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Cities and Innovation

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Postal Address:
Institut d'Economia de Barcelona
Facultat d'Economia i Empresa
Universitat de Barcelona
C/ Tinent Coronel Valenzuela, 1-11
(08034) Barcelona, Spain
Tel.: + 34 93 403 46 46
Fax: + 34 93 403 98 32
ieb@ub.edu
http://www.ieb.ub.edu

BORDERS, MARKET ACCESS AND URBAN GROWTH; THE CASE OF SAXON TOWNS AND THE ZOLLVEREIN *

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ABSTRACT: The Zollverein, the 1834 customs union between independent German states, removed all internal borders. This paper investigates its economic impact focussing on urban population growth in the state of Saxony. Implications from a economic geography model are tested with a data set on town populations and location characteristics as well as an improved distance measure created with GIS techniques to include geography and infrastructure. Saxony's Zollverein membership led to significantly higher growth for towns close to the liberalized border. The effect depended on a town's size, was reinforced through neighboring markets and worked through influencing migration and natural increase.

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Florian Ploeckl
University of Oxford
Nuffield College
1 New Road, Oxford
OX11NF, United Kingdom
E-mail: florian.ploeckl@economics.ox.ac.uk

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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 economic activity in regions close to and far from the borders?

The Zollverein was the first major customs unions and represents a historical case of peaceful border elimination, where economic unification predates the political development.[1] 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 German market led to an increase in the number and size of regional markets traders could access. This leads to the question how this institution affected the spatial location of economic activity within the states. Recent cross-country literature on the effects of trade agreements (Rose, 2004; Estevadeordal, Frantz and Taylor, 2003), or related institutions like currency agreements(Lopez-Cordova and Meissner, 2003), focus on the effects on the states as a whole, similarly Keller and Shiue (2008) investigates the price integration effect of the Zollverein between states. Shiue (2005) additionally shows that the Zollverein had an impact on market integration within a state. This paper focuses on the internal impact of the Zollverein, and is more in line with work on the effects of regional agreements like Nafta (Hanson, 1996). The theoretical basis for this is a model based on the new economic geography (Krugman, 1991). In particular I utilize Redding and Sturm 2008, which generalizes Helpman

[1] Economic unification was not the proximate cause for political unification, which was clearly military conflict. However the high level of economic integration had substantial influence on the success of political integration after the wars.(Rothe, Ritthaler and Oncken, 1934)

(1998) and formulates it in terms of market and supplier access (Redding and Venables, 2004). This theoretical framework links location size with market access and location fundamentals. Therefore I use the growth of towns in Saxony, one of the member states of the Zollverein, around its entry into the customs union in 1834 to identify effects of this institution on local and regional activity. This allows the analysis to be on a finer geographical level than alternative measures like GDP data or trade flows as well as solves the problem of non-existent or low quality historical data.

The bases of this investigation are increasing returns and agglomeration economies. International trade patterns at the onset of the industrial revolution fit Heckscher-Ohlin patterns (O'Rourke and Williamson, 2005), which raises the question whether the economic structures at the time allowed for increasing returns and agglomeration economies, at least in local and regional patterns. If the impact of the Zollverein corresponds to predictions implied by a new economic geography framework, it follows that increasing returns were already at work in the early stages of the industrial revolution that were not yet dominated by large-scale manufacturing structures and large urban agglomerations.

The focus on the effect of changes in market access requires a notion of transport costs between markets. Recent work has shown that the specific formulation of this factor matters (Bosker and Garretsen, 2008). I incorporate geography and infrastructure into the measured distance between markets using Geographic Information Systems (GIS) methods to create a more precise measure than the commonly used plain great circle distance. Population data serve as the outcome variables and are used with the distance measure to create empirical market access measures. The source is a newly collected dataset on historical population and town characteristics within Saxony and neighbouring states. Additionally geographic and institutional town characteristics are introduced into the estimations to control for the influence of institutional factors and location fundamentals.

The results of the empirical estimation, which makes use of differences in tariff changes depending on the particular neighbour state, show clearly that the Zollverein had a substantial, differential impact on regional growth of urban population. This implies that the central mechanisms, market access and agglomeration economies, were already at work at the onset of the industrial revolution. Furthermore it shows how institutional changes shaped the location of economic activity, which had a lasting impact for the development of the economy during the industrialization process into modern times.

Section 2 provides an outline of the historical context for Saxony and the Zollverein. Section 3 describes the theoretical framework, the New Economic Geography model from Redding and Sturm (2008), and derives 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 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 led to its involvement in the Napoleonic Wars. Saxony emerged with substantial territorial losses to Prussia but only minor changes to economic and political institutions.

At the Congress of Vienna, Saxony became a member of the *Deutsche Bund*, a political institution established there by the German states.[2] 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.[3] 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.[4] Although some

[2] 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)

[3] Henderson (1984) provides a historical overview, see Ploeckl (2010*b*) for an explanation why the German states, especially Prussia, preferred regional agreements over a multilateral approach for the whole of Germany.

[4] 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.

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 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 unions. The Zollverein, now a customs union encompassing a significant number of German states, came officially into being with the year 1834.[5]

The Zollverein 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).[6]

At the time of the Zollverein Saxony was a region with one of the highest population densities as well as urbanization rates within Germany (Kiesewetter, 2007). Most of its towns 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 confirmed a clear institutional separation between towns and villages and reinforced stability of the set of locations classified as towns (Blaschke, 1967).

[5] Ploeckl (2010*b*) 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.

[6] 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.

3 Theoretical Framework and Implications

Saxon towns were therefore 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) takes up this framework and extends 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 this model as the theoretical framework to investigate Saxony's urban structure and the effects of the Zollverein.

It incorporates the urban population as a mass of representative consumers, labeled L, and has each consumer living in a specific location c, which I take to be all towns within Saxony.[7] Consumers provide labor, the sole factor of production, for which they receive a location specific wage. Locations produce horizontally differentiated manufacturing goods with the differentiation of these varieties based on the Dixit-Stiglitz form[8] and the production process for each variety has a fixed cost, F, and a constant marginal cost. 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.[9] Each location is endowed with a stock of a non-tradable amenity H_c, the level of which is exogenously given for each location.[10] The amenity is supplied perfectly inelastic for consumption by consumers at the location; the total expenditure on the amenity is redistributed to the consumers. The utility function of each consumer has the Cobb-Douglas form, with an index of manufacturing varieties and the amenity as the two consumption inputs.[11] The demand from all locations for goods from location c, which is the total market size for these goods, is summarized as firm market access FMA_c, while the

[7]This is a fixed number, which corresponds to the point that the set of towns was stable during the time period in question.

[8]This implies a constant elasticity of substitution σ between the varieties.

[9]So $T_{ic} > 1$ units of the goods have to be shipped from location i, such that exactly one unit arrives in location c.

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

[11]This leads each consumer to allocate a share μ, with $0 < \mu < 1$ of her income to purchases of manufacturing goods and a share of $1 - \mu$ for the local amenity.

total supply of varieties in location c is formally defined as consumer market access CMA_c:

Full labor mobility leads to real wage equalization, which is used to link the population distribution with the defined market access measures and the stock of the local amenity in the following way:

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

where χ is a function of model parameters and the common real wage.[12]

This 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. 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).[13] The theoretical framework focuses on the other two, but these theories will not be tested here.[14] Ploeckl (2009) uses this model framework to test for the importance of market access and location characteristics for the size of towns, which is confirmed by the analysis.

The model provides an explanation for differential urban growth. The equilibrium equation implies that differential growth between towns can be caused by changes in any of 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 in-

[12] $\chi \equiv \omega^{-1/(1-\mu)} \xi^{\mu/(1-/mu)} \mu/(1-\mu)$, 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.

[13] 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 .

[14] Beeson, DeJong and Troesken (2001) gives 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.

crease 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 model linkage implies that urban population growth represents growth of the extent of economic activity in the town. The nature of the production process implies that urban population reflects the quantity, though not necessarily the value, of goods produced in the town, population growth therefore represents an increase in the absolute amount of goods produced directly. The link between urban population growth and individual productivity growth depends on which of three channels caused the population growth. If firm market access increased, then the value of the goods produced in the location increased, so urban population growth reflects an increase in individual productivity.[15] If changes to consumer market access or the amenity are the source of population growth, then individual productivity is not directly affected.[16] Consumer welfare is also affected by differential urban population growth. Changes to any of three channels cause a discrete change in welfare, urban population growth is then the mechanism which brings the resulting differential welfare between locations back to equality, which has to hold due to full labor mobility. So an increase in market access leads to a higher relative utility for consumers in the affected location, the resulting relative higher population growth in these location is reducing utility until its the same as in the other locations.[17]

The impact on the equilibrium population distribution through the three channels – firm market access, consumer market access and location characteristics – is

[15]Urban growth is directly reflecting individual productivity growth, but only as a resulting consequence. Individual productivity increased and as a consequence the town grows relatively faster until the new equilibrium has been reached.

