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

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This study investigates the impact 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 a standard gravity model setup we show that (a) paved road connections mattered economically and statistically for bilateral rye and wheat price differences while (b) early railroad connections are only significant for wheat price differences. Since we need to acknowledge potential endogeneity bias in our results, in this pilot study we merely establish for the first time the correlation between economic development and pre-railroad transport infrastructure for a Prussian province, and call for more research on the causes of macroeconomic change in early 19th century Prussia.

Keywords: Transport infrastructure; grain markets; Westphalia; early 19th century

Introduction

What are the origins and causes of modern economic growth? This question is still in 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

[1] Fogel, *Railroads* (1964); Fremdling, *Eisenbahnen* (1985); Gerschenkron, *Economic Backwardness* (1962).

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*? 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?[4]

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.[5] In addition, they also point out their positive and partially ignored consequences for overland transport.[6]

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[2] Uebele, 'National and international market integration' (2011); Pfister and Fertig, 'Population History' (2012); Pfister et al., 'Real Wages' (2011).

[3] Acemoglu et al., 'The Consequences of Radical Reform' (2011).

[4] Uebele, 'Demand Matters' (2011); Sharp and Weisdorf, 'French Revolution' (2012); Federico, 'Market Integration in Europe'.

[5] Voigt, *Verkehr* (1965), 433.

[6] Sälter, *Entwicklung* (1917); Wischermann, 'Chausseebau' (1999).

An important part of the modern growth literature has reserved a significant role for transport infrastructures.[7] 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 kilometres[8] decreasing transport costs and increasing transport speed and capacity substantially.[9] 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 Westphalia. Despite a similar approach for a Belgian region in the late 18th century, [10] no state-of-the-art quantitative analysis of this relationship has been undertaken for Germany so far.

We start with a gravity model setup that relates half-annual rye and wheat prices from 31 cities mainly from Westphalia during the period 1821-1855 to paved roads, railroads, and canals. Moreover, we follow a novel approach to measure their effects on trade. Instead of the usual bimodal dummy approach, we consider the total number of paved road (or canal or railroad) connections a city pair had. This accounts for the network effects arising when cities gained additional paved road or railroad connections

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[7] Hornung, 'Railroads' (2012); Banerjee et al., 'Access to Transportation' (2012); Atack et al., 'Railroads' (2010); Keller and Shiue, 'Institutions' (2008).

[8] Gador, *Entwicklung des Straßenbaues* (1966), 62-63.

[9] Sälter, *Entwicklung* (1917).

[10] 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.

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: For rye, paved roads had a large effect on bilateral price differences, while railroad connections did not. For wheat, which was rather a luxury and a not a staple good in Germany, distance had a smaller overall effect, and so did paved roads. Railroad connections had an effect on price differences, although small in comparison to paved roads.

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. Of course 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. 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.

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

In line with the late-comer hypothesis[11] and the transport revolution,[12] 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 important institutional breaks took place such as the creation of the German confederation or the Zollverein, but also macroeconomic changes happened that show

[11] Gerschenkron, *Economic Backwardness* (1962).

[12] O´Rourke and Williamson, *Globalization* (1999).

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.[13]

Secondly, Pfister et al. estimate a structural time series model to analyse the relationship between new developed real wage indices and population size.[14] They find a sustained growth of labour productivity with a significant increase in labour demand already in the 1810s.[15]

And thirdly, synchronous price movements at a national and international level increased substantially during the second quarter of the 19^{th} century.[16] 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).

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[13] See Pfister and Fertig, 'Population History' (2012).

[14] Pfister et al., 'Real Wages' (2011).

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

[16] Uebele, 'National and international market integration' (2011).

Method

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]’.[17] The interpretation of economic interdependence in the previous definition plays a crucial role in its theoretical analysis that can be static or dynamic.[18] In this paper, we take a static approach by analysing spatial price level convergence over time (i.e. law of one price).

