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Paving the way to modernity: Prussian roads and grain market
integration in Westphalia, 1821-1855

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Abstract

This study investigates the relation of pre-railroad transport infrastructure on Westphalian grain market integration in the early 19th century. It is motivated by recently found indications of macroeconomic change in Prussia such as increased demand for labour, disappearance of positive Malthusian shocks, and grain market integration. These coincide and correspond well with a number of institutional breaks such as border changes and state creation after the end of the Napoleonic Wars, liberal political reforms such as the abandoning of corporatist regulations in Prussia, and substantial public investment in paved roads in a number of Prussian provinces. In this article we show that (a) paved road connections mattered economically and statistically for bilateral rye and wheat price differences, (b) the usual dummy-variable approach to measure the effect of transport infrastructures proves to be unreliable and we propose a new indicator that takes into account the effects of the transport network (c) the role of the early railroad connections is not robust. In this pilot study we for the first time establish the correlation between economic development and pre-railroad transport infrastructure for a Prussian province, and thus call for more research on the causes of macroeconomic change in early 19th century Prussia.

JEL classification: F1, N10, N73

Keywords: Transport infrastructure; grain markets; Prussia; 19th century

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1. Introduction

What are the origins and causes of modern economic growth? This question is at the centre of economic history research. Especially for late-comers such as Germany and frontier economies such as the USA, there is a certain unanimity in placing the second half of the 19th century as the period in which the breakthrough took place. As one of the main determinants the railway had been singled out.¹

In the case of Germany however, recent research has shown that it experienced significant socioeconomic development already before it industrialized properly. This process has been documented in terms of market integration, demography, and labour demand and is summarized briefly in the next section.² This new branch of 19th century research raises new questions related to the potential causes of these fundamental socioeconomic changes on the European mainland. What role did new borders play after the Congress of Vienna in 1815? How much did Napoleonic reforms shape economic outcomes in formerly occupied states?³ Or alternatively, Prussian liberal reforms such as the *Gewerbefreiheit* that abolished corporatist structures of the *Ancien Régime*?⁴ Could demand for agricultural products from early industrializing England and the gradual repeal of the Corn Laws have changed the life on the continent for farmers or farm workers?⁵

¹ Fremdling, *Eisenbahnen* (1985); Gerschenkron, *Economic Backwardness* (1962); Fishlow, *American Railroads* (1965).

² Uebele, 'Market integration' (2011); Pfister and Fertig, 'Population' (2010); Pfister et al., 'Real Wages' (2012).

³ Acemoglu et al., 'Consequences' (2011).

⁴ Wegner, 'Capitalist transformation' (2013).

⁵ Uebele, 'Demand' (2011); Sharp and Weisdorf, 'French Revolution' (2012); Federico, 'Market Integration' (2012).

In addition to these institutional changes, we observe substantial investments in transport infrastructure in many parts of Germany before 1850. The qualitative historical literature has for some time been highlighting the efforts Prussia put in building large networks of paved roads, especially in the regions of Westphalia and the Rhineland.⁶ In addition, they also point out their positive and partially ignored consequences for overland transport.⁷

An important part of the modern growth literature has reserved a significant role for transport infrastructures.⁸ Through lower transport costs (forward linkages) as well as through demand for building materials (backward linkages), transport infrastructure expands market boundaries, facilitates the exchange of ideas and increases labour mobility as well as regional specialization of production.

In the vein of this reasoning, we will study the development of the paved road network in Westphalia during the first half of the 19th century. In this period, this network grew from 688 to 2075 kilometres⁹ decreasing transport costs and increasing transport speed and capacity substantially.¹⁰ We aim at using information about the paved road network as the main explicative variable for market integration, one of the indicators of early 19th century economic development in

⁶ Voigt, *Verkehr* (1965), 433.

⁷ Sälter, *Entwicklung* (1917); Wischermann, 'Chausseebau' (1999).

⁸ Hornung, 'Railroads and micro-regional' (2012); Banerjee et al., 'Access' (2012); Atack et al., 'Railroads' (2010); Keller and Shiue, 'Institutions' (2008); Donaldson and Hornbeck, 'Railroads and American Economic Growth' (2013), Kelly, 'Dynamics' (1997).

⁹ Gador, *Entwicklung des Straßenbaues* (1966), 62-63.

¹⁰ Sälter, *Entwicklung* (1917).

Westphalia. Despite a similar approach for a Belgian region in the late 18th century,¹¹ no state-of-the-art quantitative analysis of this relationship has been undertaken for Germany so far.

We start with a model that relates half-annual rye and wheat prices from 31 cities in Westphalia during the period 1821-1855 to paved roads, railroads, and canals. Moreover, we introduce a novel approach to measure their effects on trade. Instead of only taking the usual bimodal dummy approach, we also consider the total number of paved road (or railroad) connections a city pair had. This accounts for the network effects arising when cities gained additional paved road or railroad connections as well as indirect effects for those cities that benefited from transport connections in neighbouring cities without having direct access to them. Our results are straightforward: firstly, we show that distance coefficients decreased between the 1820s and the 1840s by about 22 and 16 per cent for rye and wheat, respectively. This indicates an important reduction of transport costs during our sample period. Secondly, we observe that the dummy-variable approach has serious shortcomings for measuring the effects of paved roads in our empirical analysis for two reasons. One is that the dummy variable is not significant or has the wrong sign for rye or it is just significant at the ten percent level for rye during the 1831-1843 period. And the other is that in the case of wheat the size of the coefficients is not stable from one period to another. On the other hand, our newly-developed variable that accounts for the transport network effects is after 1831 always significantly different from zero at the one percent level, has the right sign and is stable in size. And thirdly, we find no robust empirical evidence for the often-assumed positive role of railroads on Westphalian grain market integration for our sample period. This confirms the claim that initially, trains moved mainly high value-to-weight goods.¹²

¹¹ Buyst et al., ‘Road expansion’ (2006) already documents large effects on trade costs and speeds of adjustment, even though the trade cost effects were taxed away completely.

¹² Fremdling, *Eisenbahnen* (1985).

We are confident that these results are witness to largely overlooked effects of transport infrastructures other than the railroad, and that they call for more research. We are aware that this does not answer the question of causality but merely indicates correlation. In the methodological section we elaborate on this problem and indicate ways to deal with these issues in the future. However, we see this article as a pilot study whose main role is to document the gaps in the literature, and highlight the need for more and deeper research.

1.1 A fresh look at early 19th century economic development in Germany

In line with the late-comer hypothesis¹³ and the transport revolution,¹⁴ during the last decades the main focus of the literature concerning economic growth and transport infrastructures has remained on the second half of the nineteenth century, largely ignoring the first half and its consequences.

