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The Gains from Reshaping Infrastructure: Evidence from the division of Germany

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Abstract: This paper quantifies the gains from infrastructure investments and shows that reshaping the highway network after a large economic shock, the division of Germany, had positive welfare and income effects. To address the endogeneity between infrastructure and economic outcomes, I develop a multi-region quantitative trade model where infrastructure is chosen by the government to maximise welfare. I calibrate the model to the prewar German economy and estimate the key structural parameter of the model using the prewar Highway Plan. I exploit the division of Germany, a large-scale exogenous shock to economic fundamentals, to show that the model can predict changes in highway construction after the division. Using newly collected data, I document that half of the new highway investments deviated from the prewar Highway Plan. I find that the reallocation of these investments (one-third of the network) increased real income by 0.6% to 2% each year, compared to the construction of the original prewar Plan. Finally, I find a large cost of path-dependence: the ability to reshape the full network in anticipation of the division could have increased real income by an additional 1.5%.

Keywords: Transport Infrastructure, Economic geography, Economic history, Germany.

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Gains liés à la restructruration spatiale des infrastructures : les leçons de la division allemande

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Abstract : Ce travail quantifie les gains découlant des investissements dans les infrastructures et montre que la réorganisation des autoroutes après un choc économique important, la division de l'Allemagne, a eu des effets positifs sur le bien-être économique. Pour remédier au problème d'endogénéité entre l'infrastructure et les variables économiques, je développe un modèle de commerce quantitatif multirégional dans lequel l'infrastructure est choisie par le gouvernement pour maximiser le bien-être global. Je calibre le modèle à l'aide de données économiques allemandes et j'estime le paramètre structurel clé du modèle à l'aide du plan routier de l'avant-guerre. J'exploite la division de l'Allemagne, un choc exogène à grande échelle sur les fondamentaux de l'économie, pour montrer que le modèle peut prédire les changements dans la construction des autoroutes après la division. En m'appuyant sur des données originales plus récentes, je trouve que la moitié des nouvelles infrastructures autoroutières après la division s'éloignent du plan routier de l'avant-guerre. Je trouve que la réorganisation de ces investissements (un tiers du réseau de transport) a augmenté le revenu réel de 0,6% à 2% par an, par rapport à la construction du plan originel d'avant-guerre. Enfin, je trouve un coût important de la dépendance des investissements passés : la capacité de remodeler l'ensemble du réseau en prévision de la division aurait pu augmenter le revenu réel de 1.5% supplémentaire.

Mots-clefs : Infrastructure de transport, Géographie économique, Histoire économique, Allemagne.

1 Introduction

In 1939, a 500 kilometre-long highway connecting Cologne, in the west of Germany, with Berlin, in the east, was about to be completed. It was part of a highway plan designed by the Nazi Government to endow Germany with a modern highway network (Voigtländer and Voth, 2015).[1] No one at that time would have predicted that a border would divide West Germany from East Germany only ten years later. Figure 1 shows the outline of the 1934 highway plan (Panel A) and the layout of the highway network in 1974, decades later. Did the West German government reshape the highway network after the unexpected division of Germany? Did this reaction alter the gains from infrastructure investments in the following years?

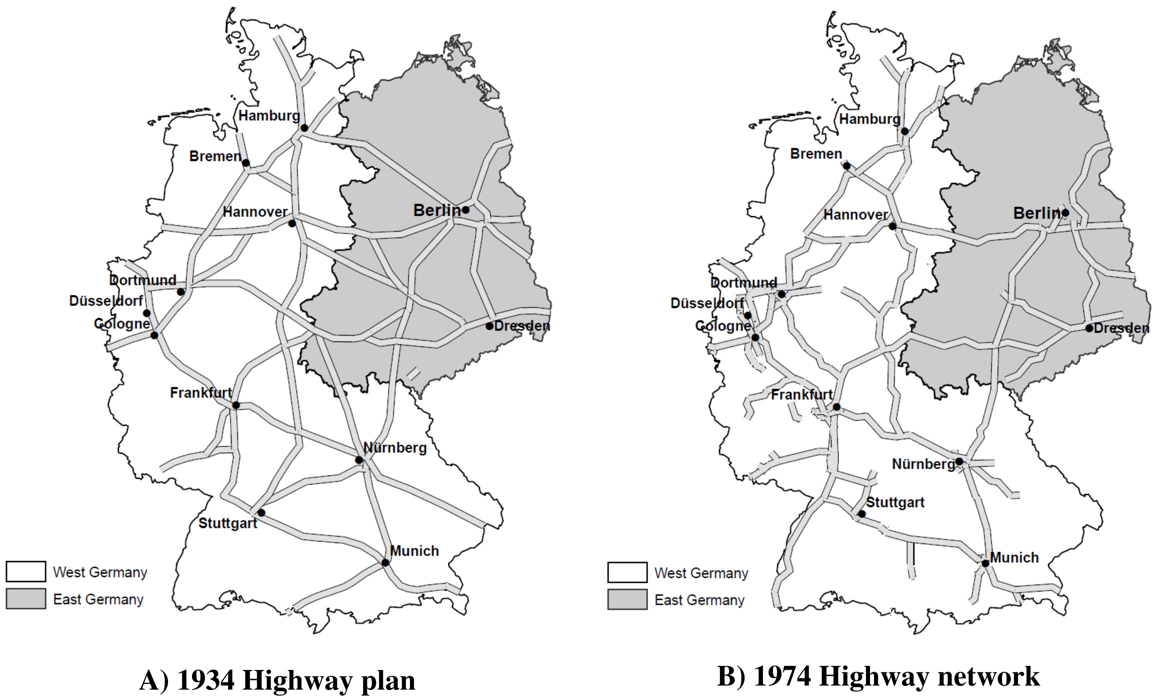
In this paper I study how the choice of infrastructure (by governments) affects economic gains, exploiting a large-scale exogenous shock to economic fundamentals: the division of Germany. Despite the importance of infrastructure for the movement of goods and people, quantifying the gains from these investments is challenging because infrastructure and economic outcomes affect one another (Redding and Turner, 2015). For example, a government may allocate infrastructure to already fast-growing regions, creating a positive relationship between infrastructure and economic outcomes.[2] In addition, infrastructure investments create large spillovers and may have relevant aggregate effects across many economic units. Thus, there is a tension between estimating the causal impact of infrastructure and capturing the general equilibrium effects of infrastructure investments.

To address the endogeneity between infrastructure and economic outcomes, I develop a quantitative spatial trade model with endogenous infrastructure investments. In the model, trade happens across many regions that are linked through the transport network. Each region has an exogenous productivity level and produces a set of tradable varieties as in Krugman (1980). Infrastructure improvements along a group of regions reduce the shipping costs between these regions, facilitating consumption of non-local varieties. Workers decide where to live and how much to consume to maximise their indirect utility, giving rise to a spatial equilibrium structure (Redding, 2016). This framework builds on the quantitative spatial models reviewed by Redding and Rossi-Hansberg (2017) but has the novelty of featuring a government that invests in infrastructure to maximise aggregate welfare.

[1] In The 1920s German politicians discussed the construction of a modern highway system. When Hitler appointed Fritz Todt to design the highway system, he traced a plan heavily inspired by the previous plans designed in the 1920s. (Zeller and Dunlap, 2010)

[2] Additional challenges, in addition to the endogeneity of infrastructure and economic outcomes, (Fogel, 1962) are the need for a general equilibrium set-up to account for spill-overs (Redding and Turner, 2015) or the complication of choosing an adequate counterfactual.

Figure 1: The division of Germany in 1949 and the Highway network



Notes: The figure displays the countries of West Germany (in white) and East Germany (in grey). Panel A shows the 1934 highway plan. Panel B shows the highways built by 1974. Source: Created by the author from newly digitised historical data.