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, transaction 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} = transactions 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 transaction costs. This equilibrium situation is maintained through the forces of arbitrage. Firstly, if the price of a certain

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

[18] Static approaches draw mainly on price levels, see Federico, ‘When did European Markets Integrate?’ (2011) and dynamic approaches base on relative price changes, see Uebele, ‘National and international market integration’ (2011).

commodity in *i* is higher than the price of the same commodity in *j* plus transactions 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:

$$\left| P_i - P_j \right| \leq T_{ij} \qquad (2)$$

In case price differentials surpass transactions costs, arbitrage takes place until they are equal or lower than transaction costs. On the other hand, if price differentials are lower than transactions 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:

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

In this case, the following condition has to be fulfilled:[19]

$$\left| P_i - P_k \right| \leq \left| T_{ij} - T_{kj} \right| \qquad (4)$$

Development of grain market integration over time

[19] This condition can be tested for many markets.

One way to implement the law of one price and track its development over time is the coefficient of variation (CoV). 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:

$$CoV_t = SD_t/\mu_t = \sqrt{\frac{1}{N}\sum_{i=1}^{n}(x_{it} - \mu_t)^2} \;/\; \mu_t \qquad (5)$$

x_{it} = grain price of city *i* in year *t*.
μ_t = average price of all cities in year *t*.
N = number of observations.

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 certain degree of market integration, whereas high values show a low degree of market integration.

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 the causality, the problem of endogeneity. In order to solve this problem, the literature mainly draws on the instrumental variable approach.[20] 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

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[20] Hornung, ‘Railroads’ (2012); Banerjee et al., ‘Access to Transportation’ (2012); Atack et al., ‘Railroads’ (2010).

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, since we still need to acknowledge potential endogeneity bias in our results. For this purpose, we propose a model that relates bilateral grain price differences (i.e. law of one price) to transport infrastructures, namely an augmented modified gravity model. Firstly, we refer to our model as 'augmented' because we have introduced explicative variables that are not included in the original model. And secondly, we use a 'modified' version because we replaced several key variables of the classical model.

The gravity model is derived from the Newtonian physics function that explains the force of gravity. It states that the attracting force between two elements is proportional to their masses and inversely proportional to the square of the distance between them. In order to use this theory for research in economics, the interpretation of its elements changes, and its formula can be represented as follows:[21]

$$F_{ij} = G\ \frac{M_i^{\alpha}\ M_j^{\gamma}}{D_{ij}^{\beta}} \qquad (6)$$

F_{ij} = transport from *i* to *j* (e.g. goods).
M_i and M_j = economic masses of countries *i* and *j* (e.g. GDP).
D_{ij} = distance between countries *i* and *j* (measured from their geographic centers).
G = a constant that may vary by country, e.g. to explain the alternative set of trade partners.

[21] See Head, 'Gravity' (2003) for more details.

The previous formula states that bilateral trade volume between countries *i* and *j* is proportional to their economic sizes (measured as GDP or population) and inversely proportional to their distance from each other. To implement this theory in a statistical model that can be estimated by the Ordinary Least Squares method (OLS), the previous formula has to be transformed by log-linearizing and including an error term:

$$\text{Ln } F_{ij} = \ln G + \alpha \ln M_i + \gamma \ln M_j - \beta \ln D_{ij} + \varepsilon_{ij} \qquad (7)$$

At this point, we modify the classical model in several ways. Firstly, we replace the original dependent variable (F_{ij}) by absolute bilateral grain price differences. By doing this, our model measures to which extent the law of one price is fulfilled. Secondly, we drop the intercept G and introduce a set of control variables consisting of city pair fixed effects to allow for unobserved heterogeneity in our model.[22] Thirdly, we omit the economic masses since we lack such information.[23] By doing this, we obtain the modified version of the gravity model:

$$PD_{ij} = \beta \ln Dij + \sum_{k=1}^{K} \theta_k X_{kij} + \varepsilon_{ij} \qquad (8)$$

Equation (8) relates price percentage differences between cities proportionally to the logarithm of their geographical distances, which is used as a proxy for transport costs.[24] X_{kij} is a vector of fixed effects, and θ_k is a vector of coefficients. The model used in this research is version of (8) augmented by indicators for transport infrastructures and time effects:

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[22] Cheng and Wall, 'Controlling for Heterogeneity' (2005).