Recent investigations of early 19th century Germany have shown that not only did important institutional breaks take place, such as the creation of the German confederation or the Zollverein, but also macroeconomic changes happened that show economic development before the onset of the industrialization. Three studies illustrate this new research focus.

Firstly, Pfister and Fertig use a new data set of German national birth and death rates to investigate the evolution of Malthusian preventive and positive checks during the time period 1730-1870. Their results point out a weakening of Malthusian positive checks after the 1820s and the subsequent transition to a non-Malthusian demographic regime.¹⁵

¹³ Gerschenkron, *Economic Backwardness* (1962).

¹⁴ O'Rourke and Williamson, *Globalization* (1999).

¹⁵ See Pfister and Fertig, 'Population' (2010).

Secondly, Pfister et al. estimate a structural time series model to analyse the relationship between newly developed real wage indices and population size.¹⁶ They find a sustained growth of labour productivity with a significant increase in labour demand already in the 1810s.¹⁷

And thirdly, synchronous price movements at a national and international level increased substantially during the second quarter of the 19th century.¹⁸ This increasing market integration might have contributed to alleviate the transfer of food surpluses to grain deficit areas, reducing the effect of local supply and demand shocks and allowing a greater regional specialization of production (i.e. Smithian growth).

2. Method

2.1 Measuring market integration

Fremdling and Hohorst define market integration as ‘a process that takes up time, which creates an economic interdependence between spatially separated [markets]’.¹⁹ The interpretation of economic interdependence in the previous definition plays a crucial role in its theoretical analysis that can be

¹⁶ Pfister et al., ‘Real Wages’ (2012).

¹⁷ Although labour productivity grew further from the 1850s onwards, its growth rate underwent just a modest acceleration in comparison with the previous period.

¹⁸ Uebele, ‘Market integration’ (2011).

¹⁹ Fremdling and Hohorst, ‘Marktintegration’ (1979), 58 use the term *individuals* instead of *markets*.

static or dynamic.²⁰ In this paper, we take a static approach by analysing spatial price level convergence over time (i.e. law of one price).²¹

The law of one price (LOP) states that prices of identical goods in integrated markets take the same level. In order to apply this theory to spatial trade, transport costs need to be considered as follows:

$$P_i = P_j + T_{ij} \quad (1)$$

P_i = commodity price in market i .

P_j = commodity price in market j .

T_{ij} = transport costs between markets i and j (commodity points)

Assuming unidirectional flow of goods from j to i , the previous formula states that prices in market i equals price in market j plus transport costs. This equilibrium situation is maintained through the forces of arbitrage. Firstly, if the price of a certain commodity in i is higher than the price of the same commodity in j plus transport costs, this translates into profits for well-informed traders, who will ship goods from j to i . This decreases prices in i as supply increases, and increases prices in j as supply decreases. And secondly, if the left side of the equation is lower than the right side, this implies a demand decrease for products of market j . This causes a price increase in i because of a supply shortage and a price decrease in j because of a demand decrease.

If we assume that trade takes place in both directions, the law of one price states that:

$$|P_i - P_j| \leq T_{ij} \quad (2)$$

²⁰ Static approaches draw mainly on price levels, see Federico, 'European Markets' (2011) and dynamic approaches base on relative price changes, see Uebele, 'Market integration' (2011).

²¹ This approach is in line with a number of previous studies such as Engel and Rogers, 'How wide?' (1994); Ejrnaes and Persson, 'Gains' (2010); Shiue, 'Political Fragmentation' (2005); Schulze and Wolf, 'Economic nationalism' (2012).

In case price differentials surpass transport costs, arbitrage takes place until they are equal or lower than transport costs. On the other hand, if price differentials are lower than transport costs, nothing happens, since there is no need for trade because both regions are self-sufficient.

If a third market k is introduced, and we assume that goods flow from i to j and from k to j , then:

$$|P_i - P_j| \leq T_{ij} \text{ and } |P_k - P_j| \leq T_{kj} \quad (3)$$

In this case, the following condition has to be fulfilled:²²

$$|P_i - P_k| \leq |T_{ij} + T_{kj}| \quad (4)$$

2.2 Development of grain market integration over time

One way to implement the law of one price and track its development over time is the coefficient of variation (CoV).²³ It is defined as the standard deviation of all prices in a given year divided by the sample mean. This measure is dimension-less (i. e. different grain varieties can be compared) and comparable over time and across space. It is formally defined as follows:

$$\text{CoV}_t = \text{SD}_t / \mu_t = \sqrt{\frac{1}{N} \sum_{i=1}^N (x_{it} - \mu_t)^2} / \mu_t \quad (5)$$

x_{it} = grain price of city i in year t .

μ_t = average price of all cities in year t .

N = number of observations.

²² This condition can be tested for many markets.

²³ Metzger , ‘Railroad Development’ (1974); Fremdling and Hohorst, ‘Marktintegration’ (1979).

The CoV measures price dispersion of city prices (x_i) with respect to their mean (μ_t) for the time period (t). Small values mean low price dispersion and indicate a low degree of market integration, whereas high values show a low degree of market integration.

2.3 Estimating the impact of paved roads on market integration

The transport infrastructure literature has been criticized for it often does not focus on the direction of causality, the problem of endogeneity. In order to solve this problem, the literature mainly draws on the instrumental variable approach.²⁴ This approach replaces the problematic variables with a new variable that addresses the two main sources of endogeneity in these studies, simultaneity and omitted variable bias. Simultaneity is the most common problem and it appears when the direction of causality might be bidirectional. This means that investment decisions may have been made after considering the most promising projects. Thus, if a region develops favourably after receiving new roads, it is not clear if that was caused by the project or would have happened without it as well. On the other hand, omitted variable bias is caused by unobserved elements in the error term that are related to the explicative variables.

The main purpose of this research is to establish the correlation between paved roads and market integration because of the novelty of our research field. To investigate this relationship, we propose the following models:

$$PD_{ijt} = \beta_1 \text{Distance}_{ij} + \beta_2 \text{Road_Dummy}_{ijt} + \sum_{k=1}^K \theta_k \Upsilon_{kit} + \varepsilon_{ijt} \quad (6)$$

$$PD_{ijt} = \gamma_1 \text{Distance}_{ij} + \gamma_2 \text{Road_Network}_{ijt} + \sum_{k=1}^K \Phi_k \Upsilon_{kit} + e_{ijt} \quad (7)$$

²⁴ Hornung, ‘Railroads and micro-regional’ (2012); Banerjee et al., ‘Access’ (2012); Atack et al., ‘Railroads’ (2010).

where PD_{ijt} is the percentage grain price difference between city i and j , $Distance_{ij}$ is the log distance between two cities, $Road_Dummy_{ijt}$ is a bilateral measure that shows if a city pair has access to the paved road network, $Road_Network_{ijt}$ is the sum of paved road connections to neighbouring cities of a city pair and ε_{ijt} together with e_{ijt} are independently and identically distributed error terms. Y_{kij} is a matrix of control variables that include city fixed effects and time fixed effects. θ_k and Φ_k are vectors of coefficients (a detailed description of each variable is provided below in Table 1).²⁵ We estimate the model with OLS.²⁶

We propose investigating the impact of paved roads using two different specifications for two reasons. Firstly, this allows for a direct comparison of the dummy and the network approaches. For example, if β_2 turns out to be insignificant while γ_2 is not, this can be interpreted as the inability of the dummy approach to capture other than direct effects of transport infrastructures and the suitability of our network approach. In the opposite case, this would empirically support the use of the classical approach to measure the effects of paved roads. Secondly, including both variables in the same regression might yield inconsistent estimates due to collinearity.