[16]Individual productivity might be affected through a second-order effect if the range of varieties produced does not increase proportionally with population growth. The increasing returns setup for production implies an increase in individual productivity when the range of varieties increases less than the total supply of labor.

[17]This reduction effect might be a possible explanation for the anthropometric evidence, which sees a reduction of heights for people born after the Zollverein (Cinnirella, 2008).

summarized in the following equation, where X is the equilibrium before any change, Y the resulting outcome.

$$\ln(\frac{L_c^Y}{L_c^X}) = \frac{\mu}{\sigma(1-\mu)}\ln(\frac{FMA_c^Y}{FMA_c^X}) + \frac{\mu}{(1-\mu)(\sigma-1)}\ln(\frac{CMA_c^Y}{CMA_c^X}) + \ln(\frac{H_c^Y}{H_c^X}) \qquad (2)$$

The town 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 $FMA^X_{Large} > FMA^X_{Small}$. A change in trade barriers increases market access for both by the same absolute amount, $FMA_\Delta = FMA^Y_{Large} - FMA^X_{Large} = FMA^Y_{Small} - FMA^X_{Small}$, which implies that the relative change is higher for the small town $\frac{FMA_\Delta + FMA^X_{Small}}{FMA^X_{Small}} > \frac{FMA_\Delta + FMA^X_{Large}}{FMA^X_{Large}}$. Since the relationship between market access growth and population growth is positive, this relatively higher change in market access implies a stronger relative growth effect for smaller towns.[18]

A further implication of the model, which is not tested by Redding and Sturm (2008), 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 also be reinforced.

4 Tariff Barriers

The main impact the Zollverein had by altering tariff barriers between Saxony and its neighbors[19] was a change to market access. Its precise impact on Saxon towns depended 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.[20] The main element of the taxation system was a general excise tax,

[18] This relationship also holds for consumer market access.
[19]See Map 1 for their relative geographical position.
[20] It levied such a tax on a few imports, but the extent was very minor (Ulbricht, 2001).

the so-called *General-Konsumtions-Akzise* (Reuschel, 1930).[21] 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. The national character of this tax implies that the levied rates were identical for all towns.

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 (Engel, 1858).

Facing huge war debts after the Napoleonic Wars, many German states turned to tariffs to raise revenues. Prussia, bordering Saxony in the north, 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).[22] At the same time, Bavaria, Saxony's neighbor in the south west, 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, restricting significantly any form of trade between the two states (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

[21] 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.

[22] 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).

tolls on the main east-west trade routes connecting the major trade fairs of Leipzig and Frankfurt.

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 the data and variables used for the three main factors: urban 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).[23] Town boundaries see almost no change during the time period in question; the extent of the incorporation of villages into towns is neg-

[23] 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).

ligible before the late 19th century (Wächter, 1901). Most papers apply a size-based approach to identifying towns, based either on absolute or on relative size (Bairoch, 1988). I use a legal definition and include all settlements that 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.[24] This institutional homogeneity avoids problems due to the economic effects of different legal environments between towns and other settlements.

The population dataset contains the years 1815, 1830 and 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.[25]. 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.[26]

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

The first category contains variables that indicate the 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.[27] Another set are

[24] 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 were 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.

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

[26] 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 are 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.

[27] 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

natural and climatic factors such as 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 the 20th century.[28] 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. Historically natural characteristics also influence the location of military installations, which is measured by the amount of military personnel in a town. These location characteristics are generally not subject to change over time. This alleviates any problem of a possible endogeneity with regard to size or growth of a town .

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 information about transportation, for example whether the town had a post office and, later, a railroad station. Another set relates to the idea of human capital, measured by the presence of the 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.[29] 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.[30] These characteristics are used together with the first set as the representation of the local amenity in specifications investigating growth patterns. Table 1 reports summary statistics, 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. Some econometric specifications will use a population-based empirical market potential variable for this. 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

whether a river is within a kilometer of the town.

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

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

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

a measure of the size of the market and d_{ci} is the distance to this market.[31] I use urban and rural markets in Saxony as well as urban markets abroad and take their respective population as the market size.

- *Urban Market in Saxony* This set contains all towns within Saxony, which, in 1834, officially had 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 also centers of economic activity in Saxony's neighbor states, and therefore represent 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 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.[32] 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.[33]

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.[34] There are no

[31] There are various market size measures used in the literature. Harris, for example, took retail sales, Hanson used 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 and Gerhold, 1995), which makes the issue moot in this context.

[32] Depending on the empirical specification, this assignment is based on either plain distance or the cost measure developed in this paper.

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

[34] Bosker and Garretsen (2008) surveys varying functional specifications to include cost factors, showing 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 such as border effects or being landlocked, and combines these with distance measurements. Given the absence of trade flow data, I follow a direct approach, by specifying the trade cost function as a power function of distance.

comprehensive historical travel time or transportation cost measures for Saxony and its neighboring regions. Historical transportation technology, furthermore, depended strongly on geographical factors.[35]

I calculate a cost measure using GIS methods to incorporate various cost modifiers to account for this dependence.[36] 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 also explained in the appendix. The outcome value is a relative distance measure, where the benchmark is travel on flat, highest quality roads. So, a distance cost value of 50km between town A and B implies that traveling from A to B is as expensive as traveling 50km on a completely flat and straight road of the highest contemporary quality.

In most cases the cost value is higher than the plain distance value between two points, and it is asymmetric due to cost asymmetries associated with differences in the elevation and slope of the two travel directions between the two points. The magnitude of this effect of geography is relatively small, since it depends on the existence of significant elevation differences between the two towns. A possible significant source for these differences in the case of Saxony and its neighbors is the *Erzgebirge*, the range of mountains to the south of Saxony, along the border with Bohemia. However, the relatively low height of these mountains and the small number of affected towns keep these differences relatively small. A major source of asymmetry, which is not included in the distance calculation, is the differential trade barriers between the two towns. The differences in trading regimes between Saxony and its neighbors, as described above, are such barriers.[37] The asymmetry of the distance measure, $d_{ic} \neq d_{ci}$,

[35] There are of course other factors which influence transaction costs, in particular cultural and social factors like different languages.(Shiue, 2005). However Saxony and its neighbour states had the same language, had no major ethnic differences and had in general fairly strong cultural, social and institutional similarities.

[36] Similar methods have been used in other academic disciplines, for example for the calculation of catchment areas in archaeology or epidemiology.

[37] Obviously, these only affect trade with foreign states, not domestic markets.

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.[38]

The effectiveness of this new distance measure is investigated by comparing it to the regular plain distance. All empirical specifications include the distance measure in some form, therefore all specifications are estimated twice, once for my measure as well as for plain distance.[39]

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 Zollverein member states. 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 initial specification looks at the connection between the change in size, as measured by the change in population growth rates, and the change in market access, as seen by the relative size of the different markets. This leads to the following specification:

$$\Delta Growth_c = \alpha + \sum_l Market_{cl}/Market_{cPre} + \varepsilon_c \tag{3}$$

where $\Delta Growth_{Pre}$ represent the change in towns' growth rates, $Market_{cl}$ is town c's market potential in market l, in particular those in Thuringia, Bohemia, Prussia and the domestic urban market in Saxony. $Market_{Pre}$ is the market access prior to the Zollverein. This specification is tested for both distance measures, absolute as well as relative change in growth rates, as well as the minimal (only domestic) and maximal

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

[39] 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.

(domestic and international) market access prior to the Zollverein.

The theoretical model assumes each town to be affected according to the size of the relevant market access. Although I use market potential as a proxy for market access not only in this initial specification but also in a number of extensions, in the main empirical specification I model 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 made with the purpose of robustness based on the nature of the liberalized tariff barriers. The specific nature of the Prussian tariffs and the Thuringian tolls imply that the barrier was not proportional to good values, and therefore transport costs.[40] The distinct and discrete nature of the tariff barriers imply that they are relatively stronger for goods with low relative transport costs, i.e those produced close to the border.

Redding and Sturm (2008) establishes a correlation between the impact on a town‘s growth and its distance to border through a simulation exercise, which is then empirically tested estimating a difference-in-difference specification. The treatment group is based on town‘s distance to border, with the threshold derived from the simulation. For the case of the Zollverein the given data prevent a similar simulation exercise, therefore I begin by using a moving threshold. The treatment group for the initial difference-in-difference specification is chosen based on town‘s geographical proximity to a specific border segment, in particular Saxony's borders with the other Zollverein states. The estimation will be repeated moving the distance threshold used to determine the treatment group further from the border in each step. The results establish whether the liberalization through the Zollverein had a significant differential effect on growth for towns close to the border.