[23] Their effect is potentially weak when using price differences instead of trade flows. The remaining effect is captured by the fixed effects.

[24] See Head, 'Gravity' (2003), 6.

$$PD_{ijt} = \beta_1 Distance_{ij} + \beta_2 Road\_Access_{ijt} + \beta_3 Road\_Conn\_Cities_{ijt} + \beta_4 Border\_Effect_{ij} + \beta_5 Water\_Access_{ij} + \beta_6 Water\_Conn\_Cities_{ij} + \beta_7 Rail\_Access_{ijt} + \beta_8 Rail\_Conn\_Cities_{ijt} + \sum_{k=1}^{K} \theta_k \Upsilon_{kit} + \varepsilon_{ijt} \quad (9)$$

A detailed description of each variable is provided below in Table 3. Υ_{kij} is a matrix of control variables that include city fixed effects and time fixed effects.[25]

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

Table 1: Variables in the model

Variable (I)	Mean (II)	Standard Deviation (III)	Min (IV)	Max (V)	Variable Description (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
$Road\_Access_{ijt}$	0.31	0.46	0	1	If both cities have access to the road network in year t it gets 1, 0 otherwise
$Road\_Conn\_Cities_{ijt}$	3.20	2.47	0	12	Joint sum of road connections to neighbouring cities of cities i and j in period t
$Water\_Access_{ij}$	0.09	0.29	0	1	If a city has access to a waterway it gets 1, 0 otherwise
$Water\_Conn\_Cities_{ij}$	1.16	1.26	0	4	Joint sum of waterway connections to neighbouring cities of cities i and j in period t
$Rail\_Access_{ijt}$	0.04	0.19	0	1	If a city has access to the railway network in year t it gets 1, 0 otherwise
$Rail\_Conn\_Cities_{ijt}$	0.41	1.03	0	7	Joint sum of railway connections to neighbouring cities of cities i and j in period t
$Border_{ij}$	0.70	0.45	0	1	If the city pair lies in different districts it gets 1, 0 otherwise

Note: All variables refer to city pairs.

Data

This paper draws on the analysis of 31 cities as a representative sample of the Westphalian grain market during the period 1821-1855. Most of these cities are located within the borders of Westphalia, which consisted of three districts at that time: Arnsberg, Minden and Münster. Hannover is the only city that does not belong to Westphalia. We include it because of its importance as a trade centre and its closeness to Westphalian borders (approximately 40 kilometres).[26]

Table 2 provides descriptive statistics of our data set at a district level. As columns II and IV along with Figure 1 show, the cities are not only equally distributed across the three districts, but also geographically across Westphalia (with the exception of Siegen and Hannover).

Table 2: Descriptive Statistics (districts)

District (I)	Number of cities (II)	Price Observations (III)	Average distance between cities in km (IV)
Arnsberg	11	1140	44.68
Minden	10	1228	59.8
Münster	10	1400	46.26

Note: price observations refer to both rye and wheat.

[26] To simplify the explanation of our data set, we treat Hannover as part of the district of Minden.

Figure 1: Overview of the analysed cities and their respective districts.

Table 3 then provides summary statistics about each city. Column IX shows information about city population size from a classification employed by the Prussian Statistical Office:[27] big city, medium-sized city, small town and rural town.[28] Most of the cities in our data set are small or very small, except of Münster, Hannover, Bielefeld and Halle, which are medium-sized cities.

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[27] Because of the difficulty to find population data for the first half of the 19th century, we had to obtain this information in several cases from Prussian censuses of the second half of this century. We will just use this information for informative purposes in this section, since it does not refer to our sample period.

[28] A city was classified as big if it had more than 100,000 inhabitants; medium-sized cities had between 20,000 and 100,000 inhabitants; small cities had between 5,000 and 20,000 inhabitants; rural towns had between 0 and 5,000 inhabitants.