The model nests a spatial equilibrium into the government's maximisation problem and can be solved backwards. First, given the initial transport network, the matrix of bilateral transport costs is determined by applying the least-cost path algorithm to all region-pairs. With the bilateral transport costs and the initial parameter values, the spatial equilibrium is given by the vector of wages, labour allocations, prices and rents for which the equilibrium conditions hold. The spatial equilibrium determines the expected utility of the economy that is used as a proxy for aggregate welfare (Redding and Rossi-Hansberg, 2017). Then, the government chooses the infrastructure investment allocation that maximises aggregate welfare, given the decentralised spatial equilibrium conditions.

In the solution of the model, optimal infrastructure in a region depends positively on two factors. First, how *large* is a region in terms of trade flows. Second, how *central* is a region in terms of trade transit.[3] The initial highway plan of 1934, in Panel A of Figure 1, can serve as an example. Cologne is a remote city, located at the edge of the German territory. However, it is included in the highway

[3]The key driver of these results is that the marginal benefit of investing in infrastructure is higher in large and central regions.

network because it is large, and thus, trades intensely with the rest of German districts. Contrary to Cologne, Nuremberg, in the south-east, is not a large city but it is central: it is located between Munich and Berlin. Because of its centrality, it is also included in the network. These predictions suggest that when the volume of trade or transit in a region changes permanently, as happened after the division of Germany, the government would like to reshape infrastructure investments.

I follow a two-step strategy to quantify the model. First, I calibrate the parameters relevant for the spatial equilibrium, keeping the infrastructure network fixed. Specifically, I take the model to data on Germany's population and road network in 1938, eleven years before the German division. I employ the 1938 population distribution to calibrate the district-specific productivity parameters and the road network to calculate the initial shipping costs. I then assess the fit of the model by comparing the model's trade predictions with domestic good shipments in 1938. Second, given the parameters calibrated in the first step, I estimate the key structural parameter of the model: the returns to highway investments. This parameter determines whether highway investments have decreasing returns and, therefore, shapes the concentration of highway investments in each district. Using the Simulated Method of Moments I estimate this parameter to minimise the difference in the concentration of highway investments between the model with endogenous infrastructure and the 1934 Highway Plan.

Given the quantification of the model I assess its ability to predict infrastructure investments. First, I test the fit of the model with the cross-section of highway investments allocated in the 1934 prewar Plan. To do so, I solve for the *optimal infrastructure* network for Germany before the division. Comparing the optimal infrastructure allocation with the 1934 Highway Plan, I find that the model explains the main patterns of investment in the prewar plan, as well as the timing of construction before division.

Second, I exploit the division of Germany to test the ability of the model to predict new highway investments. The division of Germany was a large-scale unexpected shock to economic fundamentals: the new border re-defined the country's boundaries and stopped all trade and worker flows between East Germany and West Germany (Redding and Sturm, 2008). To predict the endogenous response of infrastructure to the division shock, I assume that trade costs between East Germany and West Germany become prohibitive and re-compute the optimal infrastructure allocation for West Germany. This solution takes as fixed the investments made until 1950.

Using data on the construction of highways between 1950 and 1974, I test whether the model can predict new highway investments.[4] I focus on the additional highway construction between

[4] I use investments until 1974 because by then the network was as large as the prewar Highway Plan. In 1974, 5000

1950 and 1974 allows me to control for time-invariant specific characteristics that affect both the prewar fundamentals used in the calibration and the amount of infrastructure investments. Examples of such factors are geographical advantages such as being a port city. My estimation shows that the model has good predictive power for thel increase in highway construction by district between 1974 and 1950: the predicted changes account for 19% of the variation in new highway construction. My estimates suggest that a predicted increase of one kilometre in the model explains an increase of 0.32 kilometres in the data (statistically significant at 1 % confidence level). This test shows how a quantitative model with endogenous infrastructure can explain, to a large extent, the reshaping of highways by the West German government.

The main threat to these estimates would be the existence of changing factors, in addition to geography, happening after the division of Germany and affecting the returns to highway construction unevenly across the West German geography. One of such factors is the process of European integration during which tariffs to international trade were eliminated between Belgium, Italy, Luxembourg, Netherlands and West Germany.[5] To account for this, I extend the model to allow for international trade with other West European countries and solve for the optimal highway construction with both domestic and international trade. The extended model still has good predictive but actually predicts a smaller share of the variation in the data showing that the results are not driven by the European integration process. [6]

Finally, I document to what extent the additional three thousand kilometres built between 1950 and 1974 deviated from the prewar Highway Plan. I find that half of the new highways deviated from the prewar Highway Plan. This considerable reshaping of the highway network suggests that the Government reacted to the change in geography caused by the division.

Next, I use the model to quantify how the choice of highways affected the economic gains from infrastructure investments. First, I find that the reshaping of one third of the network by the government increased real income by 0.64% (relative to the prewar Highway Plan) in the model with domestic trade and by 2% in the model with international trade. These gains, that increased the level of real income permanently, are obtained only from reshaping the infrastructure, keeping the budget fixed. My results indicate that upgrading infrastructure following the new economic

kilometres had been built while the Plan had a length of 4300 kilometres. Due to limitations in the availability of historical highway maps I use 1974 as the best possible approximation to the length of the Plan.

[5]This process started with creation of the European Economic Community in 1957 with the Treaty of Rome.

[6]One explanation for why the model with international trade seems to be further away from the data could be that in the first years of the european integration process international trade was not so large in magnitude. For example, in 1982, around 85% of all tonnes-kilometres shipped in West Germany by road were domestic shipments while only 15% were cross-border (international) shipments.

fundamentals, rather than the prewar fundamentals, had very large income effects. Finally, this set-up allows me to quantify the aggregate cost of path-dependence. Since highway construction started in the 1930s, these initial investments did not anticipate the division shock. I find that the ability to reshape the initial highway investments would have increased real income by 1.5% compared to the optimal network constrained by the prewar highway construction.

Relation with the Literature Transport infrastructure projects represent a substantial fraction in the budget of governments and international institutions.[7] The increasing availability of spatially disaggregated data has rekindled the interest of policy-makers and academics on how to better allocate resources to infrastructure upgrading. It is not surprising that a very recent strand of the literature has focused on studying the endogenous choice of transport infrastructure. There have been two approaches so far: (1) to model endogenous infrastructure arising from decentralised decisions like Allen and Arkolakis (2017) and (2) to model endogenous infrastructure as arising from the decision of a government or planner such as Felbermayr and Tarasov (2015), Fajgelbaum and Schaal (2017) and Gallen and Winston (2018).[8] While Gallen and Winston (2018) investigate the choice of infrastructure in a general equilibrium model where infrastructure is a capital investment good that benefits all firms, in my framework the government chooses infrastructure investments in a spatial set-up and is, therefore, closest to Felbermayr and Tarasov (2015) and Fajgelbaum and Schaal (2017).

Felbermayr and Tarasov (2015) endogenise the investment decision in a stylised framework that features two countries located along a line. My model, on the contrary, embeds the government decision in a many-region spatial framework amenable to quantitative exercises, like Fajgelbaum and Schaal (2017). There are two main differences between the framework developed by Fajgelbaum and Schaal (2017) and mine. First, I model a government that chooses how to invest in infrastructure subject to the decentralised decisions of workers and firms while Fajgelbaum and Schaal (2017) model a social planner that solves for the allocation of consumption and production together with the optimal infrastructure investment. The structure of my framework, that nests a state-of-the-art spatial model in the goverment's maximisation problem, allows me to use the standard solution and calibration techniques in the trade and urban economics literature. In addition, the spatial equilibrium part of my model can be easily adapted to feature Ricardian trade as in Eaton and

[7]Between 1995 and 2005, upgrades to the transportation network constituted around 12% of total World Bank lending (Asturias et al., 2014)

[8]Allen and Arkolakis (2017) allow for the emergence of endogenous trade costs due to decentralised shipping choices of traders along the network

Kortum (2002) or to include commuting flows as in Ahlfeldt et al. (2018).[9] On the contrary, Fajgelbaum and Schaal (2017) use a general neoclassical economy model that can accommodate the Armington, Ricardian and factor-proportions models but with a discrete number of goods/sectors and exploit solution techniques developed in the transport literature to solve the optimal infrastructure problem.[10] Second, Fajgelbaum and Schaal (2017) solve for infrastructure investments and trade flows at the link level, leaving the origin and destination of good flows undetermined, while I solve for infrastructure investments at the regional level and I can track both trade flows across the network and the origin and destination of the flows. My paper contributes to this literature in two ways. First, with a new quantitative model that extends the state-of-the-art spatial framework (for example Redding (2016)) by explicitly modelling infrastructure choice. Second, this is the first paper to test the ability of a quantitative spatial model to explain changes in the infrastructure network exploiting an exogenous shock to economic fundamentals. The use of a shock such as the division of Germany allows me to test the model's predictions exploiting time-variation and, thus, controlling for time-invariant location-specific factors while the previous models in the literature have been tested using cross-sectional data.

