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Borders, Market Size and Urban Growth, The Case of Saxon Towns and the Zollverein in the 19th Century

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

Florian Ploeckl

Abstract

Changes in trade institutions, such as the 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. The effects of changes in market access were reinforced through the impact on market access in other towns and they were stronger for larger towns as well. Migration was the predominant source of the differential growth pattern.

JEL Codes: F15, N93, R12

Keywords: Zollverein, Saxony, Customs Union, Market Access, Economic Geography, GIS, Distance measurement

1 Introduction

The Napoleonic Wars engulfed a Germany that 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 unity, it experienced economic unification, especially the creation of a common market. The institutional centerpiece that swept away most trade barriers between German states was the Zollverein, a customs union founded in 1834.

C.F.Nebenius, a public official in Baden and vocal advocate of the Zollverein, saw moral improvement as the major benefit of this customs union for regions close to internal German borders. He envisioned reductions in the temptation to smuggle, and more peaceful relations with neighboring regions, due to decreased potential for conflict (Nebenius, 1835). However, he did not address the differential economic impact. What were the effects on growth in regions close to and far from the borders?

This paper answers this question through a newly collected dataset on population and town characteristics in the German state of Saxony. These data are combined with a new distance measure, which uses Geographic Information Systems (GIS) methods to incorporate geography and infrastructure, to test implications derived through the application of a New Economic Geography model (Redding and Sturm, 2008).[1] The results demonstrate the effect of the Zollverein on regional growth. I further illustrate that the new GIS-based distance measure improves the use of distance as a proxy for trade costs.

The Zollverein was one of the first major customs unions in Europe and represents a historical case of peaceful border elimination, where economic unification predates the political development. This customs union fostered economic integration in Germany through reducing 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. My project analyzes the effects of the Zollverein on local and regional development by 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 this historical time period. Urban growth, serving then as an indicator for economic growth, is used

[1] See Appendix for more information about GIS.

to identify effects on local and regional levels on a finer geographical level than is possible using alternative measures like GDP data or trade flows which also require data not available for the time period in question. I further establish that there is a connection between urban size and market access. The latter is not only determined by the size of each market, but also by the trade costs between locations. The trade literature usually uses plain great-circle distance as a proxy for these costs. This approach neglects geographic factors and infrastructure which influence the relationship between two markets. I use GIS 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 shared borders mainly with three neighbors: Prussia, Thuringia, and Bohemia.[2] Each of these borders experienced a different change due to Saxony's entry into the Zollverein. This variation in treatment 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. The increase of barriers in Bohemia had a negative but insignificant effect on the towns in question.

Section 2 provides an outline of the historical context for Saxony and the Zollverein. Section 3 describes the theoretical framework, a New Economic Geography model recently developed by Redding and Sturm (2008), and derives the implications which will be tested in the empirical section. Section 4 illustrates the changes in tariff barriers through Saxony's entry into the Zollverein. Section 5 details the GIS-based distance measure as well as the data set and the methods used in the empirical analysis. Section 6 illustrates the results of the main analysis and a series of extensions investigating particular aspects of the effects. Section 7 provides a closer look at the distance measures and the final section concludes.

2 Historical Context

Saxony existed as a political entity for centuries within the Holy Roman Empire of the German nation. It was one of the larger German powers at the time of

[2] Thuringia consists of a group of formally independent principalities, who had however strong dynastic bonds with each other

the Napoleonic Wars, located between Prussia and the Austrian province Bohemia (Keller, 2002). Its central location within continental Europe, which had made it 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 changes to economic and political institutions.

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. 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 concerning 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 institutional separation between towns and villages and stability for the set of locations classified as towns (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.[3] 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.[4] 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.[5] 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, such as the

[3] 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; Müller, 2006)

[4] Henderson (1984) provides a historical overview, see Ploeckl (2008) for an explanation why the German states, especially Prussia, preferred regional agreements over a multilateral approach for the whole of Germany.

[5] 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.

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 successfully concluded after a merger agreement between the already existing German customs. The Zollverein, now a customs union encompassing a significant number of German states, came officially into being with the year 1834.[6]

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 a unanimity requirement. The Zollverein specified administrative regulations but the actual policing and legal enforcement were 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 its institutional structure in the wake of the Prussian-Austrian war of 1866 and incorporated the customs union into the political structure of the German Empire of 1871 (Hahn, 1984; Henderson, 1984).[7]

This sudden change of trade barriers, the complete liberalization between Saxony, Prussia and Thuringia, and the increase of barriers with Bohemia permit the empirical identification of the Zollverein effects. The main impact of this customs union for Saxon towns is a change in market access, therefore I utilize a New Economic Geography model that builds upon the concept of market access. I use this theoretical framework to derive the implications of Saxony's Zollverein entry for the growth of Saxon towns. Differential changes in trade barriers with Saxony's neighbors provide a source of variation to identify the effects of changes in market access even more clearly. These trade barriers were asymmetrical, a feature that the theoretical framework can incorporate through the specification of asymmetric 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

[6] Ploeckl (2008) provides a structural analysis of the formation process of the Zollverein, which explains the observed negotiation structure, accession sequence and institutional form. Henderson (1984) provides an overview of the history of the Zollverein.

[7] Prussia annexed a number of other member states in 1866, abolished the congress and its unanimity rules and instituted a customs parliament which was dominated by its Prussian members.

of distance as a trade cost proxy.

3 Theoretical Framework

Saxon towns were clearly defined centers of economic activity as well as trade. Any framework for investigating the impact of tariff liberalization on population growth must 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. They use 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 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. An exogenous change in trade barriers such as the Zollverein leads to a new population equilibrium.

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 stable during the time period in question, 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. Each location is endowed with a stock of a non-tradable amenity H_c, the level of which is exogenously given for each location.[8] 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 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 of 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

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

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 adjustment 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 function of model parameters and the common real wage.[9]

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. This will be empirically verified, using an empirical representation of market access and a set of geographical location characteristics. 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, those for the market access measures are based on the consumption share of non-tradeables and the elasticity of substitution, on the three elements

[9] $\chi \equiv \omega^{-1/(1-\mu)}\xi^{\mu/(1-/mu)}\mu/(1-\mu)$, where ω is the common real wage, $\xi \equiv (F(\sigma-1))^{-1/\sigma}(\sigma-1)/\sigma$, F is the fixed cost for a variety, σ the elasticity of substitution and μ the expenditure share of tradeables.

show that the model implies a positive correlation between urban size and both market access measures as well as local 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, as the outcome of a random growth process (Gabaix, 1999).[10] The theoretical framework focuses on the other two, but testing these theories is not the focus of this paper.[11]

The model provides 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 leads 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 immigration leads to a higher price of the non-traded amenity until this price increase equalizes the real wage again and ends the immigration. 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 immigration 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 equilibrium. A direct increase of the local non-traded amenity results in a drop in the amenity's price and therefore in 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

[10] 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 .

[11] 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 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 only caused by the local amenity H, and the second assumes H to be fixed and any change is due to market access.

the resulting equilibrium outcome.

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

Population 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 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.[12]

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, then other towns close by 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. Similarly, a negative shock will be reinforced

4 Tariff barriers

The main impact the Zollverein had by altering tariff barriers between Saxony and its neighbors was a change to market access. Its precise impact on Saxon towns depends 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.[13] The main element of the taxation system was a general excise tax,

[12] This relationship also holds for Consumer Market access.