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.[29] 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 to the last quarter of the 19th century.[30]

Price data were originally recorded in *Reichstaler*, *Silbergroschen* and *Pfennig*.[31] We converted them into *Pfennig* and thus to decimal units using the following conversion rate: 1 Taler = 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.

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[29] Achilles, *Deutsche Agrargeschichte* (1993), 198.

[30] Kopsidis, *Marktintegration und Entwicklung* (1996), 171.

[31] Prices were collected between 1999 and 2001 for a project on factor markets in Westphalia funded by the German Research Foundation DFG from official archival sources (Amtsblätter der Regierungen Arnsberg, Münster und Minden).

[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.

Table 3: Descriptive statistics (cities)

City (I)	District (II)	Price Observations * (III)	Mean Rye Price (IV)	Mean Wheat Price (V)	First period with acc. to road network (VI)	First period with acc. to railway network (VII)	Access to waterways (VIII)	City Classification (IX)
Hamm	Arnsberg	120	598.13	816.94	1831-1843	1844-1855	Yes	Small town
Hattingen	Arnsberg	120	669.47	822.33	1844-1855	None	Yes	Small town
Herdecke	Arnsberg	120	657.72	899.80	1821-1830	1844-1855	Yes	Rural town
Langschede	Arnsberg	120	627.03	821.99	1831-1843	No	Yes	Rural town
Lippstadt	Arnsberg	120	570.43	830.69	1821-1830	1844-1855	Yes	Small town
Menden	Arnsberg	118	642.40	853.17	1821-1830	None	No	Rural town
Meschede	Arnsberg	40	504.10	900.57	1821-1830	None	No	Rural town
Schwerte	Arnsberg	120	644.95	848.49	1844-1855	1844-1855	Yes	Rural town
Siegen	Arnsberg	32	537.75	861.77	1821-1830	No	No	Rural town
Soest	Arnsberg	120	589.45	854.86	1831-1843	1844-1855	No	Small town
Witten	Arnsberg	110	643.00	869.59	1821-1830	1844-1855	Yes	Small town
Bielefeld	Minden	128	654.64	798.80	1821-1830	1844-1855	No	Medium-sized city
Büren	Minden	128	616.33	879.66	None	None	No	Rural town
Halle	Minden	128	647.59	856.74	1844-1855	None	No	Medium-sized city
Hannover*	Minden	140	602.64	835.13	1821-1830	1844-1855	No	Medium-sized city
Herford	Minden	128	625.94	858.19	1821-1830	1844-1855	No	Small town
Höxter	Minden	96	684.58	895.46	1831-1843	None	Yes	Small town
Lübbecke	Minden	96	646.35	826.92	1844-1855	None	No	Rural town
Minden	Minden	128	628.06	814.75	1821-1830	1844-1855	Yes	Small town
Paderborn	Minden	128	648.11	728.98	1821-1830	1844-1855	No	Small town
Warburg	Minden	128	560.05	760.57	1831-1843	1844-1855	No	Rural town
Ahaus	Münster	140	598.97	908.88	None	None	No	Rural town

Beckum	Münster	140	635.01	841.52	None	1844-1855	No	Rural town
Borken	Münster	140	625.99	838.07	1844-1855	None	No	Rural town
Coesfeld	Münster	140	605.39	759.38	1844-1855	None	No	Small town
Lüdinghausen	Münster	140	632.30	816.83	None	None	No	Rural town
Münster	Münster	140	643.34	680.95	1821-1830	1844-1855	Yes	Medium-sized city
Recklinghausen	Münster	140	633.73	849.70	1844-1855	None	No	Rural town
Steinfurt	Münster	140	609.97	628.38	1844-1855	None	No	Small town
Tecklenburg	Münster	140	604.30	758.10	1844-1855	None	No	Rural town
Warendorf	Münster	140	634.86	866.36	1831-1843	None	No	Small town

Note: * Prices in Silbergroschen per Prussian Scheffel. Hannover is treated as a city within the district of Minden. The price observations column refers to both rye and wheat prices. Columns IV and V present the average price of the whole sample period. Since the overall sample period is divided into 3 periods, columns VI and VII show in what period cities gained access to paved roads or to railway. The variable concerning navigable rivers and canals remains constant and shows if a city had access to waterways or not. The last column classifies cities according their size: Big city (more than 100,000 inhabitants), medium-sized city (20,000 to 100,000 inhabitants), small city (5,000 to 20,000 inhabitants) and rural town (0 to 5,000 inhabitants).