My main specification modifies this initial approach in two ways. First, I investigate the effect of the Zollverein in more geographic detail, introducing separate treatment categories for the individual border parts with Prussia, Thuringia[41] and Bohemia. Second, I select the distance thresholds based on a grid search.[42] Addi-

[40]The proportionality of transport costs rests on the regular assumption of iceberg trading costs.

[41]The Bavarian border is not included to its short length and significant distance from Saxon towns. As a robustness check I also ran the analysis including the Bavarian part in the Thuringian section, which did not change the results.

[42] 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 Redding and Sturm find for the effect of the German separation. This reduction is justified by the improvements of transportation technology between the Zollverein and the German separa-

tionally this approach reveals information not only about the change through the Zollverein, but also distinguishes the effects working before and after the customs union entry.

This leads to the following formal specification:

$$Growth_{ct} = \sum_l \beta_l(Border_{lc}*PreZollverein_t)+\sum_l \gamma_l(Border_{lc}*Zollverein_t)+\delta_t+\mu_r+\epsilon_{ct} \tag{4}$$

where subscript t denotes a time period, *Border* is a dummy which indicates whether the town is assumed to be affected through the Zollverein,*PreZollverein* indicates the time before the Zollverein, and *Zollverein* the time after Saxony's entry . 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.

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.[43]. To see whether this is the case around 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.

Furthermore the model does not make any predictions about the speed of adjustment. The data however allow to investigate the adjustment path over time based on the main difference-in-difference baseline specification. I do this through the inclusion of multiple periods after the Zollverein entry following the development of the effect over time. In particular I include four time periods of nine years[44]to illuminate the change in the effect more clearly.

In contrast to the adjustment path the model contains implications about the

tion 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

[43] 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.

[44]The periods are 1834-1843,1843-1852,1852-1861, and 1861-1871, with the last period actually lasting ten years.

effect of a town's size. In particular the strength of the effect is influenced, smaller towns should experience a larger impact. I investigate the strength of the effect along the size distribution by estimating the difference-in-difference specification with size-based subsamples. The results of the repeated estimation show the change in the effect when either a number of the largest or smallest towns are dropped from the sample.

Moving from size effects to spatial interaction, I investigate the existence of a 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 which is estimated with Maximum Likelihood,

$$Growth_c = \rho W_c Growth + \sum_k \beta_k Market_{ck} + \sum_j \gamma_j H_{cj} + \varepsilon \tag{5}$$

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 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 equilibrium of the theoretical model works not only for a constant population, but also for a growing one.(Redding and Sturm, 2008) There are two sources for the growth of the total urban population in Saxony, namely natural increase through a larger number of births than deaths, and migration, the move of rural population into towns.[45] This raises the question, which of these two growth mechanisms can be influenced by the shock to market access and therefore lead to differential growth between towns. To answer this question I utilize data about the sources of each town's population growth, migration or natural increase, which are available for the time period 1834 - 1852.[46] These numbers are used in a Seemingly Unrelated Regression approach to determine which channel was affected by the Zollverein. The formal

[45] Foreign migration is during this time too small to make a substantial impact and will therefore be lumped in with rural migration.

[46] The natural increase numbers are based on actual birth and deaths numbers, while migration is implied by the difference between natural increase and total population growth of a town.

specification is

$$Growth_{ca} = \alpha_a + \sum_k \beta_{al} Market_{cal} + \sum_j \gamma_j H_{caj} + \varepsilon_{ca} \tag{6}$$

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. $Market_l$ is the market potential in the relevant state and H_j 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 results of the initial specification, as shown in Table 2, clearly indicate that market access changes influenced town's growth rates and therefore their size. In particular towns with larger relative market in Thuringia show a strong increase, while towns with a larger market in Prussia also see a change, though it has a negative sign. Although the effect of the Bohemian market has the right sign, it is not statistically significant. The domestic urban market, as expected, did not influence changes in growth rates.

The initial difference-in-difference specification demonstrates that the Zollverein had a positive growth effect on towns close to the liberalized border. The two graphs in Figure 1 depict the resulting treatment coefficients from repeated estimations, illustrating that the effect is statistically significant and positive for towns within certain distances from the border. The size of the effect is considerable, an absolute difference of about 0.5% growth a year implies for example that towns were 9.2% larger after 15 years than they otherwise would have been. Especially the results using the cost distance measure to determine towns‘s distances to the border, and therefore the treatment group, show a clear, monotone decreasing effect, confirming that the effect weakens when towns further from the border are included in the treatment group.

The main specification takes these initial results further by demonstrating the impact of the different markets. The specification investigates the separate effects, 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 walking trips deep.[47] The corresponding values for the effect of the Thuringian and Bohemian border correspond to about one day of travel into Saxony. Maps 3 and 4 show their actual geographical location. 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. The purpose of the extension concerning location characteristics is to control whether they can explain the observed differential growth. Columns 2 and 4 show therefore 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, mirroring the results of the market potential based specification. 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 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.[48]

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

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

[48] As robustness checks. I conduct a median regression of the main difference-in-difference specification as well as a fixed effects specification, the obtained results are consistent with the regular OLS estimation.

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, which are interacted with time period dummies, 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 is due to the fact that this border had been imposed in 1815, when Prussia annexed considerable parts of northern Saxony. Although this implies that town‘s should have grown slower in the time period between the imposition in 1815 and the lifting of barriers in 1834, a related one-time migration effect reverses the sign of the impact. In the appendix I investigate the impact of this separation and the related migration effect quantitatively and reconcile the observed results with the theoretical implications of the Zollverein.

In summary, the results of the main specification show that the liberalization of tariff barriers and the increase in market access had strong positive effects on the economic activity in affected towns, as shown in their population growth. The effects appear to be very general, individual town characteristics cannot explain the observed differential growth. Especially the new markets in Thuringia to the west of Saxony had a strong positive effect, the new access to markets in Prussia reversed the imposition of barriers in 1815 and the higher barriers towards Bohemia had not much of an impact.

6.2 Adjustment Path

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.[49] The results are represented graphically in Figure 2 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 but a strong positive effect afterwards. The development indicates that the effect grew stronger over time before dropping back considerably during the 1860s. The magnitude of the additional growth after the increase 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

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

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.[50] 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, as discussed in the appendix

6.3 Size effects

The theoretical framework implies that the size of a town matters for the magnitude of the effect. 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 3 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 agglomeration economies did not exist below the

[50] Although the geographic variables are time-invariant, they are interacted with time period dummies.

threshold and consequently very small places did not see any effect of market access changes at all. Such an effect corresponds well to the results of Ploeckl (2010*a*), which uses a similar dataset covering Saxony's population in the middle of the 19th century and related agricultural endowments to determine a size threshold for urbanization of about 2000 inhabitants.

6.4 Spatial effects

Spatial econometrics is applied to look at additional spatial effects influencing the growth of towns. The interaction process between towns is modeled using 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.

Using them I investigate 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. The growth transmission mechanism is modeled by the inclusion of a weighted sum of the dependent variables of all observations, $\rho W y$, as an independent variable in the specification, which is again estimated using maximum likelihood. The two weight matrices introduced 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.[51]

The estimated values, as shown in Table 4, 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 re-

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

inforcement 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.[52]

6.5 Migration and Demographic change

The model incorporates full labor mobility as the mechanism to reallocate population. However a growing total urban population implies that the two mechanisms behind this growth, urban-rural migration and natural increase, are the relevant potential sources for differential growth of towns. 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, which was not directly observed, as the difference between total growth and natural increase. The resulting number indicates the net population change caused by migration for each town. Using these numbers for migration and natural increase I estimate the above described seemingly unrelated regression specification.

Table 5 shows the results.[53] The effect of 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

[52]The results also show that the effect of railroads on Saxon towns 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.

[53]The human capital variables show an interesting pattern. 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 causes migratory effects, but doesn't seem to affect demographic patterns .

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 natural increase furthermore shows that this institutional change and related economic growth affected not only migratory patterns but also demographic ones.

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 variables indicate that differences in the demographic characteristics of towns at the time of entry into the Zollverein had an impact on population 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 shown impact of market access on migration as well as natural increase allows to calculate the contribution of the Zollverein to urbanization in Saxony. Urban population[54] represented 32.6% of Saxony's total population in 1834 and 35.0% in 1852. Converting the above results into changes in urbanization indicates that migration due to the Zollverein led to an increase of 2.0% (or 1.4% using the plain distance measure), and natural increase made an additional contribution of 0.7% (0.6%). This implies that most of the rise in urbanization between 1834 and 1852 can be explained as a result of the Zollverein. This complements nicely with the stagnation of urbanization prior to entry. The urbanization rate stayed flat at 32.3% from 1815 to 1830. Furthermore the total magnitude of the Zollverein effect of 2.7% (2.0%) is substantial compared to the increase in urbanization during the height of the industrialization

[54] This continues to use the set of locations with town rights to determine urban settlements.

process between 1852 and 1871, which was 4.6%. If changes in the the urbanization rate are a good indicator for economic growth in a state, then the Zollverein not only had a significant impact on relative regional growth but also made a substantial contribution to total growth, even in comparison to industrialization.