[13] It levied such a tax on a few imports, but the extent and height was very minor (Ulbricht, 2001).

the so-called *General-Konsumtions-Akzise* (Reuschel, 1930).[14] 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.

Saxony's 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 a 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 to raise revenues. 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).[15] At the same time Bavaria, Saxony's neighbor in the southwest, introduced an external tariff system with relatively 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 between Saxony and Austria (Kiesewetter, 2007). The Thuringian principalities 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

[14] 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.

[15] 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).

major trade fairs of Leipzig and Frankfurt.[16]

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 for 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. A discussion of the calculations leading to the GIS-based distance measure is also included.

The size and growth of cities and towns, along with 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). This approach has two advantages in the case of the Zollverein and Saxon towns. First, I am able to focus on regional development on a disaggregated level. Second, it avoids the use of arbitrary borders due to the availability of sufficient data. Saxon towns at the onset of the industrial revolution still had quite clear boundaries, in some cases literally physical walls. Their population based on administrative boundaries therefore represents the size of the local economies quite well (Blaschke, 1967; Hohenberg and Lees, 1985).[17] Town boundaries see almost no change during the time period in question; the extent of incorporation of villages into

[16] These tolls, multiple routes and bad road conditions however kept these revenues down.

[17] This feature of Saxon towns solves the problem of delineating appropriate urban areas, since especially in the 20th century administrative boundaries no longer coincide with meaningful economic units (Blaschke, 1967).

towns is negligible before the late 19th century (Wächter, 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 of 140 towns, which is stable over time.[18] 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 until 1867, and ends 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.[19] The data show a significant discrepancy between the 1830 and 1834 numbers, with 1830 exhibiting 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.[20]

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 fewer than 500 inhabitants and the median is just over 2000.[21] Figure 1 shows log(Size) plotted against log(Rank), which is usually used to illustrate Zipf's Law. The lower end of the tail shows that the set contains a number of settlements that are significantly smaller than what would be expected under this regularity (Gabaix and Ioannides, 2004). A number of villages had attained a size considerably larger than smaller towns (Blaschke, 1967).

Saxony had for most of the 19th century the highest population density of German

[18] In 1848 Saxony received a town, Schirgiswalde, through a land swap with Austria and in the second half of the 19th 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

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

[20] 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. 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.

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

states; in 1830, the number was 93.5 inhabitants per km^2 (Kiesewetter, 2007).[22] 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.[23] 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 characteristic which explains urban size, I interpret this variable as a combination of location characteristics which influence the location decision of population. I divide 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 elevation, ruggedness of the surrounding area, access to flowing water, 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.[24] 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.[25] 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. Combined with information on military personnel I use the location characteristics in this category in the estimation of town size. Since they are not subject to change over time no problem with regard to endogeneity exists.

Next to these unchanging location characteristics I 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

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

[23] 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.

[24] Elevation is measured in meters above sea level, ruggedness is measured as the standard deviation of the elevation within a 2km radius around the town, and access to flowing water indicates whether a river is within a kilometer of the town.

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

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 a magazine, the number of children per school as well as per teacher in each town, and the presence of other higher education institutions.[26] 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.[27] 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. I use urban and rural markets in Saxony as well as urban markets abroad and take their respective population as market size.

- *Urban Market in Saxony* This set contains all towns within Saxony, which in 1834 officially have 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. The set consists of towns within a 100km radius around Saxony. The total market abroad can be split into individual parts according to country, which results in variables indicating markets in Prussia, Thuringia, Bavaria, and Bohemia 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.[28] 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.[29]

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

[27] I construct a measure of housing stock in the following way. I regress the number of houses on a polynomial of town size, the independent variable here are the residuals from this regression.

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

[29] This sum is not weighted by distance since the nature of the economic relationship between

Some specifications reported below use a population-based empirical market potential variable, which is conceptually close to the Firm and Consumer market access variables. Hanson (2005) among others uses market potential as the empirical proxy for market access in his work on the impact of NAFTA. This follows 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 and d_{ci} is the distance to this market.[30]

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), measures which implicitly include some cost factors.[31] There are no comprehensive historical travel time or transportation cost measures for Saxony and its neighboring regions. Historical transportation technology furthermore 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 changes in 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

town and countryside outweighs the importance of the relatively short distances between towns and the surrounding villages.

[30] There are various market size measures used in the literature. Harris for example took retail sales, Hanson uses income as measured by GDP, De Vries (1984) uses population. 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.

[31] Bosker and Garretsen (2007) survey varying functional specifications to include cost factors. They show that trade costs are either modeled as a direct function of the measured distance, or as a two step estimation. The latter 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.

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 not included in the distance calculation, are differential trade barriers between two towns. The differences in trading regimes between Saxony and its neighbors, as described above, are such barriers.[32] 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. However, without trade barriers between the two locations the extent of asymmetry is such that the two trade costs between the locations are highly correlated.[33]

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.[34]

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

[32] These affect obviously only trade with foreign states but not domestic markets.

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

[34] 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.

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 to a different extent. However, the main empirical specification 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 that proximity to a border is correlated with a larger increase in market access when that particular border is opened up.[35] Using this approach I can investigate the impact of the whole Zollverein as well as 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.[36]

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 is available for the case of the Zollverein. They investigate the actual effect in a discreet way by estimating a difference-in-difference specification with a distance to

[35] 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.

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

border threshold derived from their simulation. My main specification differs from theirs in two ways. First, I investigate multiple border parts, specifically the borders with Prussia, Thuringia and Bohemia, through the inclusion of separate treatment categories. Second, I select the distance thresholds based on a grid search.[37] This leads to the following formal specification:

$$Growth_t = \sum_l \beta_l (Border_l * PreZollverein_t) + \sum_l \gamma_l (Border_l * Zollverein_t) + \delta_t + \mu_r + \epsilon_t$$

where subscript t denotes a time period, *Border* is a dummy which indicates whether the town is assumed to be affected 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, Thuringia or Bohemia. δ_t are time dummies, μ_r denotes regional dummies and ϵ_t are stochastic errors. β_l and γ_l, the coefficients on the interaction of the treatment groups and time periods, are the main coefficients of interest since they illuminate 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 baseline specification but includes multiple periods after the Zollverein entry to follow the development of the effect over time.

The baseline specification focuses on growth solely due to a change in market access. However, the model implies that differential population growth can also be the outcome of changes in the local amenity.[38]. 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 controls are 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. I investigate these in two ways. First, I verify the link between

[37] 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

[38] Some location characteristics, especially those in the institutional category, change over time. Others, especially those in the geographical group, are fixed, but their effect may change over time.

town size, market access and location characteristics. Secondly, I investigate the relationship between growth, size and market access. The equilibrium of the model is determined by a system of equations.[39] The use of the actual town size in a particular year as the equilibrium population distribution allows the derivation of implied equilibrium values for the other unknowns. 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 are then used to demonstrate the impact of geographic location characteristics. I estimate

$$\hat{H} = \alpha + \sum_j \gamma_j H_j + \varepsilon$$

with each H_j 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.