The results of this paper contribute to the extensive literature about the economic effects of infrastructure investments. This literature can broadly be divided in two categories: First, papers studying the effect of infrastructure access on local outcomes (for example Donaldson (2018) on prices, Michaels (2008) and Duranton et al. (2014) on specialisation, Banerjee et al. (2012) and Faber (2014) on output).[11] These papers rely on exogenous variation in the construction of infrastructure for identification of local effects. Second, papers studying the aggregate effects of infrastructure investments (for example Donaldson and Hornbeck (2016), Allen and Arkolakis (2017) and Nagy (2016) for the US, Alder and Kondo (2018) for China, Asturias et al. (2014), Donaldson (2018) and Alder (2014) for India, Tsivanidis (2018) for Colombia and Morten and Oliveira (2018) for Brazil).[12] These studies develop rich general equilibrium models to quantify the aggregate effects of transport infrastructure projects. This paper belongs to this second category and is the first paper to quantify the gains from reshaping a fraction of the infrastructure network

[9] Allen et al. (2014) show the close relation between the structural parameters in many trade and economic geography models that feature a gravity structure.

[10] Specifically, Fajgelbaum and Schaal (2017) re-write the problem as an optimal flow problem in the transport literature, where infrastructure can be solved for to reduce the price differentials across regions.

[11] Other examples are Baum-Snow et al. (2015) on output, Ghani et al. (2016) and Atack et al. (2008) on firm size, Möller and Zierer (2018) on employment, Duranton and Turner (2012), Baum-Snow (2007), Garcia-Lopez et al. (2015), Baum-Snow et al. (2017) on population growth.

[12] Other relevant studies are Balboni (2017) on the interaction between climate change and infrastructure for Vietnam, Fretz et al. (2017) on the effects of highway on spatial sorting for Switzerland and Heblich et al. (2018) on the impact of the railway system for commuting patterns and urbanisation in London.

after a large shock. In addition, my calibration takes into account the endogeneity of infrastructure investments while all the previous work measures economic gains from infrastructure by taking infrastructure as given or exogenous.

Finally, this paper contributes to the literature on the role of geography and history in shaping economic activity, for example Davis and Weinstein (2002) on the effects of the Second World War bombings in Japan for city size, Redding and Sturm (2008) on the effects of the division of Germany for city growth and, most recently, Ahlfeldt et al. (2018) on the effects of the division of Berlin for agglomeration externalities.[13] By estimating the endogenous response of the infrastructure network to the division of Germany, I show that infrastructure reshaping is an important mechanism that can exacerbate or atenuate the effects of shocks into the future. Finally, I provide the first estimate of the aggregate cost of path-dependence from past highway investments, exploiting the unexpected division of Germany.

This paper is organised as follows: Section 2 describes the historical background that serves as a set-up to the paper and the historical data sources. Section 3 develops a new theoretical framework with endogenous infrastructure choice and section 4 explains the calibration of the model to the Pre-division economy. Section 5 tests the ability of the model to explain the 1934 highway Plan and the new highway construction after the division shock. Finally, section 6 reports the quantification of the economic effects of infrastructure and section 7 concludes.

2 Historical Background

2.1 The division of Germany in 1949

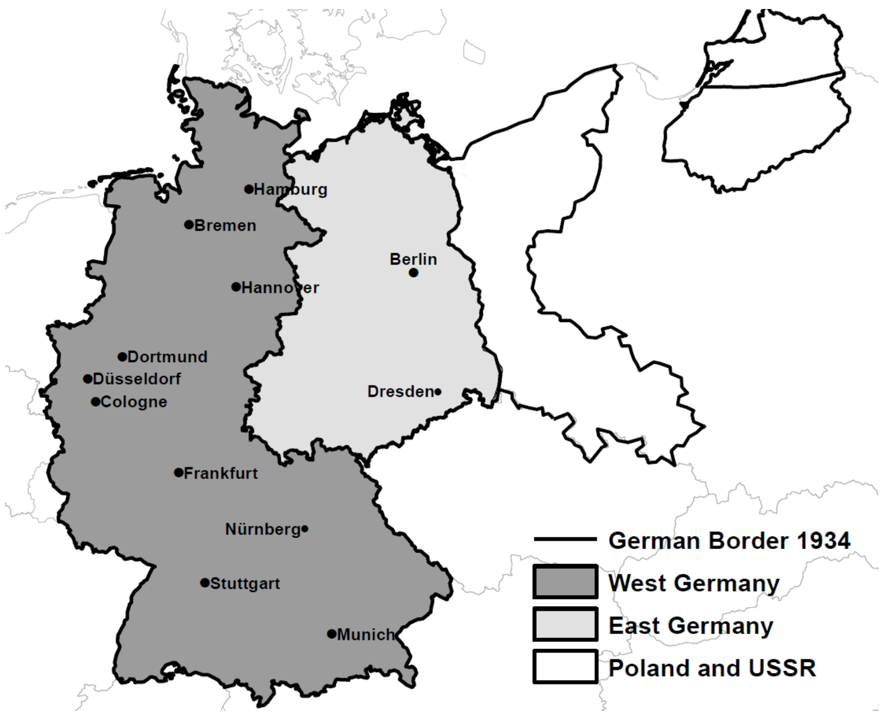
In the aftermath of the Second World War the territory of Germany became divided into four parts: two central ones (enclosing nowadays Germany) would be occupied by foreign powers and the other two, the most eastern territories, were annexed to Poland and Soviet Union. Figure 2 shows the territory that constituted the new German state under the occupation of the United States, Great Britain, France and Soviet Union, with the most significant cities at the time.

Four zones of occupation were agreed upon by 1945, with each zone under the control of one foreign power to supervise the German de-militarisation. The eastern part remained under Soviet Unionn control while the western part remained under the control of the Western allies. The

[13] Other related studies include Brulhart et al. (2012) on the effects of the Fall of the Iron Curtain for the adjustment of wages and employment in Austria and Redding and Sturm (2016) on the effects of the London Blitz for local economic outcomes at the neighbourhood level.

delimitation of the East and Western zones followed some pre-existing pattern mostly characterised by features of natural geography (Wolf, 2009). Following the deterioration of the political relations between the Western allies and Soviet Union, with the onset of the Cold War, the two zones of occupation crystallised into two independent countries, West Germany and East Germany, in 1949. Figure 2 plots the different territories that were constituted after the Second World War: West Germany, East Germany and two east*-most territories that were integrated into Poland and the Soviet Union.

Figure 2: Germany before and after World War II



West Germany was the largest territory with 53% of the former German territory and 58% of the population (40 million in 1939).[14] East Germany contained around 23% of the area and 22 % of the population. The former German capital, Berlin, was located within East Germany and was also divided into West and East Berlin. It was the largest city in Germany, with 4 million inhabitants in 1939.

In the initial years after the division, in 1949, there were some economic and political ties between the two states. Yet, the border became sealed from the Eastern side in 1952 to prevent migrations to West Germany and all trade relations halted soon after. With the construction of the

[14] All numerical figures in this section are taken from Redding and Sturm (2008), and come from the 1952 edition of the Bundesrepublik statistical yearbook.