7 Distance Measure

The difference-in-difference approach to identify the effects of the Zollverein offers the possibility to illustrate statistically the impact of including geography and infrastructure into distance measurement. The basis for the comparison is the determination of the treatment groups based on the distance measure. The sets of towns assumed to be affected by the Zollverein are selected using towns' distances to borders, resulting in different groups for the two distance measures. The effect on the growth of towns, which were selected by only of the two measures, allows to identify which of the two measures selects the affected towns more precisely. The treatment groups based on both measures are combined within one specification, which is as follows:

$$\begin{aligned} Growth_{ct} = & \sum_l \beta_{pl} Plain_{cl} * PreZV_t + \sum_l \beta_{dl} (Cost_{cl} - Plain_{cl}) * PreZV_t + \\ & + \sum_l \gamma_{pl} Pain_{cl} * ZV_t + \sum_l \gamma_l (Cost_{cl} - Plain_{cl}) * ZV_t + \sum_j \lambda_j H_{cj} * ZV_t + \delta_t + \mu_c + \epsilon_{ct} \end{aligned} \tag{7}$$

$Plain_{cl}$ and $Cost_{cl}$ are dummies indicating whether a town is in the respective treatment group for border l. $PreZV_t$ and ZV_t are dummies indicating whether period t is before or after the entry into the Zollverein. The factor $(Cost_{cl} - Plain_{cl})$ 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.[55] The specification also includes time dummies δ_t, regional dummies μ_c and the set of location characteristics H_c.

The results are shown in Table 6. An F-test for the joint hypothesis that the coefficients on $Plain_{cl}$ are equal to the corresponding coefficients on $(Cost_{cl} - Plain_{cl})$,

[55] 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).

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.[56] 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.[57] 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.

All the specifications investigating the different aspects of the effect of the Zollverein are estimated separately for both distance measures. This implies the use of distance in two particular ways, first to measure the relationship between two locations in a continuous way, and second to delineate appropriate market areas, measuring the relationship in a discrete way. A comparison of the results for the specifications using actual market potential, and based on continuous distance, show only some indication of improvement, for example the significance of market potential in the growth mechanism regressions.

Saxony's geography is rather continuous, the mountain range along the southern border is fairly low and offers sufficient possibilities for safe passage. This in connection with a relative developed road network implied that the variation in transport costs is not very extensive. This implies that an effect on long-distance trade, which would only be substantially affected through major obstacles, i.e. high mountain ranges, infrastructure-less areas like deserts, or major oceans, are between origin and destination is not to be expected for this setting and confirmed by the results. Figure 4 shows that the relative differences between the two measures are the starkest for short distances,while for longer travels they appear to converge. This demonstrates graphically that geography and infrastructure affect distance in an absolute rather than relative way. It explains the clear improvement demonstrated above for the use of distance to in a discreet way. The delineation of affected areas, especially on a regional level, is strongly influenced, leading to an improvement in the use of distance. The shown example, the determination of treatment groups for the effect

[56] 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.

[57] 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 Zollverein, clearly illuminates the contribution the inclusion of geography and infrastructure can make to the use of distance in measuring market access.

8 Conclusion

The Zollverein and Saxony's entry in 1834 present a clear and strong case of peaceful border removal, leading to a clean impact on the market access of towns. This paper utilizes differences in this impact to identify whether and how these changes to market access affected regional growth.

The opening of new markets through the 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, A town's size influences the strength of the effect, which also sees reinforcement through the effect on neighboring locations. Migration, as well as natural increase, act as mechanisms to allow changes in market access induce differential growth. Furthermore the increase in integration was a catalyst for a significant increase in urbanization as well. Institutional change, the peaceful creation of a common market, shaped the spatial dimension of the population distribution and economic activity in a significant way

The analysis further shows that geography and infrastructure influence market access. GIS offers the possibility to include this factors into distance measurement, improving the precision of these measures. The improvement is especially clear for local and regional analysis, as well as the delineation of markets. Although market access usually only looks at urban markets, especially in historical and less developed the size and extent of rural markets may play an important role. As shown, geography and infrastructure can affect them substantially and should be taken into account.

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 the historical development, the industrial revolution and onset of modern economic growth.

References

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

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

Alber, Georg. 1919. *Zollverwaltung und Zollerträgnisse in Bayern seit dem Jahre 1819.* München:Limmer.

Aldcroft, Derek. 1986. *Transport in the Industrial Revolution.* Manchester:Manchester University Press.

Angelow, Jürgen. 2003. *Der Deutsche Bund.* Darmstadt:Wissenschaftliche Buchgesellschaft.

Bairoch, Paul. 1988. *Cities and economic development : from the dawn of history to the present.* Chicago:University of Chicago Press.

Barker, T.C., and Dorian Gerhold. 1995. *The rise and rise of road transport, 1700-1900. New studies in economic and social history*, New York, NY, USA:Cambridge University Press.

Beeson, Patricia E., David N. DeJong, and Werner Troesken. 2001. "Population growth in U.S. counties, 1840-1990." *Regional Science and Urban Economics*, 31(6): 669–699.

Blaschke, Karlheinz. 1967. *Bevölkerungsgeschichte von Sachsen bis zur industriellen Revolution.* Weimar:Boehlau.

Bosker, M., and H. Garretsen. 2008. "Trade costs, market access and economic geography: Why the empirical specification of trade costs matters." *The Gravity Equation. Or: Why the World is Not Flat, Cambridge UP, Cambridge, forthcoming.*

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

Cinnirella, F. 2008. "On the road to industrialization: nutritional status in Saxony, 1690–1850." *Cliometrica*, 2(3): 229–257.

Clark, C., and M. Haswell. 1964. *The economics of subsistence agriculture.* St.Martin's Press, New York.

Crozet, Matthieu. 2004. "Do migrants follow market potentials? An estimation of a new economic geography model." *Journal of Economic Geography*, 4(4): 439–458.

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

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

De Vries, Jan. 1984. *European urbanization, 1500-1800. Harvard studies in urban history*, Cambridge, MA:Harvard University Press.

Dumke, Rolf H. 1994. *German economic unification in the 19th century : the political economy of the Zollverein.* München:Institut für Volkswirtschaftslehre, Universität der Bundeswehr München.

Engel, Ernst. 1858. "Die indirecten Steuern im Königreich Sachsen." *Zeitschrift des Statistischen Bureaus des Königl. Sächs. Ministeriums des Inneren*, 1858(8).

Estevadeordal, A., B. Frantz, and A. M. Taylor. 2003. "The Rise And Fall Of World Trade, 1870-1939*." *Quarterly Journal of Economics*, 118(2): 359–407.

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

Hahn, Hans-Werner. 1984. *Geschichte des Deutschen Zollvereins.* Göttingen:Vandenhoeck und Ruprecht.

Hanson, G. H. 1996. "Localization economies, vertical organization, and trade." *The American Economic Review*, 86(5): 1266–1278.

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

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

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

Helpman, Elhanan. 1998. "The Size of Regions." In *Topics in Public Economics.* , ed. David Pines, Efraim Sadka and Itzhak Zilcha. Cambridge:Cambridge University Press.

Henderson, W. O. 1984. *The Zollverein.* . 3rd ed., London, UK; Totowa, N.J.:F. Cass.

Hohenberg, Paul M., and Lynn Hollen Lees. 1985. *The making of urban Europe, 1000-1950. Harvard studies in urban History*, Cambridge, MA:Harvard University Press.

Keller, Katrin. 2002. *Landesgeschichte Sachsen.* Stuttgart:E. Ulmer.

Keller, W., and C. Shiue. 2008. "Institutions, Technology, and Trade." *NBER Working Paper.*

Kiesewetter, Hubert. 2007. *Die Industrialisierung Sachsens : ein regional-vergleichendes Erklärungsmodell. Regionale Industrialisierung, Bd. 5*, Stuttgart:Franz Steiner Verlag.

Kohlschmidt, Walter. 1930. "Die sächsische Frage auf dem Wiener Kongress und die sächsische Diplomatie dieser Zeit." PhD diss. W. und B.v. Baensch Stiftung, Universität Leipzig, 1930.

Krugman, P. 1991. "Increasing returns and economic geography." *Journal of political economy*, 99(3).

Lopez-Cordova, J. E., and C. M. Meissner. 2003. "Exchange-rate regimes and international trade: evidence from the classical gold standard era." *American Economic Review*, 93(1): 344–353.

Müller, Juergen. 2006. *Der Deutsche Bund, 1815-1866. Enzyklopädie deutscher Geschichte, Bd. 78*, München:Oldenbourg.

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

Ohnishi, Takeo. 1973. *Zolltarifpolitik Preußens bis zur Gründung des Deutschen Zollvereins : ein Beitrag zur Finanz- und Außenhandelspolitik Preußens.* Göttingen:Schwartz.