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

$$\ln L = \alpha + \beta \ln \sum_k Market_k + \sum_j \gamma_j H_j + \varepsilon$$

where $Market_k$ is the market potential of Saxon towns within the different markets k. It is estimated with quantile regressions to investigate the importance of market access along the conditional town size distribution. I also estimate the baseline difference-in-difference specification 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 estimates 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

[39] There are seven equations with seven unknowns, which are population, number of varieties produced, sales price, real wage, amenity price level, manufacturing price level, and total expenditure.

of agglomeration on size of towns by using the following Spatial Error autocorrelation specification which is estimated using Maximum Likelihood.

$$\ln L = \alpha + \beta \ln \sum_k Market_k + \sum_j \gamma_j H_j + \lambda W \varepsilon + \varepsilon$$

where $market_k$ is market potential in neigbor k, λ is the coefficient on the spatial term, W a spatial weight matrix and ε the error term.

Moving from size to growth, the analysis allows me to investigate 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,

$$Growth = \rho W Growth + \sum_k \beta_k Market_k + \sum_j \gamma_j H_j + \varepsilon$$

where $Growth$ is the annualized growth rate, $market_k$ is market potential in neigbor k, H_j is an element of the set of geographic and institutional variables, W is again a spatial weight matrix and ρ is the coefficient on the spatial lag variable. This is done for three periods, one before the Zollverein and two afterwards, to see whether these second order effects are visible in addition to the first order effect of the border liberalizations.

The analysis concludes with an investigation of the adjustment 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

$$Growth_a = \alpha_a + \sum_k \beta_{ak} Market_{ak} + \sum_i \gamma_i H_{ai} + \varepsilon_a$$

where $Growth_a$ is the annualized growth rate 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 exhibit a further reach for the effect connected with the Prussian borders, which is approximately two day trips deep.[40] The corresponding values for the effect of the Thuringian and Bohemian border correspond to about one day of travel into Saxony.[41] Using these border thresholds I estimate the baseline 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 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. 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 insignificantly 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 Saxon 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

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

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

location characteristics. It even increases slightly for the cost measure. The Zollverein had a clear, positive and strongly significant effect through the liberalization of the Saxon border with Thuringia.

Saxony shared its southern border with Bohemia, which as part of the Austrian Empire did not join the Zollverein. Saxony's adoption of the Zollverein's 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 significantly 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 illustrate the reduction in growth rates of affected towns due to the entry into the Zollverein and no significantly different growth between the treatment and control group afterwards.

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 considerably higher growth of towns close to the Prussian border than for towns in the control group. The effect is basically identical for both baseline 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. However, the results for the period after Saxony's entry into the Zollverein indicate that the growth of towns close to this border is not different from the growth of towns in central Saxony in any significant way. At first glance, these numbers are at variance with the model predictions, which imply a higher growth after the Zollverein but not before. This discrepancy might be due to the fact that this border had been imposed in 1815, when Prussia annexed considerable parts of northern Saxony. In a later section I investigate the impact of this separation and reconcile the observed results with the theoretical implications of the Zollverein.

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. Higher barriers against Bohemia had the expected negative effect, though insignificantly so. The effects of the new markets in Prussia, a return from higher growth to an insignificant difference, seem contradictory to the model prediction. 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.[42]

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 periods after the Zollverein entry into the baseline specification. The reduction of the length of these periods to nine years allows the incorporation of four periods until 1871 and still avoids the impact of short-term fluctuations.[43] 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.

Towns close to the Thuringian border exhibit no significantly 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 1860s. The magnitude of the additional growth after the increase

[42] 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.

[43] The last period, 1861-1871 contains ten years, the period before the Zollverein remains at 15 years due to data limitations.

in market access begins with 0.6% in the first decade and then rises to about 0.9% over the next two periods. During the 1860s 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 taking 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 adjustment path sheds further light on this issue. While the coefficients for the periods after the Zollverein 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 were 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.

The positive effect close to the Prussian border is again visible for the time period before the Zollverein. The coefficients for the periods after 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.

6.3 Prussian Migration

The previous results indicate that there was a significantly higher population growth close to the Prussian border prior to the Zollverein and no significant different growth afterwards. This result is contrary to the model implication of higher growth in the period after the entry due to the market liberalization by the Zollverein. However, this border was actually imposed in 1815, an event which also caused a one-time migration from Prussia to Saxony. This migration, the size of which is unknown, overshadows the effect of market access change. I use a conjecture about the number of migrants to derive a hypothetical population distribution for the year 1830 without this migration. These conjectured town sizes are then used to illustrate that the results can be reconciled with the model implications.

The border between Saxony and Prussia was drawn and imposed by the Congress of Vienna in 1815. Although Saxony was one of the latecomers as an ally of France, it had stayed on France's side longer 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 this arbitrarily-drawn new border (Kohlschmidt, 1930; Keller, 2002). The official annexation agreement also contained 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) reports estimates for the total net migration between Saxony and abroad in three years intervals for the time period between 1815 and 1830.

Based on a conjectured magnitude of the migration from Prussia to Saxony based on Kiesewetter's numbers, I investigate whether this one-time event can explain the observed effect. The conjecture is used to derive a counterfactual population distribution for the year 1830. The main assumptions are that all migrants move from a Prussian town that 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.[44]

[44] This calculation uses a gravity approach in determining migration flows, the level of which depends on the size of the source and destination towns as well as the distance between them. Alternative approaches lead to similar effects.

Summing up all flows into one particular town allows me to calculate its conjectured population in 1830 and the implied growth rate between 1815 and 1830.

Estimating the main difference-in-difference specification with this implied growth rate results in a conjectured coefficient for the effect of the Prussian border prior to the Zollverein. 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.[45] Figure 5 plots the resulting coefficients for the Prussian border before the Zollverein for distance thresholds ranging from 20km to 70km.

The three panels in this figure show the coefficients for the Prussia treatment group prior to the Zollverein for three different assumed migration flows from Prussia, starting with one thousand, then eleven thousand and finishing with twenty thousand people moving. Each panel illustrates the effect of the varying treatment group thresholds. There are two main results visible. One is that under fairly strong assumptions about the size of the migration flow connected with the border imposition of 1815 the seemingly positive effect can be reduced to insignificance and even turned negative. 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.

Second, the results also show the spatial dimension of this effect. To illustrate this more clearly I split the set of towns close to the Prussian border into three subsets according to their distance from the border. The additional thresholds are at 23km and 43km. Table 4 gives the results for the estimation of this specification, which is otherwise identical to the main specification with location characteristics controls. The time period after the Zollverein again sees no different growth between towns in the Prussian treatment groups and the control group. But the first time period does see a new pattern. Towns in the treatment group closest to the border as well as in the third, which is furthest away from the border, see high positive growth, while those in the middle band do not see any statistically significant different growth compared to the control group. These results indicate that the original pattern is due to two distinct effects; the strong positive effect close to the border is the result of the migration from Prussia, while at the same time there is a shift from the two

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

bands closer to the border into the third band and closer to the remaining markets in Saxony.

The imposition of the border in 1815 and the resulting market access changes actually had the expected effect, reducing growth close to the border and shifting economic activity towards remaining market access. The additional migration from Prussia compensated for that effect, which removed the need for any further adjustment when the border got liberalized again through the Zollverein. In other words I can reasonably conclude that the puzzling result for growth close to the Prussian border prior to the Zollverein reflects the movement of migrants into Saxony.