Berlin Wall in 1961, all population mobility between East and West Germany stopped as well. The division of Germany was recognised by the international community and was generally believed to be permanent.[15]

The division of Germany separated territories integrated for centuries, with origins in the Kingdom of Germany around the year 1000. The foundation of the German Empire in 1871 was the culmination of decades of different levels of economic and political integration. Internal integration of Germany improved substantially after World War I and the German territories were an economically well-integrated area by 1933 (Wolf, 2009). The division, therefore, constituted an important shock that stopped all movement of people and goods between the two states and changed the geographic configuration of West Germany.

Regarding the transportation network, the former German Empire was well connected by a railway system completed in the 1910s. This was the main mode of transportation in the XIXth century. After World War I the construction of a highway network was discussed but finally rejected by the German parliament.[16] The ascent to power of Hitler marked the beginning of the construction of a German-wide highway network that became one of the star policies of the Nazi party. This massive infrastructure project was intended as a way to decrease unemployment and to gain attention from the International press. Fritz Todt, appointed by Hitler as the Inspector General of German Road Construction, traced a plan for the Highway network in 1934 heavily inspired by the previous plans designed in the 1920s.[17]

Transit grew fast along the new highways.As we can see in Figure A.1, in 1955 short-distance shipments by truck were already three times larger than shipments by railway while long-distance truck shipments were still one-third of railway shipments.[18] By 1970, highways were already very popular, with short-distance shipments by truck being five times larger than long-distance shipments by rail and long-distance truck shipments in tons larger than railway shipments by 1985.

[15]The two German states became UN members in 1972, the perceptions of the West German population was that reunification was very unlikely even in 1980 (Gerhard Herdegen, 1992)

[16]In the 1920s German politicians discussed the construction of a modern highway system. They formed the HAFRABA association that lobbied for the construction of a restricted access motorway connecting Hamburg-Frankfurt-Basel and other connections between major cities (Zeller and Dunlap, 2010).

[17]Zeller and Dunlap (2010)

[18]The data source is the Statistical Yearbook of the Bundesrepublik, multiple years. Figure A.1 in the Appendix shows goods traffic in tons by mode of transport.

2.2 Historical data sources

In order to analyse how the division of Germany affected infrastructure investments I need three different sets of data. First, information related to the evolution of the highway network including the outline of the 1934 Highway Plan. Second, information about economic outcomes that will serve to calibrate the model and test its predictions. Finally, additional data to use as controls in the empirical application related to the geography of Germany. The unit of observation through out the analysis will be the district (*Kreise*).[19] This subsection provides an overall description of the data sources employed, further details can be found in section E of the Appendix.

The first contribution of this paper will be to document the evolution of the West German highway network and the deviations of this network from the 1934 Highway plan. To do this, I collect and geo-reference data about the 1934 Plan and the Highway network. I digitise and geo-reference the outline of the 1934 Highway Plan using historical maps and compute highway kilometres planned by district. In addition, I collect and geo-reference highway construction data for East Germany and West Germany for the years 1938, 1950, 1965, 1974, 1980 and 1989 from historical maps and road atlases; and from 1950 and 1965 for federal roads. This allows me to document the length and pattern of the network by decade and by district. Figure A.2 shows the evolution of the network between these years. Figure A.3 in the Appendix displays the pace of construction of the highway network by decade, in kilometres. Finally, I use the EuroGlobal maps dataset, available online, as a source for geo-referenced data of local roads in order to complete the German road network.

To calibrate the theoretical model and test its validity I also require information on historical economic outcomes. I use population data available by decade since 1938 at the district level (*Kreise*) from the historical census. In addition to population data, I collect and digitise data of traffic of goods by road for 18 aggregated traffic districts in Germany, for the year 1939. The traffic data is collected in tons and reported in an aggregated way, as total shipments and total reception by traffic district from the "Statistisches Jahrbuch fur die Deutsches Reich".

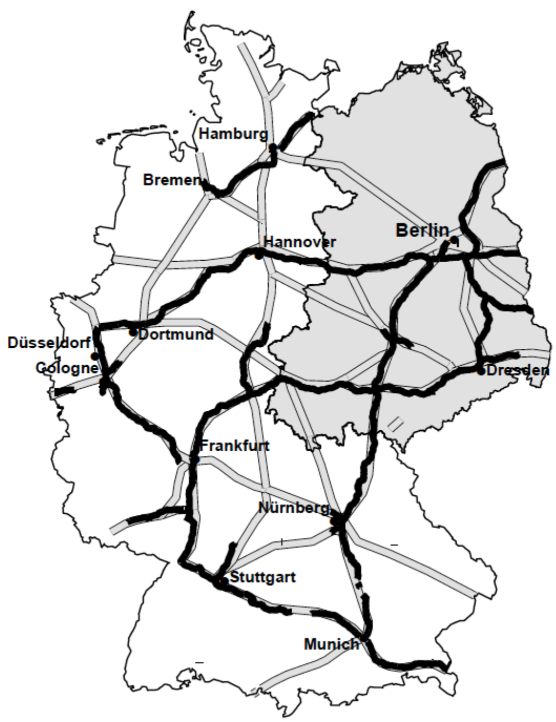
Finally, I collect supplementary geographical data such as area in squared kilometres by district and distance to different geographical boundaries such as the East German border and the border with Western Europe.

[19] There are 412 districts between East Germany and West Germany of which 313 districts are in West Germany. For the empirical results the 313 districts are merged according to Mikrocensus regions to account for metropolitan areas.

2.3 Reshaping of the Highway Network after division

In the remaining of this section I will document the construction of the German network of highways up until the division and the completion of the network in West Germany over the following decades. Figure 3 shows the 1934 Highway plan over the territories of West Germany and East Germany. As we can see, many of the planned highways were cut by the new border or passed very close to it. The existence of this Pre-division plan represents the initial design of the German government to connect the German territory before the division. This prewar Plan will be useful as a counterfactual for the network that would have been built given the economic fundamentals of 1934.

Figure 3: Highway plan of 1934 and Highway construction before division



Notes: The figure plots the territories of West Germany and East Germany, delineated in black. The outline of the 1934 Highway plan is plotted in light grey. The highway links that had been built by the year 1946 are plotted in black.

Construction was fast: half of the 6000 kilometres planned were built between 1934 and the beginning of World War II. Figure 3 depicts in dark grey the highways that had been built by the year 1946 over the outline of the prewar Highway Plan. As it is clear in the figure, the construction of highways up until the division followed the pattern of the Plan with almost no deviation. Construction resumed after World War II and by 1974 5000 kilometres had been completed. To document whether this additional 3000 kilometres were built following the 1934

Highway outline I classify the old and newly constructed highways, into investments that were planned and investments that were reshaped (allocated to a different district). Until 1950, highway construction followed the prewar Plan (95% of kilometres were planned) while I find considerable reshaping after the division. Only 47.2% of the kilometres built between 1950 and 1970 followed the 1934 Highway Plan while 52.8 % of the kilometres deviate from the 1934 planned allocation.

Table 1: Highway investment allocation (in %)

	Included in the 1934 Highway Plan		
Network	Yes	No	Total
Highway km 1950 (2128 km)	95	5	100
Highway km 1950 to 1974 (3015 km)	47.2	52.8	100

Notes: Share of highway investments (in kilometres) allocated according to the 1934 Highway Plan. Column 1 represents the share of kilometres that were included in the 1934 Highway plan while column 2 represents the share of kilometres that were not included in the 1934 Plan, and were reshaped. The first row refers to the share of kilometres built until 1950 while the second row refers to the new kilometres added between 1950 and 1970.

This decomposition shows that the highway network in 1974 was deeply reshaped compared to the original prewar highway Plan.

In the next section I build a multi-region spatial trade model with endogenous infrastructure investments to analyse the sources of these deviations, and to quantify to what extent they can be explained by the change in economic fundamentals that followed the division of Germany.