O'Rourke, K. H., and J. G. Williamson. 2005. "From Malthus to Ohlin: Trade, industrialisation and distribution since 1500." *Journal of Economic Growth*, 10(1): 5–34.

Ploeckl, Florian. 2009. "The size of towns, ca. 1834."

Ploeckl, Florian. 2010*a*. "Towns and Villages; Definition and Location in a historical setting."

Ploeckl, Florian. 2010*b*. "The Zollverein and the formation of a customs union." *Oxford University Discussion Papers in Economic and Social History*, , (84).

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

Redding, Stephen, and Anthony J Venables. 2004. "Economic geography and international inequality." *Journal of International Economics*, 62(1): 53–82.

Reuschel, Artur. 1930. "Die Einführung der Generalkonsumtionsakzise in Kursachsen und ihre wirtschaftspolitische Bedeutung." PhD diss. Helios-Druckerei Univ. Leipzig, 1930.

Rose, A. K. 2004. "Do we really know that the WTO increases trade?" *American Economic Review*, 94(1): 98–114.

Rothe, W.v. Eisenhart, A. Ritthaler, and H. Oncken. 1934. *Vorgesichte und Begruendung des Deutschen Zollvereins 1815-1834 Akten der Staaten des Deutschen Bundes und der Europaeischen Maechte.* Berlin:Friedrich List Gesellschaft Reimar Hobbing.

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

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

Wächter, Georg. 1901. "Die sächsischen Städte im 19.Jahrhundert." *Zeitschrift des königlichen sächsischen statistischen Landesamtes*, 47(1): 179–232.

Tables

Table 1: Summary Statistics

Variables	Mean	St.Dev	Min	Max
Population 1815	2779.41	5900.54	284.00	59217.00
Population 1834	3739.74	7425.40	449.00	73614.00
Population 1849	4730.59	9714.60	470.00	94092.00
Elevation	338.76	181.11	107.00	917.00
Ruggedness	29.12	16.34	3.73	94.26
Farm quality	43.30	14.62	17.00	91.00
Pasture quality	41.37	9.85	16.00	65.00
Temperature	71.76	10.69	40.00	90.00
Rain	781.20	114.93	551.00	999.00
Brown Coal	29.13	19.61	0.00	81.26
Stone Coal	30.55	19.35	0.13	93.87
River	0.61	0.49	0.00	1.00
Elbe River	0.04	0.20	0.00	1.00
Post office in 1834	0.69	0.47	0.00	1.00
Rail service years (1849)	0.67	2.22	0.00	11.00
Newspaper	0.14	0.35	0.00	1.00
multiple Newspapers	0.06	0.25	0.00	1.00
General Trade Fair	0.93	0.26	0.00	1.00
Textile Fair	0.06	0.25	0.00	1.00
Animal Fair	0.43	0.50	0.00	1.00
Housing stock	0.00	125.77	-563.86	418.15
Students/School	321.68	249.48	69.00	1630.50
Students/Teacher	129.04	55.86	28.85	346.00
Tertiary Institution	0.14	0.53	0.00	4.00
Mining population	0.01	0.04	0.00	0.24
Military population	0.02	0.05	0.00	0.30
Old age population share	0.07	0.02	0.03	0.15
Young age population share	0.33	0.03	0.24	0.40
Widowed share	0.06	0.01	0.03	0.09
Gender ratio	0.95	0.06	0.80	1.16

Further information about the individual variables, in particular their sources as well as units, is given in the appendix.

Table 2: Change in Growth Rate and relative Market Potential

Distance	Cost				Plain			
Change in Growth	Relative		Absolute		Relative		Absolute	
Market Potential	Dom	Total	Dom	Total	Dom	Total	Dom	Total
Intercept	1.00***	1.00***	0.26	0.37	1.00***	1.00***	0.31	0.45
	(0.00)	(0.00)	(0.30)	(0.39)	(0.00)	(0.01)	(0.42)	(0.54)
Thuringia	0.13**	0.23***	13.46**	22.81***	0.07**	0.11**	7.29**	11.29**
	(0.05)	(0.08)	(5.44)	(8.30)	(0.03)	(0.05)	(3.25)	(4.93)
Prussia	-0.04*	-0.07**	-4.02*	-7.29**	-0.03**	-0.05**	-3.27**	-5.35**
	(0.02)	(0.04)	(2.34)	(3.58)	(0.02)	(0.03)	(1.53)	(2.57)
Bohemia	-0.01	-0.02	-1.13	-2.26	-0.01	-0.02	-1.36	-1.87
	(0.03)	(0.04)	(2.55)	(4.17)	(0.02)	(0.03)	(1.94)	(2.85)
Saxony Urban	0.00	0.00	0.16	0.38	0.00	0.00	0.39	0.36
	(0.01)	(0.02)	(1.47)	(2.05)	(0.01)	(0.01)	(1.00)	(1.37)
Observations	140	140	140	140	140	140	140	140
$R - squared$	0.06	0.07	0.05	0.07	0.06	0.06	0.06	0.06

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

Cost and Plain denote the distance measure used to calculate market potential. Absolute and Relative denote whether the dependent variable is the absolute or relative change in the growth rate. Dom and Total denote whether the denominator used to calculate the relative market potential is either the domestic or the combined domestic and foreign market potential.

Table 3: Difference-in-difference Results

Specification	Baseline	Controls	Baseline	Controls
Distance Measure	Cost	Cost	Plain	Plain
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

Location controls contain all geographical and institutional variables listed in the appendix. Regional controls act as dummies for the main administrative regions of Saxony.(Magnitude and direction of the coefficients are robust to the exclusion of the regional controls) Time Controls indicate the general average growth in each period.

Table 4: 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	-0.226**	0.0318	0.0511	-0.252***	0.052	0.043
	(0.092)	(0.0416)	(0.0361)	(0.0916)	(0.0415)	(0.0367)
Thuringian Market	-1.09*	1.36***	0.686*	-1.19*	1.46***	0.59
	(0.633)	(0.345)	(0.4)	(0.633)	(0.342)	(0.405)
Bohemian Market	-0.386	-0.369	-0.5	-0.364	-0.437	-0.478
	(0.753)	(0.407)	(0.473)	(0.753)	(0.408)	(0.480)
Prussian Market	0.818***	-0.114	0.114	0.917***	-0.233	0.140
	(0.251)	(0.137)	(0.16)	(0.249)	(0.145)	(0.184)
Rural Market	0.000765	0.00104	-0.00483	0.00100	0.000816	-0.00338
	(0.0217)	(0.0118)	(0.0137)	(0.0216)	(0.0117)	(0.0138)
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

Reported results based on the cost distance measure, all market potential variables have been rescaled by 1000.

Table 5: SUR Migration and Natural Increase

Equation	Migration	Natural Increase	Migration	Natural Inc.
Distance Measure	Cost	Cost	Plain	Plain
Thuringian Market	0.920*	0.493**	0.243	0.159
	(0.466)	(0.204)	(0.226)	(0.101)
Bohemian Market	-1.16**	0.0517	0.521	0.0956
	(0.547)	(0.236)	(0.38)	(0.164)
Prussian Market	-0.054	-0.0331	0.270	0.128
	(0.179)	(0.076)	(0.254)	(0.110)
Rural Market	-0.0218	0.00454	-0.0438***	0.0102
	(0.0154)	(0.00658)	(0.0156)	(0.0068)
Birthrate 1834		1.18**		11.5**
		(4.92)		(5.06)
Deathrate 1834		-9.53**		-8.73**
		(4.64)		(4.77)
Gender balance		1.53***		1.47***
		(0.567)		(0.564)
Widowed Share		-6.02*		-5.39
		(3.41)		(3.42)
Youth Share		2.55*		2.3*
		(1.33)		(1.35)
Inst. Controls	Yes	Yes	Yes	Yes
Geogr. Controls	Yes	Yes	Yes	Yes
Regional Controls	Yes	Yes	Yes	Yes
adjusted R^2	0.335	0.572	0.358	0.569

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

Market potential variables are rescaled by 1000. Demographic variables are 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 town population.

Table 6: 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		

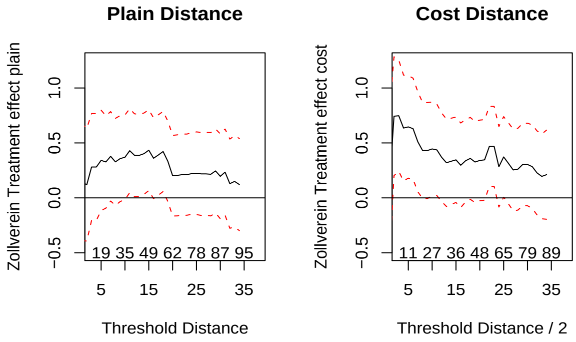
Significance Stars: *** significant at 1 % level, ** significant at 5 % level, * significant at 10% level

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 the difference between the treatment groups defined by the two measures (Cost-Plain). Time, regional and location controls are defined as in the main difference-in-difference specification.