²⁵ Whereas city fixed effects let us consider the features of each city in our regression individually, time fixed effects control for time trends.

²⁶ The dependent variable contains zeros. This results in rejecting the null of normality using standard tests in all periods. The reason why we think OLS is still appropriate is that our dependent variable is not truncated but truly contains zeros. That is, the process generating zeros is the same process generating the non-zeros. This results from the non-continuous nature of grain prices denominated in *Silbergroschen*. We anyway tested Tobit models with a threshold value of 0.05 for all subperiods, reproducing the main results of Tables 1A and 2A in the appendix. The results can be obtained from the authors upon request.

In a second step, we analyse the interplay of paved roads with other transport infrastructures (i.e. waterways and railroads) and test the robustness of the results for the estimations of Equation 6 and 7. In order to do this, we propose the following specifications:

$$PD_{ijt} = \delta_1 \text{Distance}_{ij} + \delta_2 \text{Road_Dummy}_{ijt} + \delta_3 \text{Water_Dummy}_{ij} + \delta_4 \text{Rail_Dummy}_{ijt} + \delta_5 \text{Rail_Network}_{ijt} + \sum_{k=1}^K X_k \Upsilon_{kit} + v_{ijt} \quad (8)$$

$$PD_{ijt} = \zeta_1 \text{Distance}_{ij} + \zeta_2 \text{Road_Network}_{ijt} + \zeta_3 \text{Water_Dummy}_{ij} + \zeta_4 \text{Rail_Dummy}_{ijt} + \zeta_5 \text{Rail_Network}_{ijt} + \sum_{k=1}^K \Omega_k \Upsilon_{kit} + w_{ijt} \quad (9)$$

where *Water_Dummy_{ij}* shows whether a city pair lays along the same waterway,²⁷

Rail_Dummy_{ijt} is a bilateral measure that shows whether a city pair is connected to the railway network and *Rail_Network_{ijt}* is the sum of railroad connections to neighbouring cities of a city pair.²⁸

Table 1: Variables in the model

Variable	Mean	Standard	Min	Max	Variable Description
(I)	(II)	(III)	(IV)	(V)	(VI)
PD_Rye _{ijt}	0.12	0.13	0	2.1	Absolute value of the log difference of rye prices between cities i and j in period t
PD_Wheat _{ijt}	0.1	0.1	0	1.5	Absolute value of the log difference of wheat prices between cities i and j in period t
Distance _{ij}	4.23	0.59	1.81	5.33	Log linear distance between cities i and j in km
Road_Dummy _{ijt}	0.31	0.46	0	1	If both cities have access to the road network in year t it gets 1, 0 otherwise
Road_Networks _{ijt}	3.20	2.47	0	12	Joint sum of road connections to neighbouring cities of cities i and j in period t
Water_Dummy _{ij}	0.09	0.29	0	1	If a city has access to a waterway it gets 1, 0 otherwise
Rail_Dummy _{ijt}	0.04	0.19	0	1	If a city has access to the railway network in year t it gets 1, 0 otherwise
Rail_Network _{ijt}	0.41	1.03	0	7	Joint sum of railway connections to neighbouring cities of cities i and j in period t

²⁷ Note that we do not have a variable for measuring network effects for waterways because Westphalia lacked of a waterway network during our sample period.

²⁸ Similar to the case of paved roads, it should be noted that the variables *Rail_Dummy_{ijt}* and *Rail_Network_{ijt}* are never included in the same regression due to collinearity. They appear in Equation 8 and 9 for the sake of readability.

3. Data

This paper draws on the analysis of 31 cities and towns as a representative sample of the Westphalian grain market during the period 1821-1855. The price observations were originally collected by the Prussian administration and published in official journals.²⁹

We made two decisions regarding data set construction: first, we chose places for which prices were available for the whole period 1821-1855. Unfortunately, for some of the largest cities in Westphalia such as Dortmund and Bochum the journals do not contain prices for the years 1831-1845. Thus, we formed two data sets, and called them “core” and “robustness”. The core data set contains only markets with (nearly) continuous price series including smaller places in the district of Arnsberg, so-called “Kornmärkte”. They were cargo-handling points – for example where grain was forwarded from road to canal – but not important trading centres *per se*. The robustness data set in contrast contains only observations from towns and cities representative of the administrative level below districts, the so-called “Kreise,” resulting in an unbalanced panel with less observations in the 1830s. Thus, most places appear in both data sets, but some appear only in the core data set (*Kornmärkte*), and some only in the robustness data set (*Kreise* in Arnsberg). In the main text, we present the results for the core data set and document the robustness findings in the appendix.

Second, we exclude price comparisons with markets outside Westphalia. As part of a densely populated region, Westphalia also traded with its neighbours, but as we will discuss below

²⁹ Bezirksregierung Münster (ed.): *Amtsblatt* (various years), Bezirksregierung Arnsberg (ed.): *Amtsblatt* (various years), Bezirksregierung Minden (ed.): *Amtsblatt* (various years). Prices were digitized between 1999 and 2001 at the University of Münster for the project PF 351/3 funded by the German Research Foundation DFG. The containing journals are nowadays accessible online. The respective links can be found here:

http://de.wikisource.org/wiki/Amtsbl%C3%A4tter_der_preu%C3%9Fischen_Bezirksregierungen

its interior grain market was substantial. Thus, we restrict our attention only to markets in Westphalia and control for the effect of outside trade connections at the methodological level: If some cities' price differences were systematically higher or lower than others this would be accounted for by the fixed effects in our model.

Table 2 provides descriptive statistics of our data set at district level. Westphalia consisted of three districts at that time: Arnsberg, Minden and Münster. Note that the difference between the two data sets affects only the district Arnsberg. As columns II and IV along with Figure 2 show, the cities are not only equally distributed across the three districts, but also geographically across Westphalia.