6.4 Size effects

The theoretical framework implies that the size of a town matters for the magnitude of the effect of changes in market access. However 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 for the calculation of the implied value for the location amenity. The results of a comparison between these derived values and the actual town size will be between two extremes On the one end complete equality between population and amenity values implies that market access has no influence. On the other end no correlation implies that the complete shape of the population distribution is driven by market access. I use the population distribution of 1834 to calculate the amenity values. I do this using only Saxon towns as well as using Saxon towns in combination with all towns in neighbor states; both cases are separately done for both distance measures. The R^2 from 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 "hinterland." This illustrates the influence of rural market access which is not explicitly included in the model. The numbers, 0.44 for values based on the plain measure and 0.56 based on my distance measure, imply that there is a strong positive linkage between the size of a town and its rural market. However, further research is necessary to determine whether town size drives the size of the rural market or whether the effect goes in the opposite direction. The next step is to verify that actual town characteristics explain the implied location amenity value. Table 5 shows the result of regressing the implied location amenity values on the set of geographic location characteristics.[46] Ruggedness as well as the distances to coal mines have a significant effect. Introducing variables indicating the strength of military and public mining presence shows that armed forces especially have an impact on the local population. This effect is likely due to the families of the respective personnel as well as the presence of suppliers and other related economic activities.

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 baseline 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 sequentially drop either the largest or the smallest towns from the respective samples. Dropping small towns does not affect the coefficients, but taking out large towns results in a considerable 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 town size as dependent variable and market potential measure as well as location characteristics as independent variables.[47] Figure 4 shows the graph for the market access coefficient that exhibits a clear upward trend with a slight reverse at the highest percentiles. This indicates that market access becomes more important, conditional on the market access level, the larger is the town.

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 fac-

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

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

tor 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.[48] 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.

6.5 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 access to see whether there is any spatial connection beyond the single market potential variable. To do so I use two different 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 in table 6 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 indirect 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, a direct increase which led to higher growth. Higher growth of each Saxon town increased the market access of other Saxon towns additionally and should have led to a strengthening of the effect. 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 depen-

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

dent variables of all observations, ρWy, as a dependent variable in 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 and incorporates the effect of markets in other states by including these individual market variables in the specification.[49]

The estimated values, as shown in table 7, for the coefficient on the spatial term follow a specific pattern for both weight matrix specifications. The value is negative, though statistically insignificant, before the Zollverein, it turns positive and statistically significant for the period after the access and reverts again to a negative and insignificant effect in the later time period. These numbers show the postulated reinforcement effect very clearly. Additional population growth in neighboring towns due to a market access increase influences growth in a significant and positive way. The underlying direct effect of the Zollverein, namely the increase in market access abroad, is also statistically significant and confirms the results of the main difference-in-difference specifications.

One decisive factor for market access is infrastructure. A few years after the Zollverein was introduced, railroads began 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 were 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 lagged 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 lagged the changes in market access through the Zollverein for quite some time.

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

6.6 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 8 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 more strongly 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 also has a significantly positive effect. Although these demographic 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

I provide two sets of evidence that introducing geography and infrastructure into distance measurement leads to improvements. First, a specification including both distance measures is estimated, which gives direct evidence. In a second step I detail the resulting differences from the separate use of the cost and the plain distance measure in the estimations in section 6.

The main difference-in-difference specification uses sets of towns as treatment groups, which are selected based on one of the distance measure. To investigate the difference between the implications of the two measures I estimate the following specification, which includes treatment groups based on both measures:

$$Growth_t = \sum_l \beta_{pl} Plain_l * PreZV_t + \sum_l \beta_{dl}(Cost_l - Plain_l) * PreZV_t +$$
$$+ \sum_l \gamma_{pl} Pain_l * ZV_t + \sum_l \gamma_l (Cost_l - Plain_l) * ZV_t + \sum_k H_k * ZV_t + \delta_t + \mu_r + \epsilon_t$$

$Plain_l$ and $Cost_l$ are dummies indicating whether a town is in the respective treatment group. $PreZV_t$ and ZV_t are dummies indicating whether period t is before or after the entry into the Zollverein. The factor $(Cost_l - Plain_l)$ illustrates the difference between the treatment groups for border l defined by the two distance measures. It takes on value 1 if a town is in the group defined by the cost measure but not in the group defined by the plain measure. The value -1 indicates the opposite, that the town is part of the treatment group defined by the plain measure but not part of the cost measure group. 0 indicates that the town is either part of both groups or of no group.[50] The specification also includes time dummies δ_t, regional dummies μ_r and the set of location characteristics H.

The results are shown in Table 9. An F-test for the joint hypothesis that the coefficients on $Plain_l$ are equal to the corresponding coefficients on $(Cost_l - Plain_l)$, so $\beta_{pl} = \beta_{dl}$ and $\gamma_{pl} = \gamma_{dl}$ for all l, shows that this hypothesis cannot be rejected at a 95% significance level.[51] This implies that towns which are in the treatment group based on the cost measure but not in the treatment group based on the plain measure experience the same effect as towns in the treatment group based on the plain measure.[52] This result confirms that the selection mechanism based on the cost distance measure is more precise in identifying affected towns, illustrating the effect of ignoring geography and infrastructure for distance measurement.

Table 9 demonstrates that the cost measure defines the treatment group better. The specifications in section 6 illustrate more differences between the two measures. Distance is used there in three specific ways. The first use is location characteristics, in this case distance to an active coal mine. The second application is to delineate relevant geographical areas, i.e. what is the appropriate rural hinterland of a town. The third way is to calculate a town's market potential. The comparison of the results for the plain and cost distance measures confirms the improvements through introducing geography and infrastructure in the distance calculation in all three categories. Regarding the use in location characteristics, the results for the regression of the local amenity on actual characteristics in table 5 show robust significance

[50] The following number pairs indicate the differences between the two treatment groups for the three borders, the first number is the count for +1 and the second is the count of -1. Thuringia (2/0), Bohemia(0/30), Prussia(6/4).

[51] The F-value is 1.93 and the p-value is 0.08. Testing the restriction on each coefficient pair individually shows that with one exception all have a p-value above 0.3. The difference of the coefficients on the effect of the Bohemian border prior to the Zollverein however is statistically highly significant with a p-value of 0.0024.

[52] Towns which are in the plain treatment group but not in the cost treatment group show a different effect than the other towns in the plain treatment group and are indistinguishable from towns in the control group.

of the influence of brown coal mines using the cost distance measure while there is no significance using the plain measure. For the second application, the rural market variable is created by assigning villages to the closest town based on either distance measure. The correlation between the derived size of the rural market for each town and the amenity values implied by the model is considerably stronger using the cost measure.[53] This stronger linkage demonstrates that the cost distance measure performs better in delineating appropriate geographical areas of economic relationships. The third use of the distance measure is the calculation of market potential variables. The AIC values for the spatial size analysis, table 6, show that using the cost measure improves the model fit. Similarly, the SUR regression results in table 8 show more robust results for the market access variables.

In conclusion, introducing geography and infrastructure into the calculation of distances between markets improves the precision, robustness and fit of distance as proxy for trade cost.

8 Conclusion

This paper has investigated two major questions. First, what are the implications of using a distance measurement that includes geography and infrastructure as a proxy for trade cost? Second, what were the effects of the Zollverein and its changes to market access on regional growth patterns within Saxony?

As for the first question, distances are commonly used as a proxy for trade costs in 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 also holds for the use of distance measures in a more implicit way, for example the delineation of the extent of a relevant market.