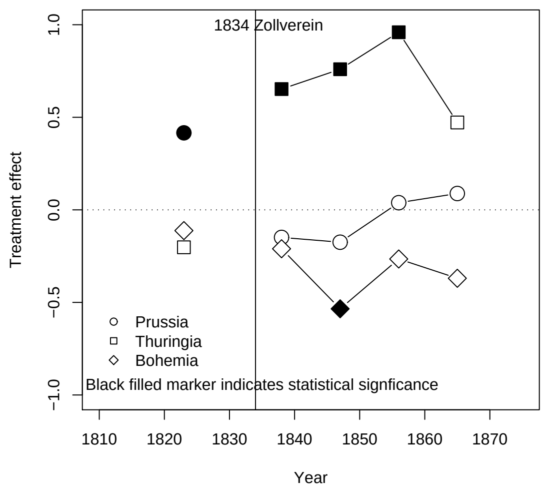
Figures

Figure 1: Treatment effect of the Zollverein with different selection thresholds



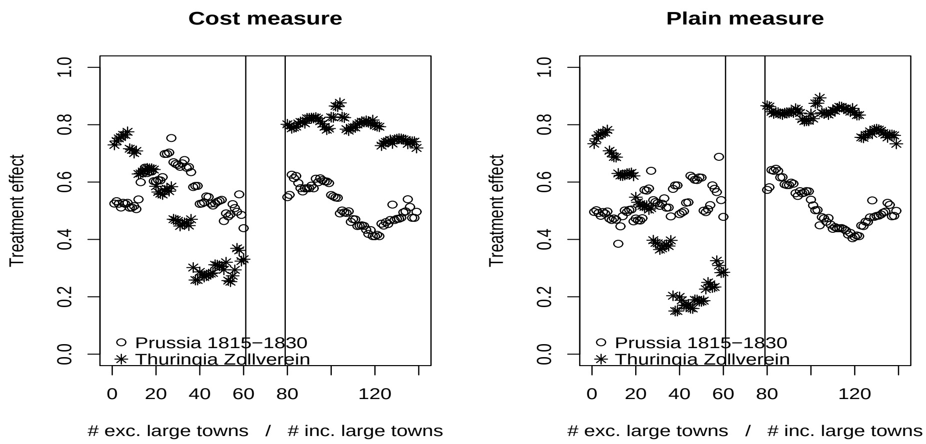
The graph plots the series of treatment effects of specifying difference-in-difference estimations with one treatment group, namely towns close to Saxony's border with another Zollverein member. The selection of the treatment groups differs by the applied threshold distance from the border, which is 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 2: Adjustment path of all three treatment effects



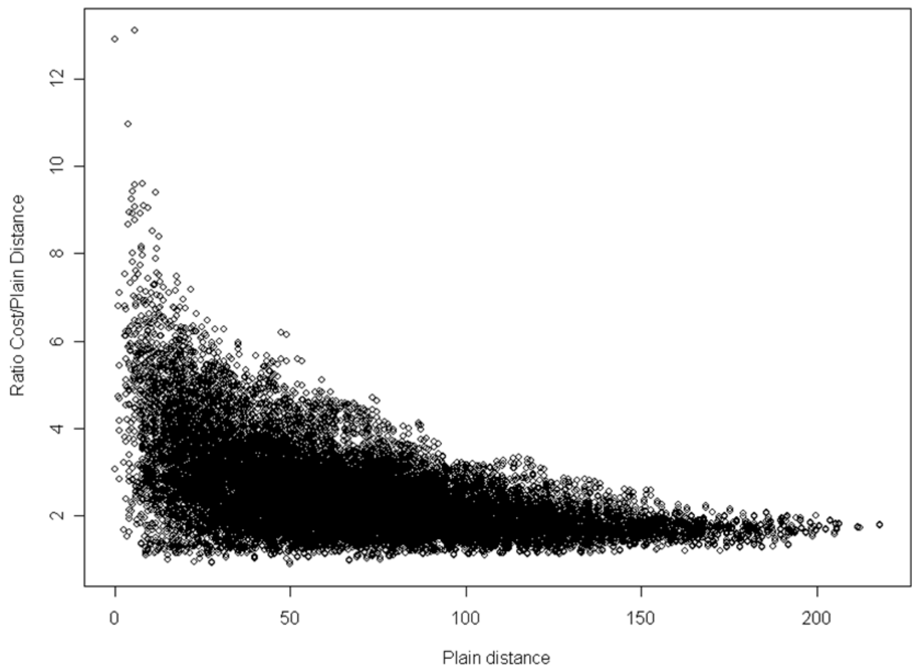
This graph shows the development of the three treatment effects over time, using the cost measure to determine the treatment group.

Figure 3: Thuringian / Prussian treatment effect for subsamples selected on size



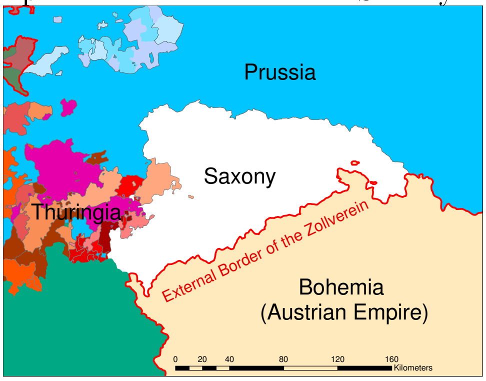
The panel shows the treatment effects of the Prussian border for 1815-1830 and for the Thuringian border after the Zollverein. For n $<$ 60, the n-largest towns are excluded from the sample. For n $>$ 80, the sample contains the n-largest towns, so the $140 - n$ smallest towns are excluded from the sample.

Figure 4: Ratio of cost to plain distance versus plain distance



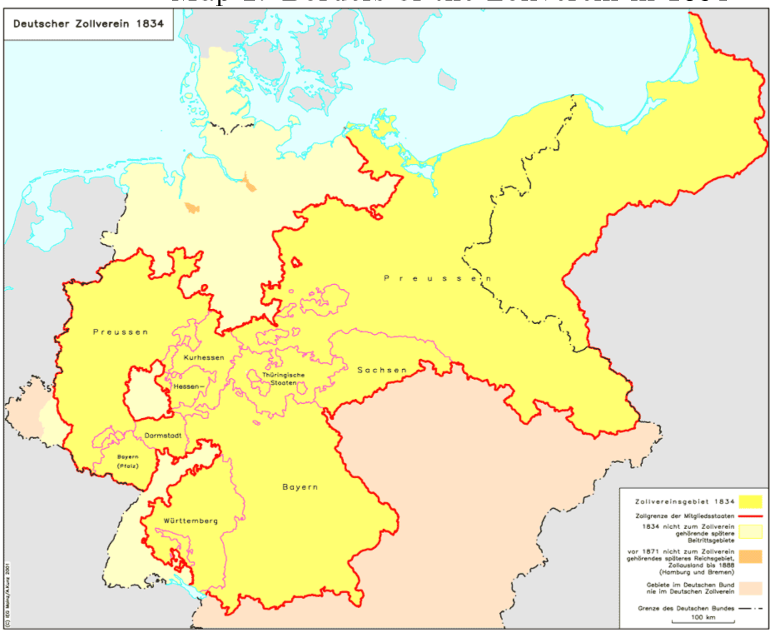
Maps

Map 1: Political borders of Saxony and neighbor states



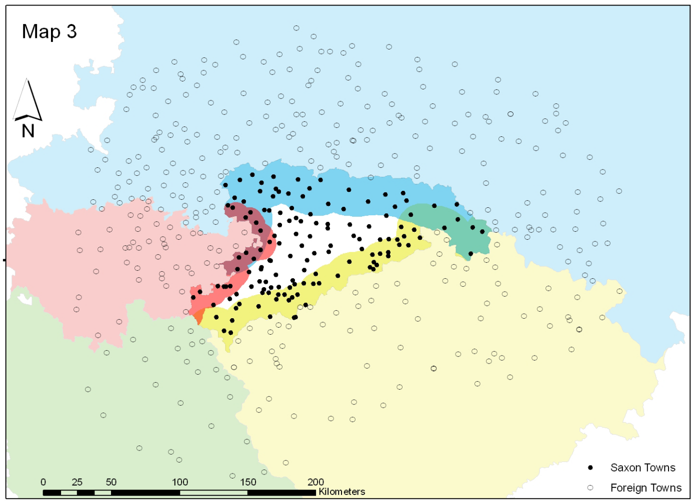
This map shows the political borders of Saxony and its neighbor states in 1834. Additionally the external Zollverein border is marked.