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 and Table 3). 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 2 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 206 kilometers (Hattingen and Hannover).

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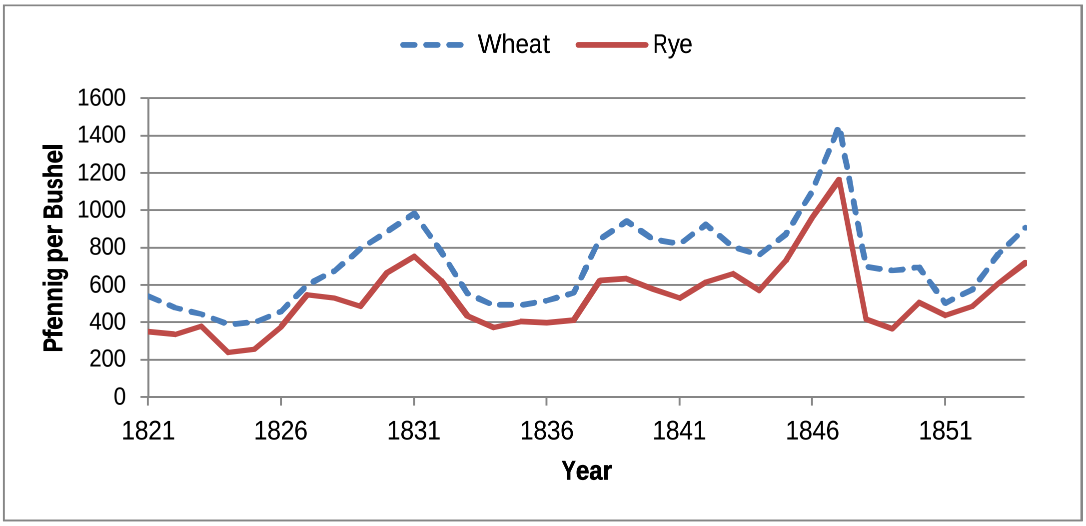
[33] Information about harvests and grain price formation for the period 1795-1846 in Germany is provided by Fremdling and Hohorst, 'Marktintegration' (1979).

[34] See Head, 'Gravity' (2003), 5.

Figure 2: Average annual price level of wheat and rye.



Note: Annual price averages for each city and year were computed for rye and wheat.

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 3 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 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

[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).

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 3 and Table 4 (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 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 4: 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
	1821-1830	1831-1843	1844-1855	1821-1830	1831-1843	1844-1855	
(I)	(II)	(III)	(IV)	(V)	(VI)	(VII)	(VIII)
Arnsberg	54	81	100	0	0	55	70
Minden	50	70	90	0	0	70	20
Münster	10	20	70	0	0	20	10