The paper shows that market access, in addition to geographic factors like natural resources, is a major determinant of town size. This link between market access and urban size allows the identification of the growth effects of a reduction or increase in trade barriers between markets. The opening of new markets through the

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

Zollverein led to a strong increase in population growth close to those new markets. This effect was especially pronounced for towns close to Thuringia. These towns experienced an increase in annual growth of about 0.7%. The trade liberalization between Saxony and Prussia reopened markets which had previously been closed due to the imposition of a new border in 1815. Migration caused by this imposition masked the expected negative economic effects of this imposition and negated any differential growth after the border opening. The increase of barriers with the southern neighbor Bohemia had the expected negative, though statistically insignificant, effect. The effects show persistence for more than two decades, shaping the spatial dimension of the population distribution and economic activity in a significant way.

The results indicate that 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 useful in illuminating how these various forces interact and how they together shaped and will shape economic geography.

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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
Thuringian Treatment	5661	6142	1260	1260	1223
Bohemian Treatment	3990	8907	532	532	1639
Prussian Treatment	6274	10861	4157	886	1335

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

	Cost Baseline	Cost Controls	Plain Baseline	Plain Controls
Thuringia Pre-Zollverein	-0.213	-0.359	-0.134	-0.233
	(0.269)	(0.321)	(0.284)	(0.352)
Thuringia Zollverein	0.725***	0.844***	0.73***	0.76***
	(0.234)	(0.258)	(0.256)	(0.290)
Bohemia Pre-Zollverein	-0.0744	0.210	0.333	0.782*
	(0.225)	(0.309)	(0.232)	(0.435)
Bohemia Zollverein	-0.359**	-0.0914	-0.0693	0.284
	(0.148)	(0.207)	(0.118)	(0.188)
Prussia Pre-Zollverein	0.498**	0.912***	0.5*	0.538
	(0.213)	(0.305)	(0.254)	(0.433)
Prussia Zollverein	-0.0551	0.0155	0.069	0.233
	(0.171)	(0.243)	(0.188)	(0.244)
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	0.688	0.67	0.685	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 coefficient values based on the cost distance measure, Columns 3 and 4 are based on the plain measure. Columns 1 and 3 are estimated using the baseline difference-in-difference specification, Columns 2 and 4 additionally include the full set of location control variables, once for both periods and once interacted with a treatment dummy for the Zollverein. Location controls contain all geographical and institutional variables listed in the appendix. Regional Controls are dummies for the main administrative regions of Saxony. Time Controls indicate the general average growth in each period.

Table 4: Multiple Prussian Treatment groups

	Band	Cost	Plain
Prussia Pre-Zollverein	0-23km/0-6km	1.03**	1.28*
		0.454	0.727
Prussia Pre-Zollverein	23-43km/6-18km	-0.146	0.0294
		0.456	0.506
Prussia Pre-Zollverein	43-62km/18-26km	1.40***	0.896*
		0.382	0.467
Prussia Zollverein	0-23km/0-6km	-0.0972	0.0789
		0.32	0.493
Prussia Zollverein	23-43km/6-18km	-0.128	0.327
		0.3	0.323
Prussia Zollverein	43-62km/18-26km	-0.033	0.192
		0.264	0.259
Thuringia Pre-Zollverein		-0.443	-0.125
		0.308	0.347
Thuringia Zollverein		0.854**	0.797***
		0.259	0.296
Bohemia Pre-Zollverein		0.079	0.726*
		0.302	0.407
Bohemia Zollverein		-0.0705	0.280
		0.209	0.195
Regional Controls		Yes	Yes
Location Controls		Yes	Yes
Observations		280	280
R^2		0.694	0.68

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

Standard errors clustered on towns

The band column indicates the distance band for the Prussian treatment group, the first pair is for the cost distance measure, the second for the plain one. The estimation is again a difference-in-difference estimation with location controls. Additionally regional controls for the main administrative regions and time controls for the general average growth are included.

Table 5: Implied Amenity value and actual location characteristics

	Cost	Cost	Plain	Plain
Elbe (Shipping)	18.2***	17.5***	19.2***	18.9***
	(5.71)	(5.45)	(5.74)	(5.47)
River	-3.61	-4.48*	-3.55	-4.16*
	(2.43)	(2.36)	(2.30)	(2.22)
Elevation	-0.0108	-0.0200	-0.00419	-0.00798
	(0.0277)	(0.0266)	(0.0246)	(0.0235)
Ruggedness	-0.193*	-0.198**	-0.242**	-0.239**
	(0.0989)	(0.0943)	(0.096)	(0.0915)
Temperature	0.221	0.062	0.352	0.182
	(0.476)	(0.457)	(0.466)	(0.448)
Rain	0.0258	0.0193	0.0235	0.0124
	(0.0227)	(0.0222)	(0.022)	(0.0216)
Farm quality	0.071	0.0963	0.116	0.132
	(0.182)	(0.176)	(0.18)	(0.173)
Pasture quality	-0.162	-0.178	-0.166	-0.202
	(0.278)	(0.268)	(0.271)	(0.261)
Stone Coal	-0.127	-0.164*	-0.289	-0.33*
	(0.0934)	(0.0896)	(0.195)	(0.188)
Stone Coal squared	0.000472	0.000617	0.0045*	0.00431*
	(0.000484)	(0.000463)	(0.00248)	(0.00237)
Brown Coal	-0.247**	-0.182*	-0.223	-0.21
	(0.0992)	(0.0964)	(0.241)	(0.23)
Brown Coal squared	0.00122**	0.00107**	0.00417	0.00415
	(0.000473)	(0.000454)	(0.0032)	(0.00306)
Public Mining authority		49*		46.9
		(28.3)		(28.5)
Military		66.8***		67.4***
		(21.7)		(21.4)
Observations	140	140	140	140
R^2	0.139	0.217	0.137	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 cost measure is used to calibrate the model, Column 3 and 4 are based on the implied values using the plain measure as proxy for trade costs. The distance to coal mines variables (Brown Coal, Stone Coal) are measured with cost distance in 1 and 2 and with the plain measure in 3 and 4. The included location characteristics are all geographical variables, institutional characteristics are excluded due to possible endogeneity. Columns 2 and 4 differe from 1 and 3 through the inclusion of variables indicating the presence of mining activity (other than coal) or the military in the town. Since the variables are defined as the share of the population employed in both occupations and include therefore town size in the calculation I present also present the results without them.

Table 6: Spatial analysis of Town size

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

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 other market potential 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). The weight matrices, market potential and coal location characteristics in column 1 and 2 are based on the cost measure, in column 3 and 4 on the plain measure.

Table 7: 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)
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)
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)
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 8: SUR Migration and Natural Increase

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

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

Seemingly Unrelated regression of the annualized growth rate due to migration or natural increase on market potential and location characteristics. The dependent variable is the annualized growth rate of the town if only migration or only natural increase is taken into account. Dependent variables are market potential as well as the set of geographic and institutional variables described in the appendix. Additionally I add demographic variables to the natural increase part of the system, namely the birth and death rate in 1834, the gender balance (male/female) as well as the share of widowed and young people (<14 years) in the total population.