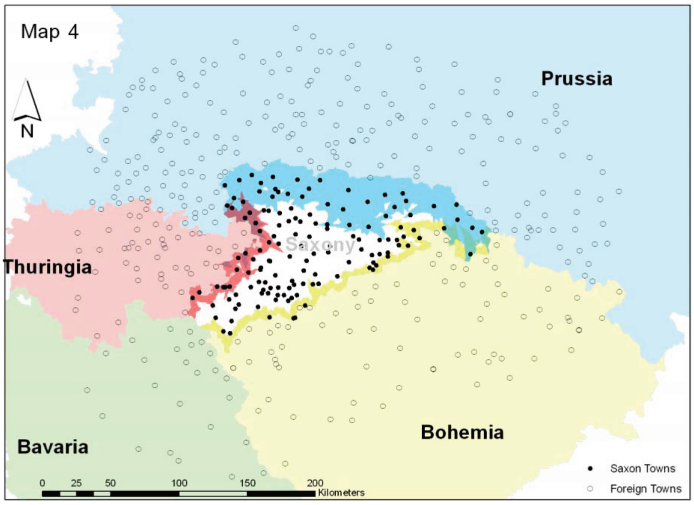
Map 2: Borders of the Zollverein in 1834



This map shows the extent of the Zollverein in 1834.

Treatment groups based on plain and cost distance





Maps 3 and 4 demonstrate the impact caused by using the detailed cost distance measure to determine distance from border. They 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, and an empty dot indicates a town in a neighboring state used to calculate market access. The lightly shaded areas indicate the respective neighbor states, the strongly colored areas are the parts of Saxony that are the respective treatment regions of the difference-in-difference estimation. Towns within the area with a white background represent the control group used in the estimation. The first illustrates the thresholds based on plain distance, while the second illustrates the thresholds used for my cost distance specifications.

Appendix

Data description sources

Population Data

The following lists the sources for the population data used in the analysis.

Saxony Statistische Mitteilungen aus dem Koenigreich Sachsen (1831 - 1849,1851 - 1855)
Statistisches Jahrbuch Sachsen (1871-1938)
Zeitschrift des königlich Sächsischen Statistischen Landesamtes (1855-1945)
Historisches Ortsverzeichnis Sachsen, 2006
TOP 50 Sachsen, CD-ROM,Landesvermessungsamt Sachsen

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

Geographic data

The following lists the data sources for geographic data:

Historical Maps

Historischer Atlas von Sachsen , Karte und Beiheft A 9 ,B II 6, F IV 1, H 16
Bayerische Landesbibliothek, Muenchen
Ref: VIII 21, VIII 23c , VIII 46, XII 118
Saechsisches Hauptstaatsarchiv, Dresden
Ref: 11345/15, 11345/16, 12884, R926

GIS data

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

River network: Saechsisches Ministerium fuer Umwelt und Landwirtschaft:
-Gewässerdurchgaengigkeitsprogramm (Oberflaechengewaesser)

Elevation: U.S.Geological Survey, National Elevation Data

Location Characteristics

The following gives a description for each of the variables used for location characteristics.

Natural endowment

Elevation This variable indicates the elevation over sea level measured in meters; the data are from current digital elevation models.
Source:U.S.Geological Survey ,National Elevation Data

Ruggedness This variable indicates the flatness of the area immediately surrounding the town. 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's location.
Source:U.S.Geological Survey ,National Elevation Data

Farmland 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 the same specification used for the empirical analysis.Saechsisches
Source: Ministerium fuer Umwelt und Landwirtschaft:GEMDAT-LABO Database, Akademie der Landwirtschaft der DDR, Muencheberg-Eberswalde

Pasture quality This variable indicates the quality of the soil with respect to pasture purposes. The data are based on the same surveys as the farmland quality and the variable is specified in the same way.
Source: Ministerium fuer Umwelt und Landwirtschaft:GEMDAT-LABO Database, Akademie der Landwirtschaft der DDR, Muencheberg-Eberswalde

Temperature This variable indicates the suitability of a location's annual temperature with respect to agricultural purposes. The data are based on the same surveys as the farmland quality and the variable is specified in the same way.
Source: Ministerium fuer Umwelt und Landwirtschaft:GEMDAT-LABO Database, Akademie der Landwirtschaft der DDR, Muencheberg-Eberswalde

Rain This variable indicates the average rainfall at the location. The data are based on the same surveys as the farmland quality.
Source: Ministerium fuer Umwelt und Landwirtschaft:GEMDAT-LABO Database, Akademie der Landwirtschaft der DDR, Muencheberg-Eberswalde

Brown Coal [58] This variable indicates the distance to brown coal mines active in the late 1830s and early 1840s. The data about active mining locations come from the Historical Atlas of Saxony. The distance is specified in kilometers and is either measured as plain distance or with an introduced cost measure, and enters quadratically into the regressions.
Source: Historischer Atlas von Sachsen , Karte und Beiheft A 9

Stone Coal This variable indicates the distance to hard coal mines active in the late 1830s and early 1840s, the data for which derive from the Historical Atlas of Saxony. The data are specified in the same way as those for brown coal.
Source: Historischer Atlas von Sachsen , Karte und Beiheft A 9

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

Rivers This variable indicates whether there is a flowing water body within a kilometer of the town location, which is specified as a simple dummy variable.
Source: Saechsisches Ministerium fuer Umwelt und Landwirtschaft: -Gewässerdurchgängig
(Oberflächengewässer)

Institution and Infrastructure

Elbe One of the major means of transportation in the early 19th century was shipping, especially so on rivers. In Saxony, only the Elbe offered this possibility, as no other river was navigable. Rivers also have other effects such as as a source of energy, but this variable captures the effect of shipping, since most Saxon towns were located at rivers. The variable is a 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 are taken from a compilation accompanying the Historical Atlas of Saxony.
Source: Historischer Atlas von Sachsen , Karte und Beiheft

Rail service This variable indicates whether and for how long the town had a railway station within the investigated period. It is specified as the number of years the station was operating during this time period. The data are from the same source as the information about the postal service.
Source: Historischer Atlas von Sachsen , Karte und Beiheft A 9

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 were published b the Saxon Statistical Office.
Source: *Mittheilungen des statistischen Vereins fuer das Koenigreich Sachsen*,1833

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

Housing This is a variable indicating the stock of housing in each town in 1834. The stock is specified by the 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's population. The data were collected simultaneously with the census numbers and published in the same location. Souce: Zeitschrift des königlich §ächsischen Statistischen Landesamtes , 1901-1902

Education These variables indicate the level of educational activity in each town. "Tertiary Institutions" indicates whether there were any schools beyond regular schools, for example a university, seminary or teacher college, "Teacher" indicates the number of students per teacher in this town, and "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 Prussian Migration

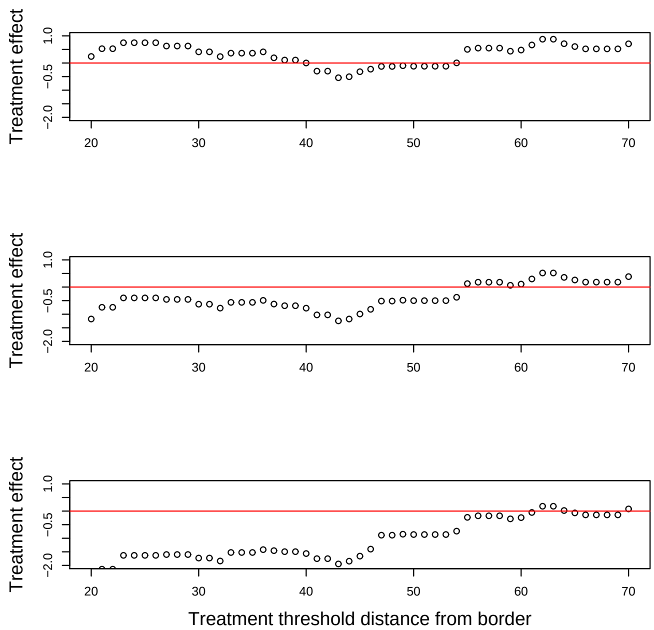
The estimation results indicate that there was a significantly higher population growth close to the Prussian border prior to the Zollverein and no significant different growth afterwards. This result is contrary to the model implication of higher growth in the period after the entry due to the market 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.[59] Summing up all flows into one

[59] 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.

Figure 1: Counterfactual effect of the Prussian border imposition in 1815



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.[60]The following figure 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

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

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. The following table 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 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.

Table 7: 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

Appendix Geographic Information Systems

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

Basic Data Concepts

Geographical Information systems employ 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, while 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, known as "polylines" and "polygons". 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, while a polygon example is the territory of a state.