3 A theoretical model of endogenous infrastructure choice

In this section, I outline a spatial trade model with endogenous transport infrastructure.[20] I first characterise the spatial equilibrium of the model given an initial infrastructure network. Next, I introduce a government that chooses how to invest in the infrastructure network to maximize aggregate welfare. The solution of the model characterises the optimal infrastructure investment, defined as the upgrade in the infrastructure network that maximises welfare. Finally, I use the model to derive qualitative predictions about the response of infrastructure to a shock such as the division of Germany in 1949. The framework features many locations that produce an endogenous measure of differentiated varieties like in Krugman (1980). These varieties can be traded across space subject to transport costs. Workers move across locations to maximize their expected utility that depends on real income and heterogeneous preferences for locations. The model builds on the family of quantitative spatial models reviewed by Redding and Rossi-Hansberg (2017) and is specially close

[20] A detailed exposition of the theoretical framework is contained in section C of the Appendix.

to Redding (2016). I make two contributions with respect to this framework. First, I introduce a new transport cost function that includes infrastructure quality. Second, infrastructure quality is chosen by the government to maximise aggregate welfare.

3.1 Model Set-up

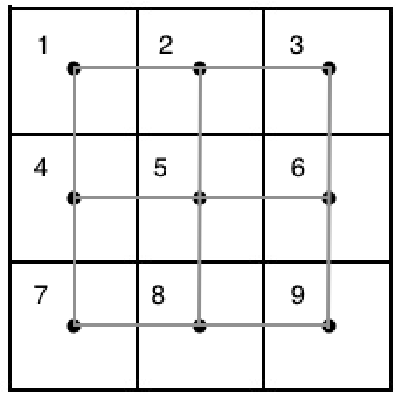
Workers The model features costly trade across many districts, $i = 1...N$, endowed with exogenous labour productivity, A_i. There is a measure L of workers in the economy. Workers derive utility from the consumption of differentiated varieties of the tradable good, from the consumption of housing and from the district they choose to live in. Workers spend a fraction α of their income on the available differentiated varieties and have CES preferences across varieties, with elasticity of substitution $\sigma > 1$. The remaining income share (1-α) is spent on housing. Finally, workers have heterogenous preferences across different districts. These preferences are modelled as an idiosyncratic taste component b_i. Worker ω draws a vector of N realisations $\{b(\omega)_i\}_{i=1...N}$ from a Fréchet distribution with shape parameter ϵ, that governs the dispersion of preferences across workers for different districts.[21]

Firms Production of the differentiated varieties takes place under monopolistic competition, following Krugman (1980). Firms pay a fixed cost of production as well as variable costs in terms of labour, so each firm produces a single differentiated variety in equilibrium. Firms maximise profits by charging a constant mark-up over the marginal cost of production equal to $\frac{1}{\sigma-1}$. Production uses labour as the only input and labour productivity is determined by the district-specific productivity level A_i. The free entry condition drives profits down to zero and pins down the scale of production of each firm. The labour market clearing condition can be solved for the total number of varieties produced in a district and will be a function of the size of the district in terms of population.

Housing Residential land is assumed to be in fixed supply, as a function of land endowments. I denote the endowment of residential land in district i by H_i, that can be used for housing. Each agent spends $(1 - \alpha)$ share of her income on renting residential land. Expenditure on land in each location is redistributed lump-sum to the workers residing in that location as in Redding (2016). This implies that total income in district i, denoted by $v_i L_i$, will equal total labour income plus

[21] The parameter ϵ governs the dispersion of heterogenous preferences across workers. A large ϵ implies a low dispersion of the distribution (low standard deviation). Thus, the idiosyncratic preferences are more similar across districts for all workers. Workers have resembling tastes so they react more strongly to changes in real incomes. On the contrary, when ϵ is small the dispersion in preferences is large, and workers are very heterogenous in their taste.

Figure 4: Example of simple geography



Notes: Geography with 9 regions; dots are the population centres. In grey the initial transport network, with the same initial quality.

expenditure on residential land: $v_i L_i = w_i L_i + (1 - \alpha) v_i L_i = w_i L_i / \alpha$. This assumption minimises the effects of introducing a housing market in the model while still allowing for a dispersion force that motivates workers to spread across locations because they "dislike" paying high rents.[22] The land market clearing condition will pin down the equilibrium land rent, r_i, in each location.

Geography The geography of the framework is as follows. Districts have some geographic surface of similar size. Workers are concentrated in the centre of the district where consumption and production happen. The set of districts, $i = 1...N$, are located on a finite plane of generic shape. Each district is connected to the adjacent locations by the infrastructure network.[23] These network links can be transited freely by workers but moving goods is costly. The cost of transit depends on the distance that has to be covered and the quality of the infrastructure along that geographic distance. Figure 4 provides an illustrative example. This geography can be represented by a graph of edges (infrastructure links) and vertices (population settlements). The set of settlements in this network is fixed, so there is no city creation or destruction. The set of links is also taken as given.[24] The quality of the links, on the contrary, can be improved by investing in infrastructure.

[22] The real income in location i will be $w/(P^{\alpha} r^{1-\alpha})$

[23] In the calibration of the model the connexion to adjacent districts will be given by the assumed underlying network that is constructed from the existing local roads and federal roads (Bundesstrasse)

[24] The assumption of a fixed network of links that can be upgraded in terms of quality is also present in related papers in the literature. This constitutes an important difference with the literature about banking, social and business networks where the links are endogenous. Allen and Arkolakis (2014), on the contrary, consider the continuum of space as the domain for the transport cost function that is defined at every point of the plane (instantaneous trade costs). The existence of transport network changes the cost of transit over specific points of the plane.

3.2 Transport Costs

Consuming non-locally produced varieties is costly because of the dispersion of production and population across the grid of districts.[25] The price of variety i consumed in district n is given by the production price, p_i, and the transport cost of shipping between district i and district n:[26]

$$p_{i,n} = p_i T_{i,n}. \tag{1}$$

I will now define how the matrix of transport costs $\{\mathrm{T}_{i,n}\}_{i,n=1\ldots N}$ is determined.

Cost of transit The cost of shipping a good along district i will depend on geography, D, which determines the distance that has to be covered across the district, and the quality of infrastructure, Φ, that will determine how costly (slowly) can this distance be transited. The ad-valorem cost of shipping across district k is defined as the cost of transit:

$$\text{Cost of transit}_k = \frac{D_k}{\phi_k^\gamma}. \tag{2}$$

where I use ϕ_k to denote the district-level infrastructure in k and Φ to denote the vector of infrastructure allocations. I assume that the quality of infrastructure is homogeneous within a district.[27] This specification of transit costs means that D_k/ϕ_k^γ units of the good shipped will be paid for shipping 1 unit of any good across district k. As we can see, a higher infrastructure investment will reduce the ad-valorem cost of transiting a district. In the quantitative exercise ϕ_k will be the quality of the road and its empirical counterpart will be highway construction.

I assume that $\phi_k \geq 1$, so that the transport cost will always be bounded by the physical geography, meaning that the ad-valorem transport cost cannot be smaller than 1. Parameter γ is the returns to infrastructure investments. It measures the elasticity of the ad-valorem transit cost to infrastructure investments. I assume it to be positive, so that the cost of transit is decreasing on infrastructure investments. It determines whether infrastructure has increasing returns (γ>1) or decreasing returns (γ<1).

[25] I assume a domestic closed economy. Thus, there are no tariffs or other trade costs in addition to transport costs.

[26] Without loss of generality, I denote the origin of a trade flow with subscript i and the destination of a trade flow with subscript n.

[27] In the real world a district may have one very high-quality highway and one very low-quality road. Therefore, we may think of ϕ_i as the average quality of the infrastructure stock in district i.