Table 9: Distance measure comparison

	Type	Coefficient	Standard Error	N
Thuringia Pre-Zollverein	Plain	-0.130	0.356	20
Thuringia Pre-Zollverein	Cost-Plain	-0.668**	0.297	2
Thuringia Zollverein	Plain	0.775***	0.296	20
Thuringia Zollverein	Cost-Plain	0.794***	0.268	2
Bohemia Pre-Zollverein	Plain	0.772	0.471	49
Bohemia Pre-Zollverein	Cost-Plain	-0.156	0.354	30
Bohemia Zollverein	Plain	0.128	0.318	49
Bohemia Zollverein	Cost-Plain	-0.162	0.234	30
Prussia Pre-Zollverein	Plain	1.02**	0.417	43
Prussia Pre-Zollverein	Cost-Plain	1.14**	0.45	10
Prussia Zollverein	Plain	0.155	0.259	43
Prussia Zollverein	Cost-Plain	-0.165	0.285	10
Regional Controls		Yes	Yes	
Regional Controls		Yes	Yes	
Location Controls		Yes	Yes	
Observations		280	280	
R^2		0.68		

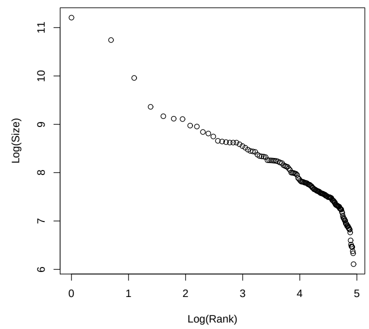
Significance Stars: *** significant at 1 % level, ** significant at 5 % level, * significant at 10% level

Standard errors clustered on towns

N indicates the size of the respective treatment group. Type indicates whether the variable equals the treatment groups defined with the plain measure (Plain) or whether it contains the difference between the treatment groups defined by the two measures (Cost-Plain). The latter takes the value 0 if the town is either in the control group or the treatment group for both measures, it takes the value 1 if it is in the treatment group based on the cost measure but not in the group for the plain measure, and it takes the value -1 if the town is not in the cost measure treatment group but in the plain distance treatment group. Time, regional and location controls are defined as in the main difference-in-difference specification.

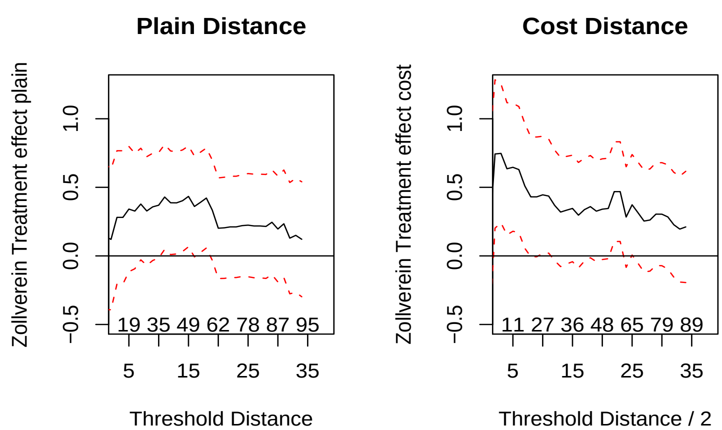
Appendix Figures

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



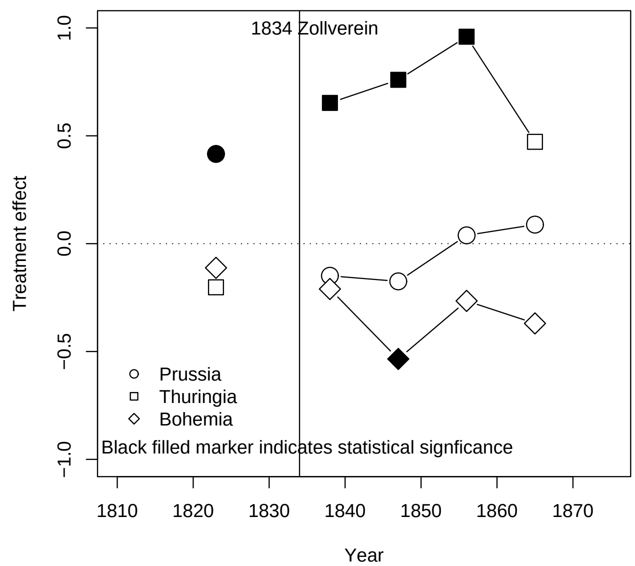
The graph plots the logarithm of town size against the logarithm of town size rank, which is the standard way to illustrate Zipf's law. Many studies about town sizes report a statistical regularity, namely that the resulting line has a slope of -1. In case of my sample the right tail drops sharply, implying 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



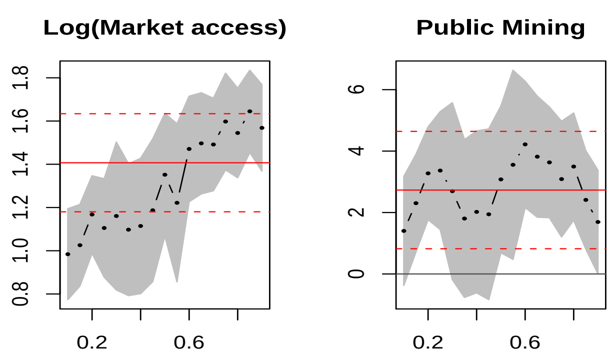
The graph plots the series of treatment effects of specifying a difference-in-difference estimations with one treatment group, namely towns close to Saxony's border with another Zollverein member. The selection of the treatment groups differ by the applied threshold distance from the border, which is 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



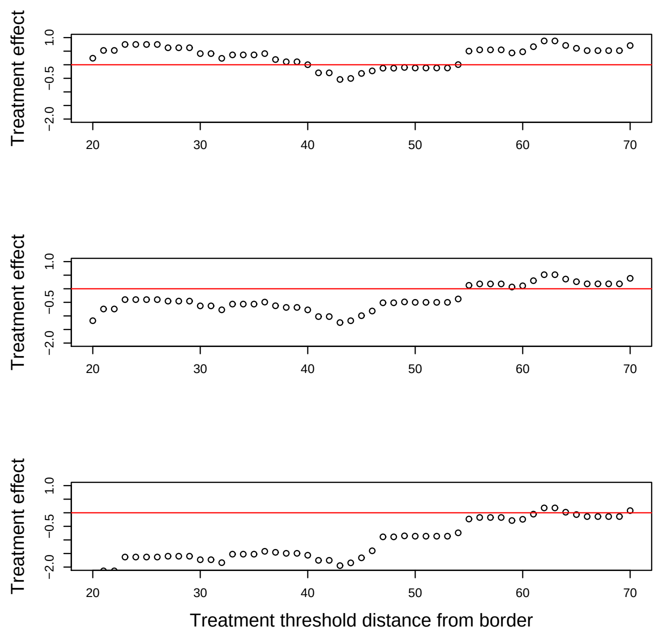
This graph shows the development of the three treatment effects over time, using the cost measure to determine the treatment group.