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

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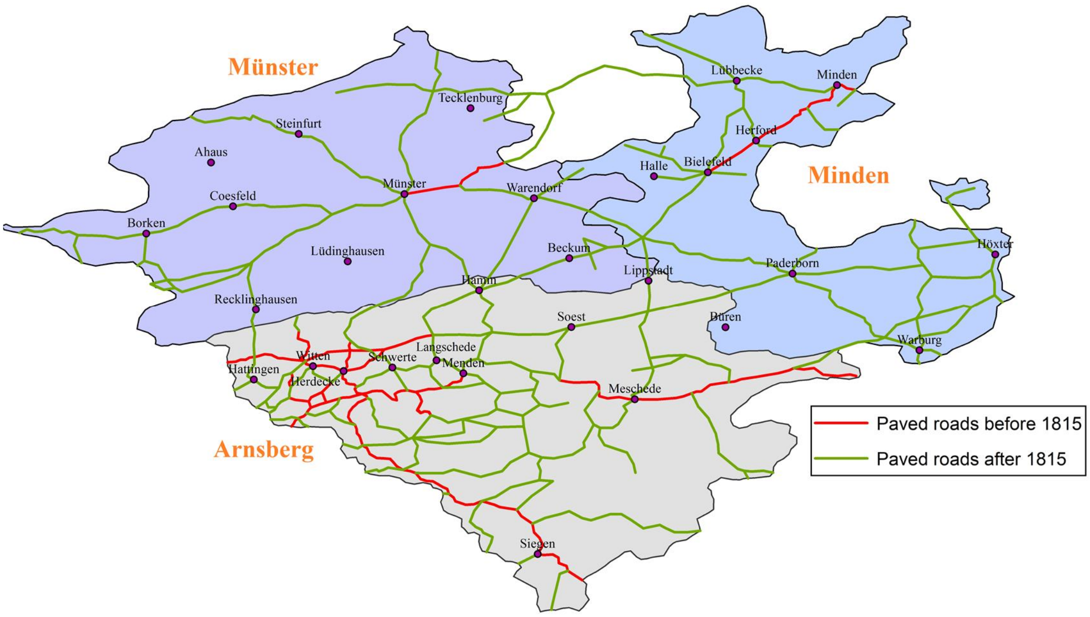
[36] Sälter, *Entwicklung* (1917); Gador, *Entwicklung des Straßenbaues* (1966).

Figure 3: Paved road network during the first half of the 19th century



Note: this digitalized map was made using the historical map by Sälter (1917) as background map.

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 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 4, column VIII).

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[37] Mühlen, *Wasserstraßen* (1980), 9.

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 4 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]

Results

Market integration during the period 1821-1855

Figure 4 shows the development of grain price spreads over the three subperiods. 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 takes shape and grain price dispersion becomes very low (especially in the 1850s), indicating a high degree of market integration.

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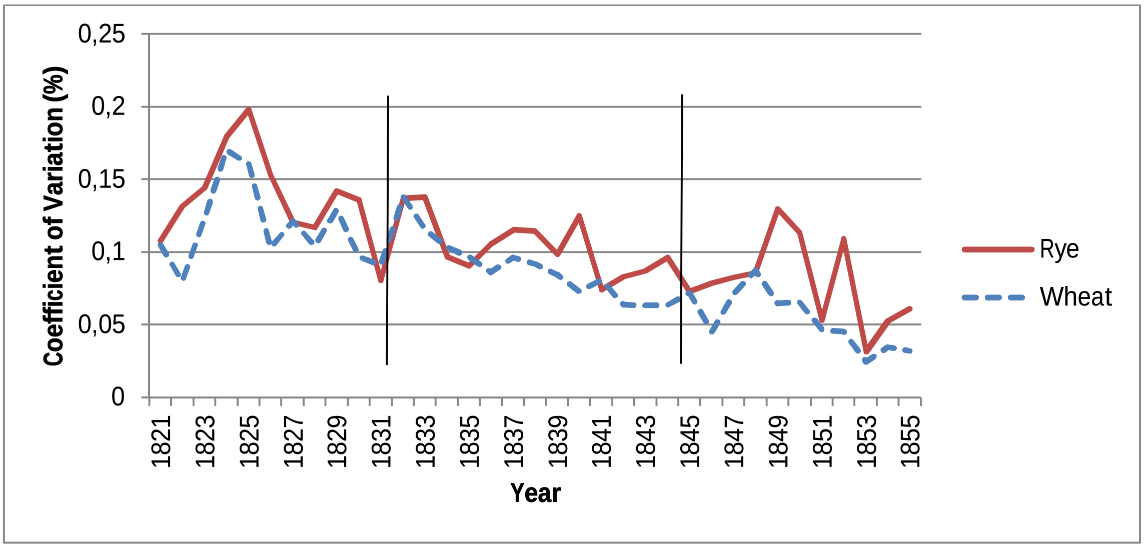
[38] Kaiserliches Statistisches Amt, 'Statistik des Deutschen Reiches' (1878). We are indebted to Richard Tilly who made us aware of this source.