Table 2: Descriptive Statistics (districts)

District	Number of cities	Price Observations	Average distance between cities in km
(I)	(II)	(III)	(IV)
Arnsberg	11	1140	44.68
Minden	9	1124	52.41
Münster	10	1400	46.26

The grain types analysed are rye and wheat. Rye was the most important grain in most of Germany for baking bread: Around 1800, its cultivation comprised about one quarter of the arable surface in Westphalia. Furthermore, it was the most frequently traded grain type with a trade volume between 60 and 80 per cent.³⁰ Wheat was the second most important grain type with a higher price-to-weight ratio. Its cultivated area increased by almost 80 per cent between the second and the last quarter of the 19th century.³¹

Price data were originally recorded in *Reichstaler*, *Silbergroschen* and *Pfennig*. We converted them into *Pfennig* and thus to decimal units using the following conversion rate: 1 Taler

³⁰ Achilles, *Deutsche Agrargeschichte* (1993), 198.

³¹ Kopsidis, *Marktintegration* (1996), 171.

= 30 Silbergroschen = 360 Pfennig. The resulting prices are *Pfennig* per Prussian Scheffel.³²

Moreover, the comparability of this data is ensured since all market prices come from the same source and the same region.

There are two price observations for each year, each referring to an average value of retail and wholesale prices in a market within either May or October. In general, time series are complete for both wheat and rye (see column III in Table 2). In the case of the district of Minden price series range from 1824 to 1854 (except of Höxter and Lübbecke where data is available from 1832 onwards). For the cities located in the district of Arnsberg there is price information available from 1821 to 1850 with the exception of Siegen (1821-1828) and Meschede (1821-1831). For the district of Münster time series are complete.

Figure 1 shows the equally weighted average prices for both grain types. Wheat prices lie always above rye prices, since wheat is considered a superior good with respect to rye and therefore has a higher value-to-weight ratio. Their price developments show a similar rising trend over time with strong fluctuations in 1831 and 1847 due to bad harvests.³³

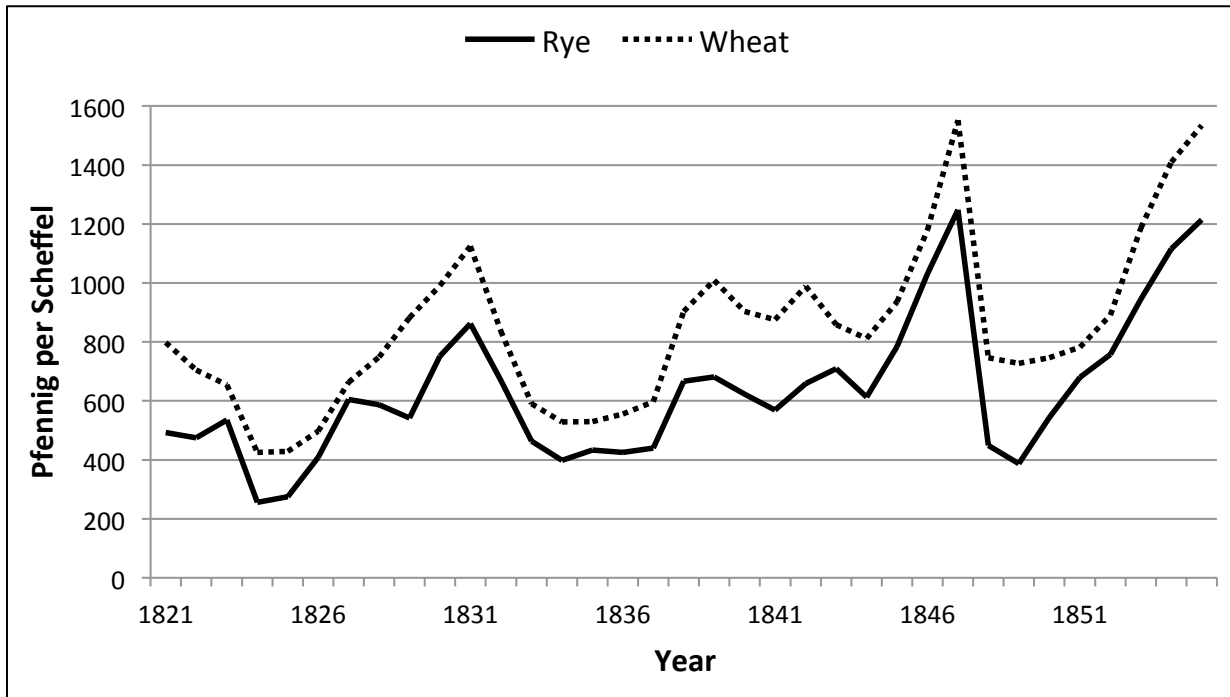
The distance between city pairs is a straight line that incorporates the curvature of the earth and it was calculated using a formula from spherical trigonometry.³⁴ The smallest distance between two cities is six kilometers (Menden and Langschede) and the largest one is 173.96 kilometers (Borken and Höxter).

³² A *Silbergroschen* contained 0.557 grams of silver, while a Prussian *Scheffel* had a volume of 54.9614 litres. See Witthöft, *Deutsche Maße* (1993), 84, vol. 2.

³³ Information about harvests and grain price formation for the period 1795-1846 in Germany is provided by Fremdling and Hohorst, 'Marktintegration' (1979).

³⁴ See Head, 'Gravity' (2003), 5.

Figure 1: Average annual price level of wheat and rye.



To obtain data on transport infrastructures, we looked for reliable sources that could be matched with our data set. For this purpose, historical maps turned out to be the most suitable source. Historical atlases show political frontiers, (sometimes) geographical elements and transport infrastructures, especially paved roads and railways. We combined this source with secondary literature, which provides exact information about railroad lines and paved roads.

In order to use the data on transport infrastructure in our model we used two methods. Firstly, we looked if a city pair had access to a transport network and coded this information in a dummy variable. With this method, we aimed at the direct effects of transport infrastructures on bilateral trade that appear when cities have access at all. Secondly, we used an alternative method to account for the indirect or network effects of a certain means of transport, which work through the connections of third cities. With this distinction, we argue that the mere connection to a paved road is not enough to explain the positive effects of transport infrastructures on trade but that the position in the trade network matters. Thus, a connection to a hub should reduce trade costs more than a connection to an end node that itself leads nowhere. As Figure 2 bears out, the city pairs Münster-Hamm and Recklinghausen-Hattingen are a good example. We observe that a dummy variable

treats them equally and does not capture the stronger trade cost effects of having nine paved road connections to neighbouring cities (Münster-Hamm) instead of five (Recklinghausen-Hattingen). Therefore, we take the sum of directly neighbouring cities reachable through a certain transport network as the explanatory variable.

Lack of data made it impossible to gather paved road information on a yearly basis. For this reason, we divided our sample period in three subperiods: 1821-30, 1831-43 and 1844-55. They were chosen following criteria on data availability and equal-sized time periods. We assume that paved roads built in a certain year would remain and be used at least until the end of our sample period in 1855. This represents a realistic assumption since paved roads were built with a long-term perspective. They embodied large investments and enabled the funding of new investments through the establishment of tollbooths.