Least-cost path problem Given the cost of transit along all districts, what is the cost of shipping a good from district i to district n? In this network economy there will be many alternative paths to ship a good between districts i and n. I assume goods are shipped following the least-cost path. Thus, the transport cost matrix will be the collection of bilateral transport costs along the least-cost path between each district pair.[28] To represent the cost-minimising combination of N-by-N paths that connect all districts I define a least-cost path matrix for each district. Each of these matrices is N-by-N and indicates whether a district k is included in the path that links any other district-pair along the cost-minimising route. It is related to the *transition matrix* in the network literature as it indicates how to transition from one node of the network to any other. For district k, the element $\mathbb{I}^k_{i,n} \in \mathbb{I}^k$ indicates whether district k will be on the path when shipping goods from district i to district n and is defined as:

$$\mathbb{I}^k_{i,n} = \begin{cases} 1, & \text{if } k \text{ is a transit district in } \textit{the path between i and n} \\ 0, & \text{if } k \text{ is not a transit district in } \textit{the path between i and n}. \end{cases} \tag{3}$$

We can now define the transport cost between any two districts i and n, $T_{i,n}$, as

$$T_{i,n} = \left[\sum_k \mathbb{I}^k_{i,n} \frac{D_k}{\phi_k^\gamma} \right], \tag{4}$$

where ϕ_k is the infrastructure level in district k, D_k is the length of district k and $\mathbb{I}^k_{i,n}$ is the (i, n) element of the least-cost path matrix of district k. The transport cost between i and n is simply the sum of the geographical distance between them scaled by the infrastructure quality of all the districts that are transited along the least-cost path.[29]

Figure 5 illustrates the transport cost function with a simple example. Consider the three German districts in the figure (A, B and C) located sequentially. The transport cost between A and B will be $T_{A,B} = \frac{D_A}{\phi_A^\gamma} + \frac{D_B}{\phi_B^\gamma}$ because these two regions are contiguous. Yet, the transport cost between A and C will be $T_{A,C} = \frac{D_A}{\phi_A^\gamma} + \frac{D_B}{\phi_B^\gamma} + \frac{D_C}{\phi_C^\gamma}$. The distance and infrastructure level in district B will affect the transport cost between A and C. In standard trade models, this middle term will always be zero because direct shipping is assumed. This assumption implies that the cost of shipping between any origin and any destination only depends on origin and destination-specific parameters. However, to

[28]This is similar to modelling a shadow transport sector that operates under perfect competition, and therefore, ships goods at the minimum costs.

[29]Given that we have defined $\{\mathbb{I}^k_{i,n}\}$ as the least-cost path matrix this implies that we can also express the transport friction between n and i as $T_{i,n} = min_m(T(p^m_{i,n}))$ where $T(p^k_{i,n})$ is the transport cost of shipping a good from i to n along path m and M would be the set of possible paths.

study road transportation we need a more general specification of the transport cost function that takes into account the spatial nature of transport costs.

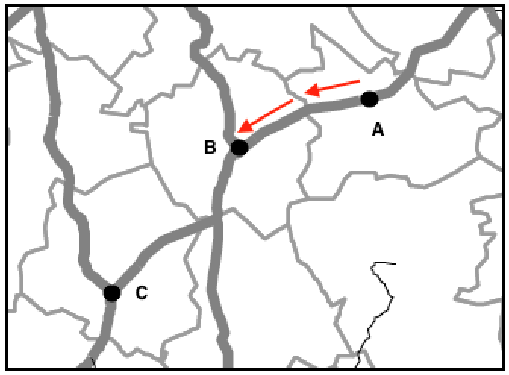


Figure 5: Transport costs: Illustration

Notice that the least-cost path indicator $\{\mathbb{I}^k_{i,n}\}$ will always be one when $k = i$ and $k = n$. But when $k \neq \{i, n\}$ there will be differences in the value of this indicator for different districts. Districts located in the centre of the geography will be along the path of most trade flows. Districts located in the margins of the geography will almost never be transited by trade flows between other districts.

Finally, I adopt a normalisation common to all trade models by assuming $T_{i,i} = 1$, equivalent to assuming free intra-district trade and normalising the cost of trading out of the district by the internal shipping cost.

3.3 Location choice and Spatial equilibrium

Worker location choice and Welfare Workers choose where to live by maximising indirect utility, given by real income and the idiosyncratic preference taste. The distribution of indirect utility is also Fréchet and, given the properties of this probability distribution, we can write the share of workers that choose to live in district i as:

$$\frac{L_i}{L} = \frac{(v_i/P_i^{\alpha} r_i^{1-\alpha})^{\epsilon}}{\sum_{n=1}^{N}(v_n/P_n^{\alpha} r_n^{1-\alpha})^{\epsilon}}, \tag{5}$$

where $v_i = w_i/\alpha$ denotes total income in location i. Expected utility for a worker across locations is given by:[30]

$$\tilde{U} = \delta \left[\sum_{i=1}^{N} (v_I/P_i^{\alpha} r_i^{1-\alpha})^{\epsilon} \right]^{1/\epsilon}, \tag{6}$$

[30]See part C of the appendix for derivation details

where $\delta = \Gamma\left(\frac{\epsilon}{\epsilon-1}\right)$ and $\Gamma(.)$ is the gamma function. We impose $\epsilon > 1$ to ensure a finite value of the expected utility. Because indirect utility follows a Fréchet distribution the expected utility conditional on living in district i is the same across all districts and equal to the expected utility of the economy as a whole.[31] Following Redding (2016), I use this measure of expected utility as a proxy for aggregate welfare.

Spatial equilibrium For a given initial transport network defined by $\{D, \Phi, \{\, \mathrm{I}^k_{i,n}\}_{\forall i,n,k}\}$ and exogenous land endowments $\{H_i\}_{\forall i \in N}$ and productivities $\{A_i\}_{\forall i \in N}$, the spatial equilibrium is a combination of wages, price indices, rents and labour allocations, $\{w_i, P_i, r_i, L_i\}$ such that for all districts the goods and housing markets clear in each district, the domestic labour marker clears domestically and expected utility is equalised across all workers. The equilibrium trade shares and rental rates can be solved as a function of these four equilibrium variables. The following equations define the equilibrium vector $\{w_i, P_i, r_i, L_i\}$:

The goods market clearing is given by the balanced trade condition:

$$w_i L_i = \sum_j \frac{L_i}{\sigma F}\left(\frac{\sigma}{\sigma-1}\frac{w_i}{A_i}T_{i,j}\right)^{1-\sigma}(P_j)^{\sigma-1}w_j L_j, \forall i. \tag{7}$$

The Price index in district i given by:

$$P_i^{1-\sigma} = \sum_j \frac{L_j}{\sigma F}\left(\frac{\sigma}{\sigma-1}\frac{w_j}{A_j}T_{j,i}\right)^{1-\sigma}, \forall i. \tag{8}$$

The rental rate is given by the clearing of the housing markets:

$$r_i = \left(\frac{1-\alpha}{\alpha}\right)\frac{w_i}{L_i}, \forall i. \tag{9}$$

The fraction of workers that chooses to live in district i is determined by the worker's utility maximisation problem and implies the following workers' residential choice equation:

$$\frac{L_i}{L} = \frac{(v_i/P_i^{\alpha}r_i^{1-\alpha})^{\epsilon}}{\sum_{n=1}^{N}(v_n/P_n^{\alpha}r_n^{1-\alpha})^{\epsilon}}. \tag{10}$$

Equations (7), (8), (9) and (10) can be solved for the equilibrium vector $\{w_i, P_i, r_i, L_i\}$. Lastly, the equilibrium level of expected utility, $\tilde{U}$, is implicitly determined by the domestic labour market clearing, $\sum_i L_i = L$.

[31] Because more productive districts attract more workers despite their preference taste the expected value of indirect utility, $\mathrm{E}(b_n w_n/P_n^{\alpha}r_n^{1-\alpha})$ will equalise across locations.