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

Figure 4: Coefficient of variation of rye and wheat from 1818 to 1867.



Note: See Figure 2.

Table 5 presents the same information as Figure 4, but using price dispersion averages for each period instead. Columns I and II show that rye price dispersion is always higher on average than wheat dispersion. The overall price spread decrease for both grain types is very similar, although it is higher for wheat (55 per cent) than for rye (45 per cent). Moreover, it is worth noting that this process becomes particularly intense for wheat in the 1840s and 1850s with a 40 per cent decrease of price spread (see Table 4, columns III and IV).

Table 5: Coefficient of variations for rye and wheat.

Periods	Coefficient of Variation		Interperiod decline	
	Rye (I)	Wheat (II)	Rye (III)	Wheat (IV)
1821-30	14.3%	11.9%	-	-
1831-43	10.3%	8.9%	28%	25.3%
1844-55	7.9%	5.4%	23.1%	40%

Note: The averages above are equally weighted.

Table 6 offers a more detailed view of this process at a district level using bilateral percentage price differences. Two points are especially interesting: firstly, the low degree of grain market integration in the district of Minden during the first period, and its dramatic change in the second period. And secondly, the further wheat market integration increase in the last period (also shown in Table 5).

Table 6: Percentage bilateral price differences at district level.

District	Mean Rye Price			Mean Wheat Price		
	1821-1830	1831-1843	1844-1855	1821-1830	1831-1843	1844-1855
(I)	(II)	(III)	(IV)	(V)	(VI)	(VII)
Arnsberg	0.1402	0.0911	0.0767	0.1425	0.0906	0.0709
Minden	0.205	0.1181	0.0711	0.1825	0.1177	0.0512
Münster	0.1092	0.0684	0.0745	0.1095	0.0701	0.0528

Note: Each value represents the percentage average grain price difference with cities located within a certain district.

Figure 4, Table 5 and Table 6 show evidence of an increasing economic integration before the coming of the railway. This early process might have contributed to the emergence of market integration in the 1850s.

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

Analysis of the role of roads on market integration using the gravity model

Table 7 and Table 8 show the results of our gravity model for rye and wheat separately. In both cases, *Distance* is significant and has the expected sign. This means that the further two cities are from each other, the higher their price differences and the less integrated they are. Furthermore, the coefficients decrease over time, indicating that distance between markets became economically less important. This indicates a decline of transaction costs that in the case of wheat is considerably smaller than in the case of rye (between one third and one quarter). The lower effect of distance on wheat price differences is consistent with the picture given by Figure 4, 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. This should translate into negative coefficients for wheat at the *Border* variable. In comparison, if rye was traded rather within than between districts, opposite signs at *Border* can be expected.

Table 7: Gravity model results for rye.

Gravity Model Results

	1821-1830	1831-1843	1844-1855
Distance	0.0362***	0.0394***	0.0325***
	(0.00340)	(0.00184)	(0.00487)
Road_Conn_cities	-0.00996***	-0.0130***	-0.00782***
	(0.00219)	(0.000854)	(0.00180)
Border	0.0161***	0.00962***	0.00243
	(0.00402)	(0.00225)	(0.00502)
Rail_Conn_Cities			-0.00226
			(0.00252)
Observations	6791	10447	7584
R-squared	0.315	0.718	0.128
Adjusted R-squared	0.311	0.717	0.123

Standard errors in parentheses
* p<0.1, ** p<0.05, *** p<0.01

Note: The dependent variables are the absolute value of percentage bilateral price differences. All regressions include year and city fixed effects. For a detailed description of the independent variables, see Table 3.

Table 8: Gravity model results for wheat.