Putting together the data set, we found several inconsistency problems between the sources (i.e. some cities show road connections just in some years). These inconsistencies might have arisen because some authors did not distinguish between *Landstraßen*³⁵ (rural roads) and *Chausseen* (paved roads). To overcome this problem, we classified them following a two-step analysis. We first checked if a certain road also appeared in subsequent maps. If so, we assumed it had a certain importance and therefore it was likely to be a paved road. In a second step, we double-checked this information by comparing it with lists of paved roads in the secondary literature.³⁶

The establishment of paved roads was not equally and rather randomly distributed among districts. As Figure 2 and Table 3 (columns II, III and IV) show, the network density varies significantly from district to district. Cities within the district of Arnsberg had most of paved road

³⁵ *Landstraßen* were not paved. The bad conditions of these roads have often been described by contemporaries. Several of them were collected by Sälter, Entwicklung (1917) and Beckmann and Stenkamp, *Express* (1996).

³⁶ Sälter, Entwicklung (1917); Gador, Entwicklung des Straßenbaues (1966).

connections during the whole sample period because of the importance of this region as a coal-mining and proto-industrial center. Regarding Münster, cities in this district did not have a well established network until the 1840s. In Minden, the situation was much more developed than in Münster with 70 per cent of sample cities connected to the road network by the second period.

Table 3: Access to transport infrastructures at district level.

District	Percentage of cities with access to roads			Percentage of cities with access to railways			Percentage of cities with access to waterways
(I)	1821-1830 (II)	1831-1843 (III)	1844-1855 (IV)	1821-1830 (V)	1831-1843 (VI)	1844-1855 (VII)	(VIII)
Arnsberg	54	81	100	0	0	55	70
Minden	44	66	88	0	0	55	22
Münster	10	20	70	0	0	20	10

Figure 2: Paved road network during the first half of the 19th century



Including data on waterways proved to be more simple, since their number and length did only slightly change during the first half of the 19th century. They consisted of the navigable rivers Ruhr, Lippe, Vechte, Ems and Weser and the Max-Clemens canal. The Ruhr was undoubtedly the most important waterway in this region (located in the middle of the province and being a tributary of the Rhine). It was the most used waterway in Germany for trade in the 19th century because of the coalmines close to it.³⁷ Another important Westphalian waterway is the Lippe; a tributary of the Rhine as well located several kilometres to the north. The remaining waterways can be classified as secondary, since either they barely flow through Westphalian lands or they could not be travelled

³⁷ Mühlen, *Wasserstraßen* (1980), 9.

by ships with more than 50 tons load. The rivers Weser, Ems and Vechte belong to the former group and the Max-Clemens canal to the latter.

The district that could benefit most from this means of transport was Arnsberg. 70 per cent of the sample cities within this district had access to water transport. However, this was not the case for Münster and Minden with 10 and 20 per cent, respectively (see Table 3, column VIII).

Information regarding railroad connections was gathered from historical maps and then compared with a list of railway connections.³⁸ The first Westphalian railroad was opened in 1847, namely the so-called *Köln-Mindener* line. It provided an important connection of the prosperous western parts of the Prussian kingdom with the eastern parts. In the following years, new railroads were built around this first line such as the Münster-Hamm railroad in 1848 or the Paderborn-Hamm line in 1850.

As column VII of Table 3 shows, most railroads were built in the districts of Arnsberg and Minden. 70 per cent of our sample cities in Minden had a railway connection and 55 per cent in Arnsberg. The district of Münster had just one railroad line during the sample period.³⁹

4. Results

4.1 Market integration during the period 1821-1855

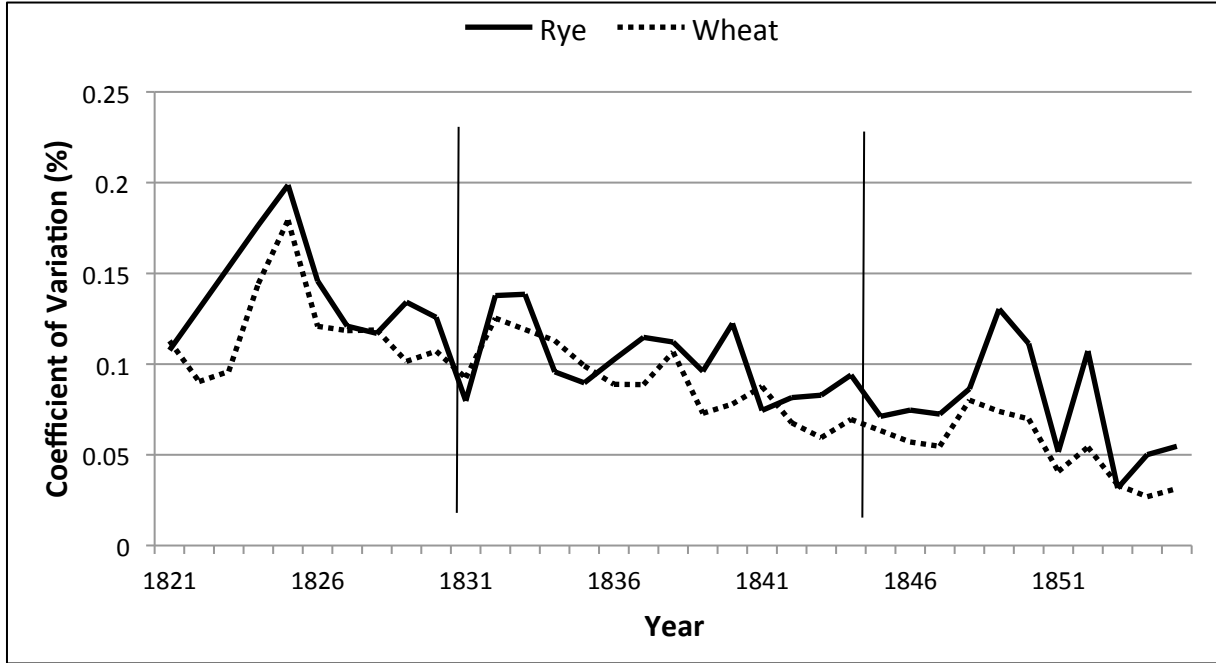
Figure 3 shows the development of grain price spreads over the sample period. In general, there is a progressive decline of both rye and wheat price dispersion. The period 1821-1830 is characterized by relatively high price dispersion. It also contains the most prominent peaks of the whole sample period in the years 1824 (for wheat) and 1825 (for rye). During the last two subperiods, this process

³⁸ Kaiserliches Statistisches Amt, 'Zur Eisenbahn' (1878). We are indebted to Richard Tilly who made this source available to us.