Figure 4: Size Quantile regression Coefficients on Market access



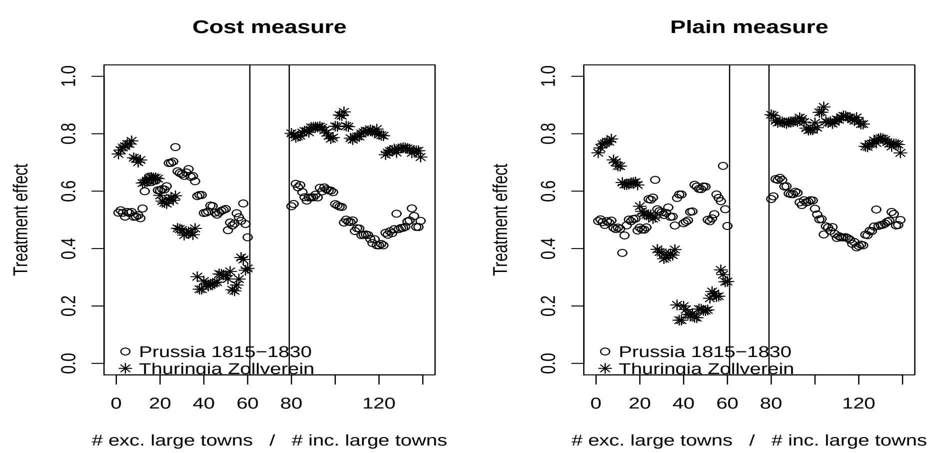
Each graph has the respective quantile on the x-axis and the resulting coefficient for that particular quantile on the y-axis. (black line are the coefficients, grey area are 90 percent confidence intervals, red solid line is the corresponding OLS coefficient, red dashed line are regular standard error.)

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



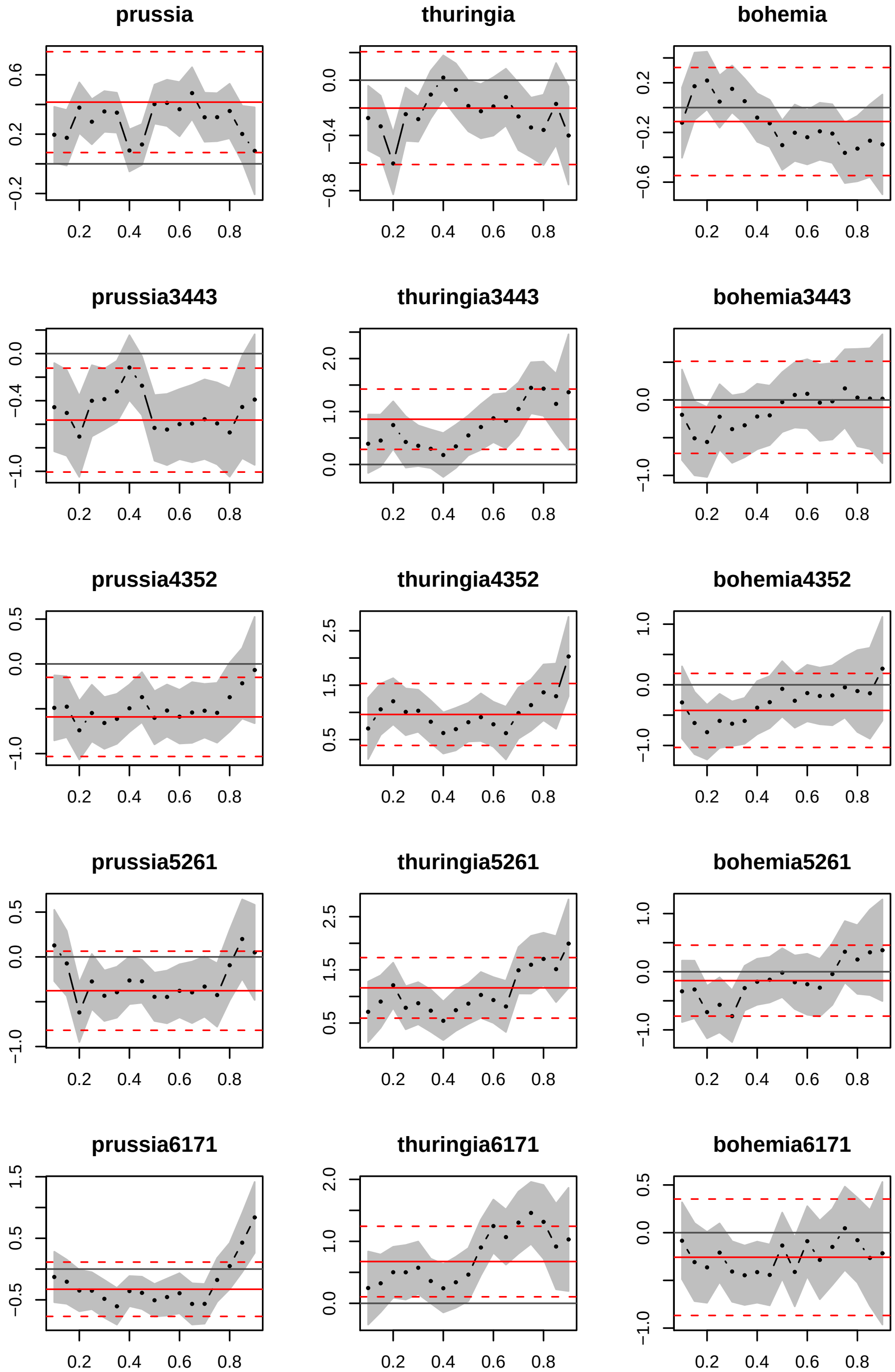
The three panels show the counterfactual treatment effect for the period 1815-1830 when the migration flow due to the Prussian border imposition in 1815 is assumed to be 1000,11000 or 20000 (from top to bottom) and 1830 town sizes are adjusted accordingly. Each panel shows the development of the effect 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 effects on the treatment groups estimated with quantile regressions (10th to 90th quantile, in steps of 5%). The specification contains multiple treatment periods after the entry into the Zollverein. The numbers in the name of each panel indicate the period in question, so prussia3443 is the effect on the Prussian treatment group in 1834 to 1843.

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
Becher, Siegfried, "Statistische Uebersicht der Bevoelkerung der oesterreichischen Monarchie", Verlag der Cotta'schen Buchhandlung, Stuttgart 1841

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 [54] This variable indicates distance to Brown Coal mines active in the

[54] 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

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 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.

translated as brown coal, while Steinkohle is stone coal

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.