It is possible to transform data from one approach to the other. For example, I present 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 geo-referencing 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 is, 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 then used in the distance measurement procedure described below. The goal is to create a layer, the z-value of which indicates the cost of crossing this cell. The distance calculation takes elevation patterns into account separately, so the cost layer combines roads and rivers. Relative cost factors are parameter values that can be changed relatively easily; 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 a number of historical maps.Maps drawn in 1834 show the network of major trade routes spanning Saxony and its neighbors; road classifications are quite consistent between them. The resulting network is illustrated in the following map. 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. These values are based on historical cost transportation comparisons taken fromClark and Haswell (1964). The estimation results based on the cost measure derived with these values are very robust to changes in them. How exactly these cost factors 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.(Aldcroft, 1986) Naturally,

Figure 2: Map of road network in Saxony in 1834

rivers and roads cross, and given the assumption of existing bridges and fords the road cost value is used for that particular cell.

Elevation As described below, elevation enters slightly differently into the calculation than roads and rivers. One is the increase in actual traveled 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 $VF = \frac{1}{1-0.1*Slope}$. This choice of functional form is based on its appropriateness for the impact on transportation costs. Again the estimation results are very robust to the precise shape of the specified function.

PathDistance function

The objective of the PathDistance cost function 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:

$$Costdistance = Surfacedistance * Verticalfactor$$

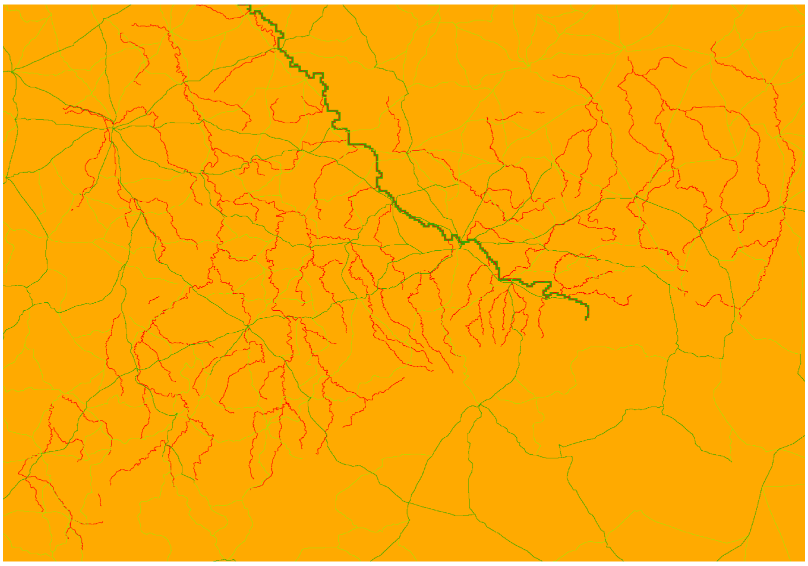
Source cells All cost functions require a source raster, which may contain single or multiple zones. These zones may or may not be connected. The original values assigned to the source cells are retained, and there is no limit to the number of source cells within the source raster. As a practical example, one class of source cells is 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 such as 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 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, described above, is a unit-less system. The applied cost layer is shown in the following map:

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 that could be traveled on a flat surface with cost factor 1 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, the base of which is derived from the cell size and

Figure 3: Costlayer for distance calculations



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 and 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 degrees. ArcGis has a range of available functions for the determination of the vertical factor. For example, one possibility is a linear transformation, while 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. A graphical representation of a resulting grid is given in Map 6. 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.

2009

2009/1. Rork, J.C.; Wagner, G.A.: "Reciprocity and competition: is there a connection?"
2009/2. Mork, E.; Sjögren, A.; Svaleryd, H.: "Cheaper child care, more children"
2009/3. Rodden, J.: "Federalism and inter-regional redistribution"
2009/4. Ruggeri, G.C.: "Regional fiscal flows: measurement tools"
2009/5. Wrede, M.: "Agglomeration, tax competition, and fiscal equalization"
2009/6. Jametti, M.; von Ungern-Sternberg, T.: "Risk selection in natural disaster insurance"
2009/7. Solé-Ollé, A; Sorribas-Navarro, P.: "The dynamic adjustment of local government budgets: does Spain behave differently?"
2009/8. Sanromá, E.; Ramos, R.; Simón, H.: "Immigration wages in the Spanish Labour Market: Does the origin of human capital matter?"
2009/9. Mohnen, P.; Lokshin, B.: "What does it take for and R&D incentive policy to be effective?"
2009/10. Solé-Ollé, A.; Salinas, P..: "Evaluating the effects of decentralization on educational outcomes in Spain?"
2009/11. Libman, A.; Feld, L.P.: "Strategic Tax Collection and Fiscal Decentralization: The case of Russia"
2009/12. Falck, O.; Fritsch, M.; Heblich, S.: "Bohemians, human capital, and regional economic growth"
2009/13. Barrio-Castro, T.; García-Quevedo, J.: "The determinants of university patenting: do incentives matter?"
2009/14. Schmidheiny, K.; Brülhart, M.: "On the equivalence of location choice models: conditional logit, nested logit and poisson"
2009/15. Itaya, J., Okamuraz, M., Yamaguchix, C.: "Partial tax coordination in a repeated game setting"
2009/16. Ens, P.: "Tax competition and equalization: the impact of voluntary cooperation on the efficiency goal"
2009/17. Geys, B., Revelli, F.: "Decentralization, competition and the local tax mix: evidence from Flanders"
2009/18. Konrad, K., Kovenock, D.: "Competition for fdi with vintage investment and agglomeration advantages"
2009/19. Loretz, S., Moorey, P.: "Corporate tax competition between firms"
2009/20. Akai, N., Sato, M.: "Soft budgets and local borrowing regulation in a dynamic decentralized leadership model with saving and free mobility"
2009/21. Buzzacchi, L., Turati, G.: "Collective risks in local administrations: can a private insurer be better than a public mutual fund?"
2009/22. Jarkko, H.: "Voluntary pension savings: the effects of the finnish tax reform on savers' behaviour"
2009/23. Fehr, H.; Kindermann, F.: "Pension funding and individual accounts in economies with life-cyclers and myopes"
2009/24. Esteller-Moré, A.; Rizzo, L.: "(Uncontrolled) Aggregate shocks or vertical tax interdependence? Evidence from gasoline and cigarettes"
2009/25. Goodspeed, T.; Haughwout, A.: "On the optimal design of disaster insurance in a federation"
2009/26. Porto, E.; Revelli, F.: "Central command, local hazard and the race to the top"
2009/27. Piolatto, A.: "Plurality versus proportional electoral rule: study of voters' representativeness"
2009/28. Roeder, K.: "Optimal taxes and pensions in a society with myopic agents"
2009/29, Porcelli, F.: "Effects of fiscal decentralisation and electoral accountability on government efficiency evidence from the Italian health care sector"
2009/30, Troumpounis, O.: "Suggesting an alternative electoral proportional system. Blank votes count"
2009/31, Mejer, M., Pottelsberghe de la Potterie, B.: "Economic incongruities in the European patent system"
2009/32, Solé-Ollé, A.: "Inter-regional redistribution through infrastructure investment: tactical or programmatic?"
2009/33, Joanis, M.: "Sharing the blame? Local electoral accountability and centralized school finance in California"
2009/34, Parcero, O.J.: "Optimal country's policy towards multinationals when local regions can choose between firm-specific and non-firm-specific policies"
2009/35, Cordero, J,M.; Pedraja, F.; Salinas, J.: "Efficiency measurement in the Spanish cadastral units through DEA"
2009/36, Fiva, J.; Natvik, G.J.: "Do re-election probabilities influence public investment?"
2009/37, Haupt, A.; Krieger, T.: "The role of mobility in tax and subsidy competition"
2009/38, Viladecans-Marsal, E; Arauzo-Carod, J.M.: "Can a knowledge-based cluster be created? The case of the Barcelona 22@district"

2010

2010/1, De Borger, B., Pauwels, W.: "A Nash bargaining solution to models of tax and investment competition: tolls and investment in serial transport corridors"
2010/2, Chirinko, R.; Wilson, D.: "Can Lower Tax Rates Be Bought? Business Rent-Seeking And Tax Competition Among U.S. States"
2010/3, Esteller-Moré, A.; Rizzo, L.: "Politics or mobility? Evidence from us excise taxation"
2010/4, Roehrs, S.; Stadelmann, D.: "Mobility and local income redistribution"

2010/5, Fernández Llera, R.; García Valiñas, M.A.: "Efficiency and elusion: both sides of public enterprises in Spain"
2010/6, González Alegre, J.: "Fiscal decentralization and intergovernmental grants: the European regional policy and Spanish autonomous regions"
2010/7, Jametti, M.; Joanis, M.: "Determinants of fiscal decentralization: political economy aspects"
2010/8, Esteller-Moré, A.; Galmarini, U.; Rizzo, L.: "Should tax bases overlap in a federation with lobbying?"
2010/9, Cubel, M.: "Fiscal equalization and political conflict"
2010/10, Di Paolo, A.; Raymond, J.L.; Calero, J.: "Exploring educational mobility in Europe"
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