³⁹ This situation remained until 1856, when the Emden-Münster railroad was built.

takes shape and grain price dispersion becomes very low (especially in the 1850s), indicating a high degree of market integration.

Figure 3: Coefficient of variation of rye and wheat from 1821 to 1855.



In the next section, we show that infrastructure development was strongly correlated with Westphalian grain market integration, especially from the 1830s onwards.

4.2 Analysis of the role of paved roads on market integration

Table 4 and Table 5 show the results of estimating Equations 6 and 7 for rye and wheat separately. In both cases, *Distance* is significant and has the expected sign. The coefficients decrease over the whole sample period, indicating that distance between markets became economically less important. This suggests a decline of transport costs that in the case of wheat is considerably smaller than in the case of rye (16 and 22 per cent, respectively). For the period 1831-1843, the *Distance* coefficient is larger than for the period before in the case of rye. However, it should be noted that this increase is significantly smaller when accounting for differences within this period. By analysing the periods 1831-1834 and 1835-1843 separately, we find that *Distance* coefficients

are 0.0407 and 0.0307 respectively. This shows that the large coefficient for the period 1831-1843 is partly due to the first four years of that period. Moreover, it is worth mentioning that the lower effect of distance on wheat price differences is consistent with Figure 3, showing that the wheat market was more integrated than the rye market. These differences may have been caused by a more intensive wheat trade between than within districts.

To test the relationship between paved roads and market integration, we study the variables *Road_Dummy* and *Road_Network* separately. In the case of rye, the first one carries no explanatory power and proves to be insufficient to capture the effects of the paved road network. As Table 4 shows, it becomes significant for the second subperiod but has the wrong sign. On the other hand, the *Road_Network* coefficient is significant and negative for rye during the second and third periods (see Table 4, columns III and IV). However, during the first period the sign and the level of significance are not robust to the choice of the estimator and fixed effects used. In particular, the coefficient becomes insignificant if we replace the OLS estimator by a Tobit estimator and/or clustered standard errors while the rest of the results remain stable.⁴⁰ It is thus reassuring that estimating Equations 6 and 7 with the expanded robustness data set yields highly significant negative coefficients both at *Road_Dummy* and *Road_Network* (see appendix Table 1A, columns I and II).

⁴⁰ Results may be obtained upon request.

Table 4: Regressions results for rye.

	1821-1830		1831-1843		1844-1855	
	(I)	(II)	(III)	(IV)	(V)	(VI)
Distance	0.0475*** (0.0028)	0.0476*** (0.0028)	0.0461*** (0.0015)	0.0461*** (0.0015)	0.0369*** (0.0032)	0.0369*** (0.0031)
Road_Dummy	-0.0042 (0.0065)		0.0104*** (0.0034)		0.0021 (0.0089)	
Road_Network		0.0054*** (0.0016)		-0.0045*** (0.0009)		-0.0093*** (0.0017)
City FE	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	6.283	6.283	9.723	9.723	7.002	7.002
R2	0.319	0.319	0.347	0.346	0.123	0.123
Adjusted R2	0.315	0.315	0.344	0.343	0.118	0.118

Table 5: Regression results for wheat.

	1821-1830		1831-1843		1844-1855	
	(I)	(II)	(III)	(IV)	(V)	(VI)
Distance	0.0282*** (0.0028)	0.0281*** (0.0028)	0.0338*** (0.0014)	0.0339*** (0.0014)	0.0238*** (0.0011)	0.0237*** (0.0011)
Road_Dummy	0.0055 (0.0061)		-0.0059* (0.0031)		-0.0169*** (0.0055)	
Road_Network		0.0003 (0.0014)		-0.0055*** (0.0007)		-0.006*** (0.0006)
City FE	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	6.109	6.109	9.723	9.723	7.002	7.002
R2	0.236	0.236	0.352	0.351	0.243	0.242
Adjusted R2	0.231	0.231	0.349	0.349	0.239	0.238

For wheat, *Road_Network* coefficients show a clearly negative relationship between paved roads and price differences during the last two periods (see Table 5, columns IV and VI). Similar to rye, we do not find a robust correlation between paved roads and market integration for the 1820s, which however changes in favour of our predictions with the larger robustness data set (see appendix Table 2A, columns I and II). Regarding *Road_Dummy*, it is significant and has the expected sign for the last two periods. For the period 1831-1843 though, the statistical relationship is less clear as the coefficient is significantly different from zero at the 10 per cent level.

Comparing the dummy and the network approach in Table 4 and 5, we observe that the conventional dummy-variable approach presents serious shortcomings in our study for three reasons. Firstly, in the case of rye it is unable to show a consistent relationship between paved roads and market integration since the *Road_Dummy* coefficients are either insignificant or have the wrong sign. Secondly, in the case of wheat the coefficient for the second period is only marginally significant and quite unstable since it almost triples from the second to the third period. On the other hand, *Road_Network* is highly significant and stable in size. Thirdly, using the robustness data set for the first and third periods, only in one of four cases, rye in period one, is *Road_Dummy* negative and significant, while *Road_Network* always is (see appendix Table 1A and Table 2A, columns I and III).

Paved roads were economically relevant.⁴¹ In the case of rye, an extra paved road connection reduces the price gap by 0.0045 in the period 1831-1843 and by 0.0093 in the period 1844-1855. If we look at the average price gap in both periods (0.1663 and 0.1183 respectively) our results suggest that getting an additional paved road connection accounts for 2.7 per cent of the reduction of that gap for the period 1831-1843 and almost 8 per cent for the last period. In the case

⁴¹ For the economic interpretation of our results we follow Shiue, 'Political Fragmentation' (2005).

Moreover, we will just consider the variable *Road_Network* for this analysis due to the aforementioned problems related to the dummy variable.

of wheat, one extra paved road connection reduces price gap by 0.0055 and 0.006 in the last two periods. These extra connections account for 3.8 per cent of the reduction of the average price gap for the period 1831-1843 and 5.6 per cent for the last period (the average price gaps for both periods are 0.1447 and 0.1066). Finally, if we look at the size of the coefficients at *Road_Network* with respect to the *Distance* coefficients, we see that for both grain types they are 10 to 15 per cent of the average distance coefficient for the period 1831-1843, and 25 per cent for the period 1844-1855. This means that an additional connection to the paved road network reduced distance costs considerably.

4.3 Analysis of the interplay of paved roads with other means of transport

In the following, we will focus on the interplay of paved roads with waterways and railroads by estimating Equations 8 and 9. Table 6 and 7 present the results for rye and wheat respectively. It should be noted that the period 1844-1855 is analysed using four specifications. Specification (V) and (VI) include railroads using the dummy-variable approach, and specification (VII) and (VIII) include railroads using the network approach.