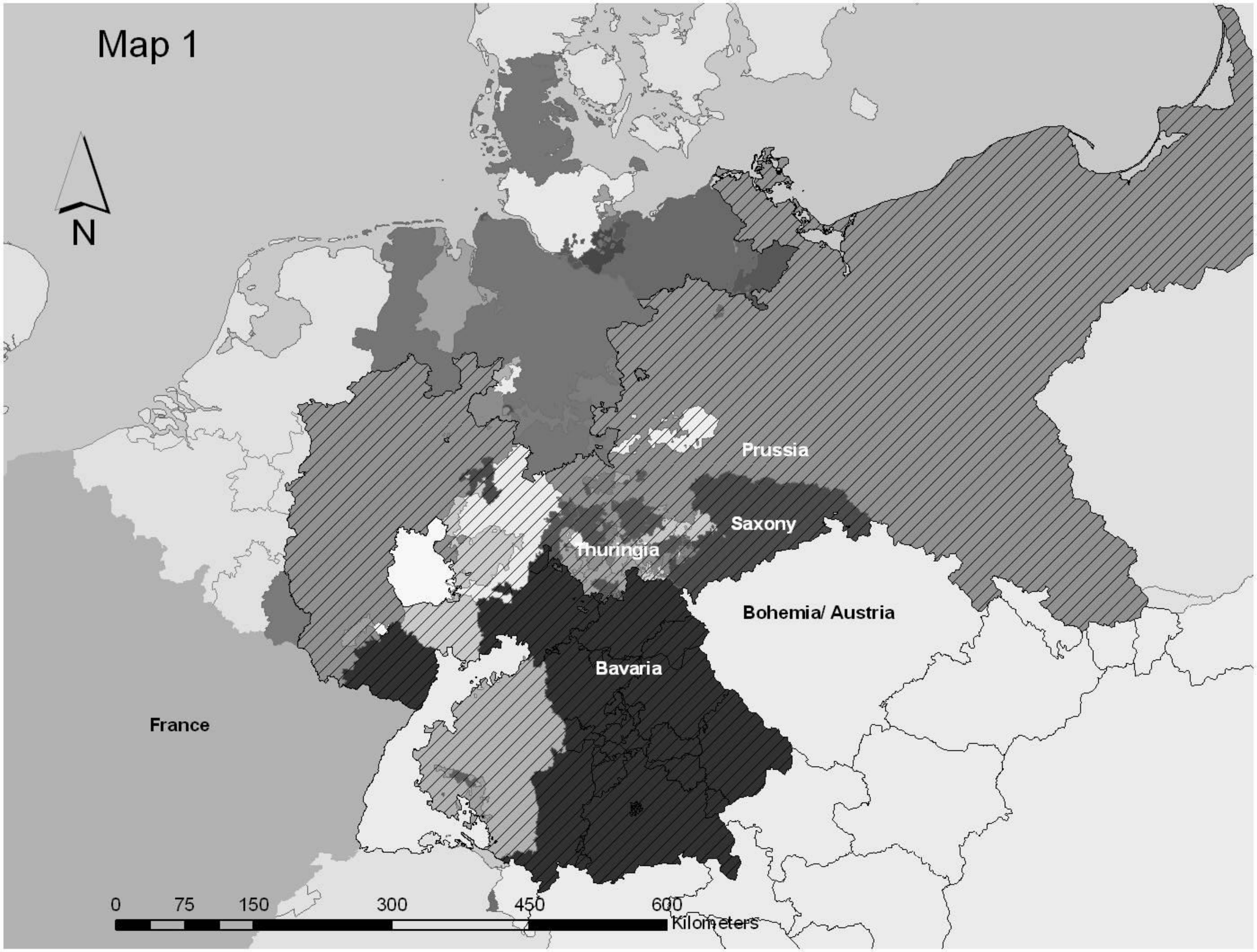
Appendix Maps

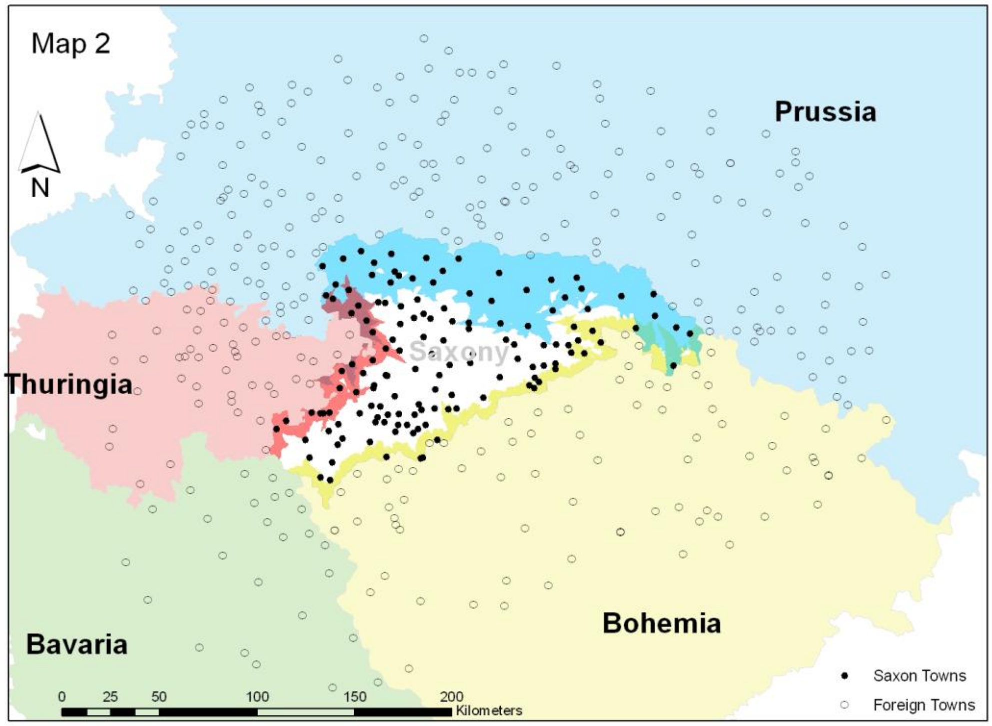
Map 1

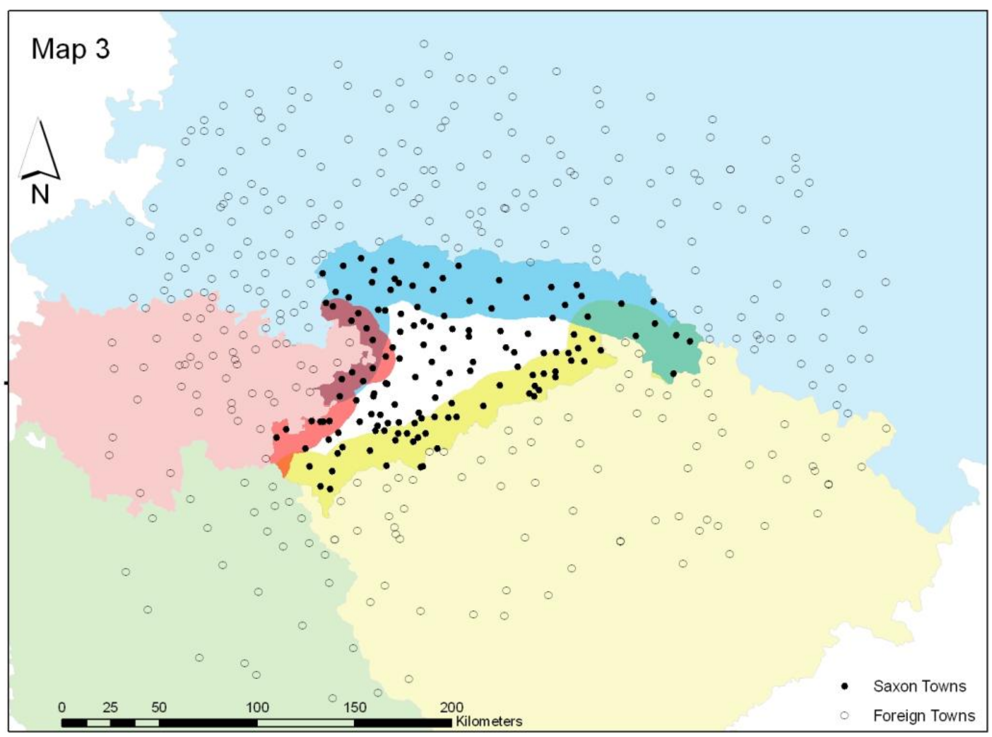
This map shows the political borders within Germany and the extent of the Zollverein in 1834. The area which is black left-shaded indicates the boundaries of the Zollverein at its formation in 1834.

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
Saxony
Thuringia
Bavaria
Bohemia
Saxon Towns
Foreign Towns
0 25 50 100 150 200
Kilometers


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