Existence and Uniqueness As shown in Redding (2016) the condition for the existence and uniqueness of the spatial equilibrium will hold if the elasticity of expected utility to the labour share in a district is negative, this is, if the dispersion forces are stronger than the agglomeration forces of the model.[32] In the kind of models with housing and imperfect labour mobility, the condition for existence and uniqueness of the equilibrium is

$$\sigma\left(1 - \frac{\alpha}{1 + \frac{1}{\epsilon}}\right) > 1. \tag{11}$$

3.4 Problem of the Government: Choice of Infrastructure Investment

I model the choice of infrastructure as a Stackelberg game between the Government and the economic agents in the economy (workers and firms). The Government is the leader and thus has the advantage to choose first in the game. The game is solved by backward induction. Thus, the Government chooses infrastructure to maximise expected utility, $\tilde{U}$, constrained by the choices of workers and firms, given by the decentralised equilibrium allocation. This set-up is similar to a Ramsey problem with a Government that maximises welfare replacing the FOCs from the problems of consumers, firms and workers into the constraints.

I assume that the Government can choose how to allocate a fixed amount of resources to improve infrastructure across all the districts in the economy. This budget, that I denote by Z, is modelled as an endowment of the government and thus, is assumed to be exogenous. The cost of investing in district i is $c_i\phi_i$ and the budget constraint of the government is:

$$\sum_i c_i \Phi_i \leq Z. \tag{12}$$

The marginal cost of construction is equal to c_i, that is allowed to differ across districts.

Government's problem We can write the problem of the Government as follows:

$$\underset{\{\Phi_j\}}{\text{Max}}\ \delta \left[\sum_{i=1}^{N} (v_i(\Phi)/P_i(\Phi)^{\alpha} r_i(\Phi)^{1-\alpha})^{\epsilon} \right]^{1/\epsilon},$$

subject to:

[32] The proof follows the same structure as in Allen and Arkolakis (2014)

1. *Goods market clearing*

$$w_i L_i = \sum_j \frac{L_i}{\sigma F} \left(\frac{\sigma}{\sigma - 1} \frac{w_i}{A_i} T_{i,j} \right)^{1-\sigma} P_j^{\sigma-1} w_j L_j, \forall i. \tag{14}$$

2. *Labour market clearing*

$$\frac{L_i}{L} = \frac{(w_i / P_i^{\alpha} r_k^{1-\alpha})^{\epsilon}}{\sum_{k=1}^{N} (w_k / P_k^{\alpha} r_k^{1-\alpha})^{\epsilon}} \text{ and } \sum_i L_i = \bar{L}. \tag{15}$$

3. *Minimum trade costs*

$$T_{i,k} = \left[\sum_n \mathbb{I}_{i,k}^n \frac{D_n}{\Phi_n^{\gamma}} \right]. \tag{16}$$

4. *Government's budget constraint*

$$\sum_i c_i \Phi_i D_i \leq Z, \tag{17}$$

where $P_i = \left[\sum_j \frac{L_j}{\sigma F} \left(\frac{\sigma}{\sigma-1} \frac{1}{A_j} T_{j,i} \right)^{1-\sigma} \right]^{1/(1-\sigma)}$, $r_i = \left(\frac{1-\alpha}{\alpha} \right) \frac{w_i}{L_i}$ and $\delta = \Gamma(\frac{\epsilon}{\epsilon-1})$, where Γ is the gamma function.

Intuition for Welfare effects To build some intuition about the effects of infrastructure investment on welfare let us consider the same problem but without allowing the matrices of least-cost paths to change and in a model with no housing ($\alpha = 1$). This assumption avoids a response of the shipping decision to a change in infrastructure upgrading and abstracts from the response of rents to new investments.[33] Holding the shipping path between every pair of districts constant, the first order condition with respect to ϕ_j is:[34]

$$\begin{aligned} \frac{\partial \mathcal{L}}{\partial \phi_j} = 0 : & \underbrace{\delta^{1/(1-\epsilon)} \sum_i \sum_k (\frac{U}{v_i})^{1-\epsilon} \frac{X_{k,i}}{P_i} \gamma \mathbb{I}_{k,i}^j \frac{D_j}{\phi_j^{\gamma+1}} p_k}_{\text{Direct effect}} + \underbrace{(\sigma - 1) \sum_i \sum_k \eta_i X_{ki} \left(\frac{\partial T_{ki}}{\partial \phi_j} \frac{1}{T_{ki}} - \frac{\partial (P_k)}{\partial \phi_j} \frac{1}{P_k} \right)}_{\text{Response of wages}} \\ & + \underbrace{\epsilon \sum_i \lambda_i \frac{L_i}{L} \left(\frac{\partial P_i}{\partial \phi_j} - \sum_k \frac{\partial P_k}{\partial \phi_j} \frac{1}{P_k} \right)}_{\text{Response of Labour}} = \underbrace{\mu c}_{\text{Marginal cost}}, \end{aligned} \tag{18}$$

[33]Allowing for changes in the shipping path would just add an additional term to the expression below, accounting for how the shipping path matrix will change after an infrastructure upgrading. This effect is not quantitatively very large.

[34]The derivations use Roy's inequality to get the direct effect and can be found in the part C of the Appendix.

where v_i denotes now real income in district i, $v_i = \frac{w_i}{P_i^{\alpha} r_k^{1-\alpha}}$.

Equation (18) shows that infrastructure investment is chosen so that the marginal benefit of investing in a district, left-hand side of the equation, equates the marginal cost of building infrastructure in that district. Notice that the marginal benefit of investing in district j includes the sum of the gains from investing in district j across all districts in the economy that may benefit from the change, similar to the Samuelson rule for the allocation of public goods.

The marginal benefit is composed of a direct effect and the indirect effect coming from the response of wages and population. As we can see, the direct effect is just the partial equilibrium effect of an upgrade of infrastructure on aggregate welfare, before the adjustment of wages and population. This effect is the largest, quantitatively, and affects real income through the effect of infrastructure investments on the Price index of tradable goods. In addition to the partial equilibrium effects the change in infrastructure quality will trigger a response of wages and population that will adjust in response to the new infrastructure quality. In quantitative terms the response of wages and population is small compared to the response of the Price index. Intuitively, the response of wages is increasing on the elasticity of substitution across goods, σ, and the response of population is increasing on the degree of homogeneity across workers, ϵ (recall that $\epsilon \to \infty$ is the case with perfect worker mobility).[35]

We can build intuition about the optimal infrastructure allocation by approximating infrastructure investment in district j with the *partial equilibrium* effects. Rearranging the terms of equation (18) we can write an expression for the infrastructure investment level in district j:

$$\phi_j^{\gamma+1} \approx D_j C \left(\underbrace{\sum_k \left(h_{k,j} + h_{j,k} \right)}_{\text{Size=Importance as } \textit{source} \text{ of trade}} + \underbrace{\sum_{i \neq j} \sum_{k \neq j} \mathbb{I}_{k,i}^{j} h_{k,i}}_{\text{Centrality=Importance as a } \textit{hub} \text{ for trade}} \right), \tag{19}$$

where the function $h_{k,j} = v_k^{1-\epsilon} \frac{X_{j,k}}{P_k} p_j^{-\sigma}$ is increasing in exports from k to j. Equation (19) shows that infrastructure investments will be higher in districts that trade more, first term in the parenthesis, and in districts that are transited by large trade flows, second term in the parenthesis.

This expression is a non linear function of the weighted sum of total trade flows that originate in j, end in j or transit j, with weights being a function of real incomes. To see why notice that

[35] Notice that changes in the transport costs will trigger a larger response of wages if goods are very good substitutes, thus triggering a large trade response to changes in prices, and if workers are very mobile, thus triggering a large response of workers to changes in real income.

$\mathbb{I}_{k,i}^{j}$ will be one every time $i = j$ or $k = j$ and when j is transited by a trade flow between a pair of regions not including j. For all other trade flows the indicator $\mathbb{I}_{k,i}^{j}$ will be zero and will not show up in this expression. Thus, the infrastructure level in district j will be a function of the total trade flows that originate or end in j and of the trade flows that transit j. The labels indicate that we can think of this expression as a function of the importance of district j in terms of size (importance as a *source* of trade) and in terms of centrality (importance *hub* for trade flows).