Regarding rye (see Table 6), three points are worth mentioning. Firstly, the coefficient of *Water_Dummy* is significant and has the right sign for the whole sample period. However its size is exceptionally high since it is almost double the size of the distance coefficient in the first period. In the second and last period, it is up to four times the *Distance* coefficient. Thus we think that this variable is not only capturing the effect of waterways on price differences, but also other effects. For example, 55 percent of the cities with access to waterways are cities located in the Ruhr valley. Cities in this area belong practically to the same market because they had the function of connecting the northern part of the province with a grain production surplus to the more proto-industrialised

southern part with a grain deficit.⁴² Therefore, including the waterway dummy probably captures the low price differences between pairs with similar functions in the regional market, and not a transport cost effect.

There are two more problems related to this variable. One is the lack of variance in waterway number and length during our sample period. The second is that it is almost perfectly explained by a district (border) dummy, since 70 per cent of cities with access to waterways belonged to the district of Arnsberg (see Table 3, column VII). For these reasons, interpreting this variable in the same way as the variable *Road_Dummy* is likely to be misleading.

All these conjectures seem to be confirmed when estimating the same models with the robustness data set for the first and third subperiods. This data set adds cities without water access to the district of Arnsberg and thus potentially relieves some of the collinearity between water access and the district dummy. Consequently, *Water_Dummy* becomes insignificant across models and periods (see appendix Table 1A, columns I and II).

The second thing worth mentioning about the core data set results is that the performance of the variable *Road_Dummy* does not improve relative to the regressions without alternative means of transport, as it is insignificant for the first and last period and significant but with the wrong sign for the second period. On the other hand, *Road_Network* becomes insignificant in the second period after including the variable for waterways, but remains significant and stable in sign and size with regard to the inclusion of railroad variables (columns VI and VIII).

Double-checking using the robustness data set for periods one and three dispels most of the doubts raised by these findings against our network approach: The coefficient at *Road_Network* remains negative and significant across all periods and specifications while *Road_Dummy* is mostly insignificant.

⁴² Lampp, 'Getreidehandelspolitik' (1911).

The third observation to mention is that we find no statistical relationship between railroads and rye market integration for the period 1844-1855 as *Rail_Dummy* (specifications V and VII) and *Rail_Network* (specifications VII and VIII) are never significant, which does not change when *Water_Dummy* is excluded. These results remain when checking with the robustness data set (see appendix Table 1A, columns I and II).

Table 6: Regression results for rye including other means of transport.

	1821-1830		1831-1843		1844-1855		1844-1855	
	(I)	(II)	(III)	(IV)	(V)	(VI)	(VII)	(VIII)
Distance	0.0392*** (0.003)	0.0395*** (0.003)	0.0381*** (0.0017)	0.0380*** (0.0017)	0.0288*** (0.0037)	0.0289*** (0.0037)	0.0287*** (0.0038)	0.0288*** (0.0037)
Road_Dummy	-0.0076 (0.0065)		0.0097*** (0.0033)		0.0063 (0.009)		0.0064 (0.009)	
Road_Network		0.0103*** (0.0018)		0.0003 (0.001)		-0.057*** (0.0019)		-0.0055*** (0.002)
Water_Dummy	-0.0662*** (0.009)	-0.0651*** (0.0089)	-0.0640*** (0.0051)	-0.0643*** (0.0051)	-0.0820*** (0.0123)	-0.0819*** (0.0123)	-0.0821*** (0.0123)	-0.0819*** (0.0123)
Rail_Dummy					-0.0059 (0.0043)	-0.0058 (0.0043)		
Rail_Network							-0.0018 (0.0011)	-0.0017 (0.0011)
City FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	6.283	6.283	9.723	9.723	7.002	7.002	7.002	7.002
R2	0.324	0.323	0.355	0.354	0.129	0.129	0.129	0.129
Adjusted R2	0.319	0.319	0.352	0.351	0.124	0.124	0.124	0.124

With respect to wheat (see Table 7), the following three points can be mentioned. Firstly, even though *Water_Dummy* coefficients are not as large as for rye, they are exceptionally high. As before, we cautiously refrain from interpreting this variable due to the aforementioned problems associated to it. This is also borne out by the robustness data set. When estimated with wheat the coefficient emerges insignificant in the first period, and becomes weakly significant with the wrong sign in the last period (see appendix Table 2A).

Secondly, *Road_Dummy* is now significantly different from zero at the one percent level for the second period and the size of the coefficients for the last two subperiods does not change significantly. The coefficients at *Road_Network* decline roughly by half but remain highly significant and with the right sign for the two last periods. This supports the robustness of our previous results. Estimating the same model with the robustness data set strengthens the argument for the network approach and against the conventional approach: *Road_Dummy* turns insignificant and *Road_Network* stays significant across all specifications (see appendix Table 2A).

Thirdly and finally, the coefficients for *Rail_Dummy* and *Rail_Network* are significant and have the right signs in specifications VI, VII and VIII at the 10 percent level. However, they become insignificant when the variable *Water_Dummy* is excluded from the regressions (see Table 8). Therefore, the empirical evidence for the role of railroads on Westphalian grain market integration is not robust in our sample period. This finding supports the view that railways did not become economically relevant for the trade of staple goods before the 1860s.⁴³ Evidence from the larger robustness data set however suggests that railroads may have had an effect at least for the higher value product of wheat: both *Rail_Dummy* and *Rail_Network* turn highly significant however at about 1/3 of the size of the relevant paved road coefficient *Road_Network* (see appendix Table 2A, columns III, IV, V and VI).

⁴³ Fremdling and Hohorst, 'Marktintegration' (1979),

Table 7: Regression results for wheat including other means of transport.

	1821-1830		1831-1843		1844-1855		1844-1855	
	(I)	(II)	(III)	(IV)	(V)	(VI)	(VII)	(VIII)
Distance	0.0226*** (0.0032)	0.0225*** (0.0031)	0.0293*** (0.0016)	0.0294*** (0.0016)	0.0190*** (0.0012)	0.0189*** (0.0012)	0.0190*** (0.0012)	0.0189*** (0.0012)
Road_Dummy	0.0033 (0.0061)		-0.0062*** (0.0031)		-0.0143*** (0.0055)		-0.0144*** (0.0055)	
Road_Network		0.0037* (0.0017)		-0.0027*** (0.0009)		-0.0038*** (0.0007)		-0.0038*** (0.0007)
Water_Dummy	-0.0442*** (0.0085)	-0.0446*** (0.0084)	-0.0360*** (0.0044)	-0.0358*** (0.0044)	-0.0475*** (0.0045)	-0.0478*** (0.0045)	-0.0475*** (0.0045)	-0.0478*** (0.0046)
Rail_Dummy					-0.0049* (0.0026)	-0.0051* (0.0026)		
Rail_Network							-0.0011 (0.0006)	-0.0011* (0.0006)
City FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	6.109	6.109	9.723	9.723	7.002	7.002	7.002	7.002
R2	0.238	0.238	0.355	0.354	0.254	0.254	0.254	0.254
Adjusted R2	0.233	0.233	0.352	0.352	0.250	0.249	0.250	0.249

Summing up, this study of regional grain price development in Westphalia shows that the increasing market integration during the first half of the 19th century cannot be attributed to institutional factors such as the creation of a common Westphalian market and the railway only. The demonstrated correlation between paved roads and market integration shows that cities with more paved road connections were better integrated at least from 1830 onwards. When including additional data for the 1820s, a statistically significant effect of paved roads can already be found in those years.

