multiple rasters. The units that are assigned to the cost raster can be any type of cost desired. The dollar cost, time, the energy expended, or a unitless system would derive its meaning relative to the cost assigned to other cells. The cost surface can be either a floating-point or an integer raster. My cost layer, which I described above, is a unit-less system.

Distance units Cost distance functions apply distance in cost units, not in geographic units. The cost values assigned to each cell are per-unit distance measures for the cell. That is, if the cell size is expressed in meters, the cost assigned to the cell is the cost necessary to travel one meter within the cell. If the resolution is 50 meters, the total cost to travel either horizontally or vertically through the cell would be the cost assigned to the cell times the resolution ($totalcost = cost * 50$). To travel diagonally through the cell, the total cost would be 1.414214 times the cost of the cell, times the cell resolution ($totaldiagonalcost = 1.414214[cost * 50]$). Given the structure of my cost layer the resulting total cost for any path indicates the distance which could be travelled on a flat surface with cost factor one at the same cost.

Surface distance The surface distance is the actual ground distance (as opposed to map or planimetric distance) that must be traveled when moving from one cell (FROM) to another (TO). The first step in calculating the surface distance is to produce a right triangle whose base is derived from the cell size and whose height is the z-value defined by the input surface raster for the FROM cell, minus the z-value of the TO cell. To determine the actual surface distance, the third side of the right triangle is calculated using the Pythagorean theorem (a2 + b2 = c2).

Vertical factors The vertical factors (VFs) determine the difficulty of moving from one cell to another, while accounting for the vertical elements that may affect the movement. To determine the VF for moving from one cell to the next, the slope between the FROM cell and the TO cell is calculated from the values defined in the input vertical factor raster. The resulting slope is the vertical relative moving angle (VRMA), which is used as the argument for a function determining the vertical factor in the PathDistance calculations for the cell-to-cell movement. This vertical factor establishes the vertical factor from the center of the starting cell to the center of the destination cell. The VRMA is specified in degrees, its range is from -90 to +90 degrees, compensating for both positive and negative slopes. The resolution of the VRMAs used to determine the vertical factor is 0.25 degree. ArcGis has a range of available functions for the determination of the vertical factor. For example one possibility is a linear transformation, others are of polynomial or trigonometric nature. There is also the possibility of specifying a cutting angle, such that for any angle steeper (or shallower) than this the vertical factor becomes infinity and transportation impossible on this path.

Distance Extraction The cost function creates a grid, where each cell contains the distance value to the nearest source cell. To calculate the distance between town A and town B I apply the cost function with town A as the sole source cell. It is then possible to extract the distance value for town B, which has a point shape, and add it to its table of information. Since the distance is not symmetric I have to apply the cost function with every town as the single source cell to create the full distance matrix.

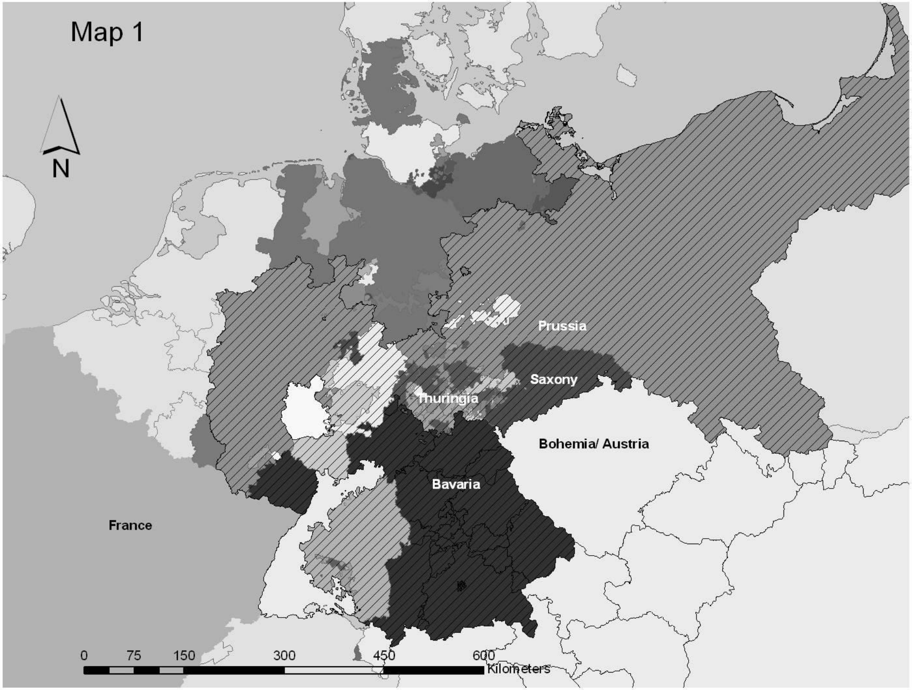
Appendix Maps

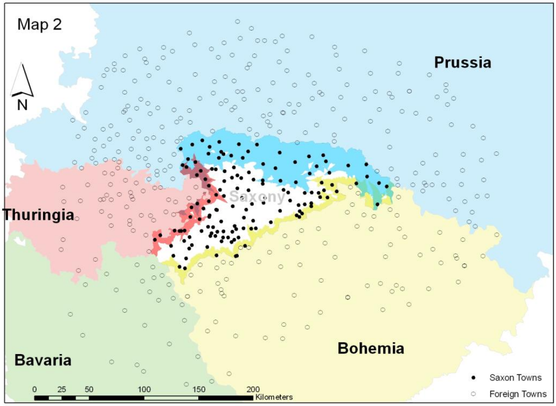
Map 1

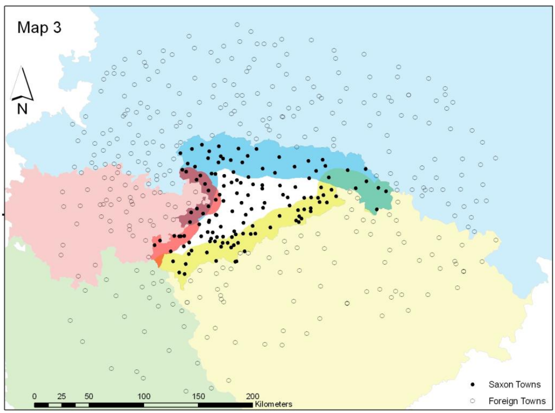
This map shows the political borders within Germany and the extent of the Zollverein in 1834. The area which is black left-shaded indicates the boundaries of the Zollverein at its formation in 1834.

Map 2 / Map 3

These maps illustrate graphically the location of towns in Saxony and neighbor states as well as the distance thresholds for the difference-in-difference estimation. A full black dot indicates a Saxon town, an empty dot indicates a town in a neighbor state used to calculate market access. The lightly shaded areas indicate the respective neighbor states, the strongly coloured areas are the parts of Saxony which are the respective treatment regions of the difference-in-difference estimation. Towns within the area with white background represent the control group used in the estimation. Map 2 illustrates the thresholds based on my cost measure, map 3 illustrates the thresholds used for plain distance specifications.


Map 1
N
Prussia
Saxony
Thuringia
Bohemia/ Austria
Bavaria
France
0
75
150
300
450
600
Kilometers


Map 2
N
Prussia
Thuringia
Saxony
Bavaria
Bohemia
0 25 50 100 150 200 Kilometers
Saxon Towns
Foreign Towns


Map 3
N
0 25 50 100 150 200 Kilometers
Saxon Towns
Foreign Towns