Gravity Model Results

	1821-1830	1831-1843	1844-1855
Distance	0.0343***	0.0301***	0.0231***
	(0.00339)	(0.00177)	(0.00141)
Road_Conn_cities	-0.00168	-0.00765***	-0.00554***
	(0.00163)	(0.000792)	(0.000749)
Border	-0.0145***	0.000906	-0.000677
	(0.00454)	(0.00210)	(0.00163)
Rail_Conn_Cities			-0.00239**
			(0.00100)
Observations	6609	10447	7584
R-squared	0.238	0.349	0.240
Adjusted R-squared	0.234	0.346	0.235

Standard errors in parentheses
* p<0.1, ** p<0.05, *** p<0.01

Note: See Table 6.

In the case of rye, *Border* coefficients are significant during the first two periods and have the expected positive sign (see Table 7, columns II and III). Its coefficients show a decreasing trend, which can be interpreted as an increasing inter-regional trade due to a reduction in transaction costs caused partly by transport infrastructures. On the other hand, the coefficients at the border-dummy for wheat are not significant during the last two periods and negative during the first period. This may indicate that wheat was traded more between districts than rye until the 1840s.

To test the relationship between paved roads and market integration, we study the variables *Road_Access* and *Road_Conn_Cities*. The first one carries no explanatory power and proves to be insufficient to capture the effects of the paved road network.[40] Especially in the third subperiod, this variable does not have enough explanatory power, since almost all cities were connected to the paved road network. On the other hand, *Road_Conn_Cities* overcomes the limits of the dummy approach and has significant and negative coefficients for rye during the whole sample period (see Table 7, columns II, III and IV). However, this result is robust only from 1830 onwards, while in the first period the sign of the coefficient oscillates depending on the particular model setup. For wheat, *Road_Conn_Cities* coefficients show a clearly negative relationship between paved roads and price differences during the last two periods (see Table 8, columns III and IV). Similar to rye, we do not find a robust correlation between paved roads and market integration for the 1820s. This is consistent with the hypothesis that in this period institutional changes (abolition of internal barriers and the creation of Westphalia

[40] For this reason, we did not include it in the results.

as a Prussian province) might have played a key role in 1820s Westphalian market integration.[41]

Paved roads were obviously economically relevant. The coefficients at *Road_Conn_Cities* are a quarter to a third of the average distance coefficient. This means that an additional connection to the paved road network reduced distance costs considerably.

The role of railways is less clear than that of paved roads. *Rail_Access* is not significant in both cases, and *Rail_Conn_Cities* is only significant for wheat, while its effect is only half that of paved roads. This finding supports the view that railways did not become economically relevant for the trade of staple goods before the 1860s.[42]

Finally, we cannot find a relationship between water transport and grain market integration. The dummy variable *Water_Access* carries no explanatory power for two reasons: first, waterway number and length remained constant during our sample period. Second, the water access dummy 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 4, column VII). The alternative variable *Water_Conn_Cities* is not able to capture network effects as no transport network existed, but only isolated waterways. For this reason, it assumes the shape of a dummy variable and correlates highly with *Water_Access*.

The 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

[41] Kopsidis, 'Creation of a Westphalian' (2002).

[42] Fremdling and Hohorst, 'Marktintegration' (1979),

integration shows that cities with more paved road connections were better integrated from 1830 onwards.

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.[43] 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 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 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 to create three cross-sections between 1821 and 1855. We confronted this development with rye and wheat prices for roughly three dozens

[43] Pfister and Fertig, 'Population History' (2012); Pfister et al., 'Real Wages' (2011); Uebele, 'National and international market integration' (2011).

Westphalian cities, and formulated a gravity model relating bilateral percentage price differences to distance and a newly developed indicator of the connectedness of transport infrastructures.

The results show very clearly that distance coefficients decreased between the 1820s and the 1840s by about 20-30 per cent, and that an additional connection to the paved road network reduced percentage price differences by about the same magnitude after 1833. Including train connections after 1844 had also a reducing effect in the case of wheat prices, but to a smaller extent confirming the claim that initially, trains moved mainly people, not 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 of 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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