Table 8: Regression results for wheat during the 1844-1855 excluding *Water_Dummy*.

	1844-1855			
	(I)	(II)	(III)	(IV)
Distance	0.0237*** (0.0011)	0.0236*** (0.0011)	0.0237*** (0.0011)	0.0236*** (0.0011)
Road_Dummy	-0.0165*** (0.0055)		-0.0166*** (0.0055)	
Road_Network		-0.0058*** (0.0006)		-0.0058*** (0.0007)
Rail_Dummy	-0.0039 (0.0026)	-0.0042 (0.0026)		
Rail_Network			-0.0008 (0.0006)	-0.0009 (0.0006)
City FE	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes
Observations	7.002	7.002	7.002	7.002
R2	0.243	0.242	0.243	0.242
Adjusted R2	0.239	0.238	0.239	0.238

5. Conclusion

This paper attempts to contribute a potential explanatory factor for Germany's macroeconomic transition in the early 19th century. This transition has recently been discovered and consists of the transition to a non-Malthusian demographic regime, a rise of labour demand, and increasing national and international grain market integration.⁴⁴ So far, only tentative explanations can be formulated such as a change of the political environment after the end of the Holy Roman Empire and the Napoleonic Wars, liberal economic reforms by Prussia, and gradual technological change including the implementation of transport and communication infrastructure such as paved road networks. The latter is what we analyse in this paper as a potential explanatory factor, because it improved the conditions for mutual exchange over longer distances through lower costs, higher

⁴⁴ Pfister and Fertig, 'Population' (2010); Pfister et al., 'Real Wages' (2012); Uebele, 'Market integration' (2011).

transport capacity and higher speed of transport. These improvements may have reduced food risk, and fostered Smithian growth in terms of division of labour.

Our case study is Westphalia, which already under French occupation experienced rapid paved road network growth and accelerated during the 1820s (by 1830, Westphalia was the Prussian province with the second-longest paved road network after the Rhine province). Paved road data could be retrieved from secondary sources and historical maps for three cross-sections between 1821 and 1855. We confront this development with rye and wheat prices for roughly three dozens Westphalian cities, and formulate a model relating bilateral percentage price differences to distance and transport infrastructures. For the analysis of transport infrastructures we use the usual dummy-variable approach and an indicator of the connectedness of transport infrastructures that represents network effects.

The results of our study can be summarised in three points. Firstly, we show that distance coefficients decreased between the 1820s and the 1840s by about 22 and 16 percent per cent for rye and wheat, respectively. This indicates an important reduction of transport costs during our sample period. Secondly, we observe that the dummy-variable approach has serious shortcomings for measuring the effects of paved roads in our empirical analysis for two reasons. One is that this variable is mostly not or marginally significant or has the wrong sign in the case of rye, and the other is that in the case of wheat the size of the coefficient is not stable from one period to another. On the other hand, our newly-developed variable that accounts for transport network effects is significantly different from zero at the one per cent level and stable in size in the periods after 1831 when transport infrastructure mattered in Westphalia. And thirdly, we find no robust empirical evidence for the role of railroads on Westphalian rye market integration in our sample period. The evidence we do find for wheat points at a much smaller effect compared to paved roads. This confirms the claim that initially, trains moved high value-to-weight goods.

We are aware of the fact that this empirical setup is not immune against endogeneity or simultaneity bias, since transport infrastructures may have been built between cities that were already better integrated than others, or that already existing trade networks may have determined both the development of percentage price differences and the design of the road network alike. However, we consider this study not as the final word on paved roads' role in early 19th century Germany's economic development, but merely as a determined call for deeper research in this particular period and research area.

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Appendix

Figure 1A: Overview of the markets contained in the robustness data set



Table 1A: Regression results for rye (robustness data set).

	1821-1830			1844-1855		
	(I)	(II)	(III)	(IV)	(V)	(VI)
Distance	0.0578*** (0.0036)	0.0605*** (0.0036)	0.0447*** (0.0024)	0.0448*** (0.0024)	0.0447*** (0.0024)	0.0448*** (0.0024)
Road_Dummy	-0.0388*** (0.0077)		0.0100 (0.0076)		0.0100 (0.0076)	
Road_Network		-0.0083*** (0.0025)		-0.0148*** (0.0012)		-0.0148*** (0.0012)
Water_Dummy	0.0198 (0.0275)	0.0114 (0.0275)	0.0140 (0.0144)	0.0142 (0.0144)	0.0139 (0.0144)	0.0141 (0.0144)
Rail_Dummy			0.0013 (0.0035)	0.0015 (0.0035)		
Rail_Network					0.0003 (0.0007)	0.0004 (0.0007)
City FE	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	8136	8136	11244	11244	11244	11244
R2	0.276	0.273	0.153	0.153	0.153	0.153
Adjusted R2	0.272	0.269	0.149	0.149	0.149	0.149

Table 2A: Regression results for wheat (robustness data set).

	1821-1830			1844-1855		
	(I)	(II)	(III)	(IV)	(V)	(VI)
Distance	0.0345*** (0.0027)	0.0350*** (0.0027)	0.0257*** (0.0011)	0.0257*** (0.0011)	0.0258*** (0.0011)	0.0258*** (0.0011)
Road_Dummy	-0.0064 (0.0053)		0.0022 (0.0065)		0.0019 (0.0065)	
Road_Network		-0.0038** (0.0018)		-0.0075*** (0.0006)		-0.0078*** (0.0006)
Water_Dummy	-0.0255 (0.0229)	-0.0269 (0.0229)	0.0086* (0.0049)	0.0086* (0.0049)	0.0094* (0.0049)	0.0094* (0.0049)
Rail_Dummy			-0.0126*** (0.0020)	-0.0125*** (0.0020)		
Rail_Network					-0.0022*** (0.0004)	-0.0022*** (0.0004)
City FE	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	7518	7518	11244	11244	11244	11244
R2	0.254	0.254	0.324	0.324	0.324	0.324
Adjusted R2	0.250	0.250	0.321	0.321	0.321	0.321

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