3.5 The division of Germany in 1949

The theoretical framework developed in this section helps us understand what is the optimal infrastructure pattern across regions in a general equilibrium framework. As indicated in equation (19) infrastructure investment will be higher in districts that are an important *source* of trade flows, and in districts that are an important *hub* for trade flows. In this framework, a permanent change in the size of trade flows or trade transit in a district would create incentives to reshape the infrastructure network. Given some infrastructure budget, the new investments would be allocated to maximise aggregate welfare given the new fundamentals and the initial transport network.

The division of Germany into East Germany and West Germany in 1949 was a sharp shock to the German economic geography (Redding and Sturm, 2008). Firstly, it caused a reduction in the domestic trade of West German districts as all trade with East Germany stopped. Besides, the transit of goods changed once the inner border was established, causing previously central districts, in the centre of the country to become remote after division. Finally, it caused a change in the transportation network since the border cut through some existing roads.

In the next section I take the model to historical data of Germany and I provide several tests of the ability of the calibrated model to capture the economic geography of Germany.

4 Calibration of the model: Spatial equilibrium

In the previous section I have built a quantitative spatial model that incorporates endogenous infrastructure investments. In this section, I take the model to the data. The goal of this section is to achieve a quantification of the model that captures the economic geography of Germany and can be used to study the economic gains from infrastructure investments

I follow a two-step strategy to quantify the model detailed in the previous section. First, I calibrate the model to the German economy before the division. This calibration, that will target the year 1938, abstracts from the endogenous response of infrastructure investments. The goal of this first step is to test whether the spatial equilibrium model with fixed infrastructure can match the 1938 German data. I use newly collected data of shipments of goods by road within Germany to assess the fit of the model's predictions.

The second step is to use the model to evaluate the performance of the model in the post-division period. To this end, I use population, trade and highway data from the decades between 1950 and 1974. I use this data to show the ability of the model to predict the response of different economic outcomes to the division shock.

4.1 Strategy: Calibration before division

The goal of this calibration is to obtain a quantitative model that represents as close as possible the spatial equilibrium of the German economy before the division. To take the model to the data I need to calibrate two sets of parameters: first, the pre-division transport network that will determine the initial transport cost matrix, and, second, the parameters of the model that will determine the spatial equilibrium.

4.1.1 Initial network and Transport costs

The geography of this model is a graph composed of a set of districts linked by the transport network. This graph represents the underlying geography of Germany and is assumed to be fixed. On the contrary, the quality of the links can be upgraded by investing in infrastructure. I build the underlying graph as follows. I combine the highways, (Autobahns) and all federal highways (Bundesstraße) that existed in 1938.[36] I add the local roads needed to ensure that all districts in Germany are connected to the network. This gives me a network that contains all german districts.[37] Figure A.4 in the Appendix displays the roads chosen for the initial network and the graph corresponding to this network.[38]

After building the network, I compute the cost of transporting goods following Combes and Lafourcade (2005). I compute the shipping cost by adding a time-related component and a distance-related component. These costs are the frictions that the government will be able to reduce by investing in infrastructure quality. Finally I convert the computed initial transport costs (in euros) to

[36]The federal highways are roads with multiple lanes but not limited-access like Autobahns

[37]I provide further details of the construction of the network in D of the Appendix.

[38]For the network construction I use the Network Analysis toolkit in the geographic information software ArcGIS.

ad-valorem transport costs by scaling the cost of shipping by the average value of the shipment of a truck in Germany in 1950. Full details about the cost computation can be found in part D of the Appendix.

Given the graph and the associated transit costs I can compute the initial transport cost matrix by applying a least-cost path algorithm to the network. This calibration yields the transport cost matrix in 1938.

4.1.2 Parameter choice

In addition to the transport cost matrix $\{T_{i,n}\}$, calculated as explained above, the model described in section 3 has several additional parameters to be calibrated. First, there are two district-specific vectors of parameters: $\{A_i\}$, the exogenous productivity of each district and $\{H_i\}$, the land endowment of each district. Then there are standard parameters present in other trade and spatial models. This is the case of α, the share of tradable goods in total expenditure, ϵ, the shape parameter of the Fréchet distribution from which idiosyncratic tastes are drawn and $(\sigma - 1)$, the trade elasticity. Finally, the model has three parameters related to the construction of infrastructure: γ, the elasticity of transport costs to infrastructure investments, Z, the budget of the government for infrastructure upgrades and $\{c_i\}$ the district-specific marginal cost of construction.

Standard parameters calibrated to exogenous values I calibrate $\{\epsilon, \alpha\}$ to existing values in the literature. I set the shape parameter of the Fréchet distribution to $\epsilon = 3$ following the estimated value from domestic migration flows across U.S. counties by Monte et al. (2015). I vary this parameter in robustness checks to $\epsilon = 7$, value estimated for the heterogeneity of worker's preferences governing commuting and location choices within Berlin in Ahlfeldt et al. (2018). I calibrate an expenditure share of tradables of α=0.7, leaving an expenditure share of housing of $(1 - \alpha) = 0.3$ following Redding and Sturm (2008) in their study about the population growth effects of the German division. Notice that this choice of parameters ensures that the condition for the existence of a unique and stable spatial equilibrium is fulfilled.

Standard parameters calibrated to Germany 1938 The district-level land endowments, $\{H_i\}$, are equated to the surface of each district in squared kilometres as measured in the data.

Given the land endowments, the district-level productivities, $\{A_i\}$, are calibrated to match the population distribution of Germany in the year 1938. I compute the productivity level of each district by inverting the spatial equilibrium and solving for the vector of district productivities that, in equilibrium, delivers the population distribution observed in the data.[39] I use population at the district-level for 1938 from the German Census collected in the Statistical Yearbooks of the Federal Republic of Germany.

Parameter estimated using the full-structure of the model: Trade elasticity Finally, I use data on shipments by road over 10 distance brackets in 1938 to calibrate the trade elasticity parameter $(1-\sigma)$. For this estimation I use the full structure of the model with fixed infrastructure. First, I estimate the elasticity of trade shipments to distance using historical data of shipments and obtain an estimate of $\beta = -2.8^{***}$. This estimate is larger than the average magnitude estimated in the literature but transiting through ground-transport means, such as roads, has been shown to yield substantially higher distance coefficients(Disdier and Head (2008)).

Under the standard assumptions of the gravity equation this elasticity is the product $\beta = (1-\sigma)\times\nu$, where $\nu = \partial log(T_{i,j})/\partial log(dist_{i,j})$. The consensus in the literature is to choose $\nu = 0.3$ (Monte et al. (2015) among others). The parameter ν does not have an exact counterpart in my model. It will be a combination of the elasticity of transport costs to distance along different types of road and conditional on transit over the least-cost path.

To compute the value of σ implied by the estimated elasticity of $\beta = -2.8^{***}$ we need the elasticity ν in 1938 as implied by my model. To this end I set the elasticity of substitution to σ=5, following the consensus in the trade literature (for example (Broda et al., 2008)), and compute the implied trade flows across all district pairs conditional on the parameter values chosen above. The elasticity of trade shipments to distance in the model with $\sigma = 5$ is $\beta^{model} = -1.84^{***}$, which implies a value of $\nu = \partial log(T_{i,j})/\partial log(dist_{i,j}) = 0.46$. Given $\nu = 0.46$, I set $\sigma = 7$ in order to achieve an elasticity of trade flows with respect to distance that matches the estimated elasticity in the data of 1938 ($\beta^{model} = -2.8$). Table B.1 shows that the elasticity of trade shipments to distance in the model with $\sigma = 7$ is $\beta^{model} = -2.78^{***}$, equal to the elasticity estimated in the data.

Parameters related to Infrastructure-choice Finally, to solve for the optimal infrastructure in the model, I calibrate the parameters related to infrastructure choice, $\{\gamma, Z, c\}$. The calibration and estimation of the parameters related to infrastructure choice, $\{\gamma, Z, c\}$is explained in the next section.

[39]This calibration technique is explained in the survey by Redding and Rossi-Hansberg (2017)

4.2 Model fit: Performance before division

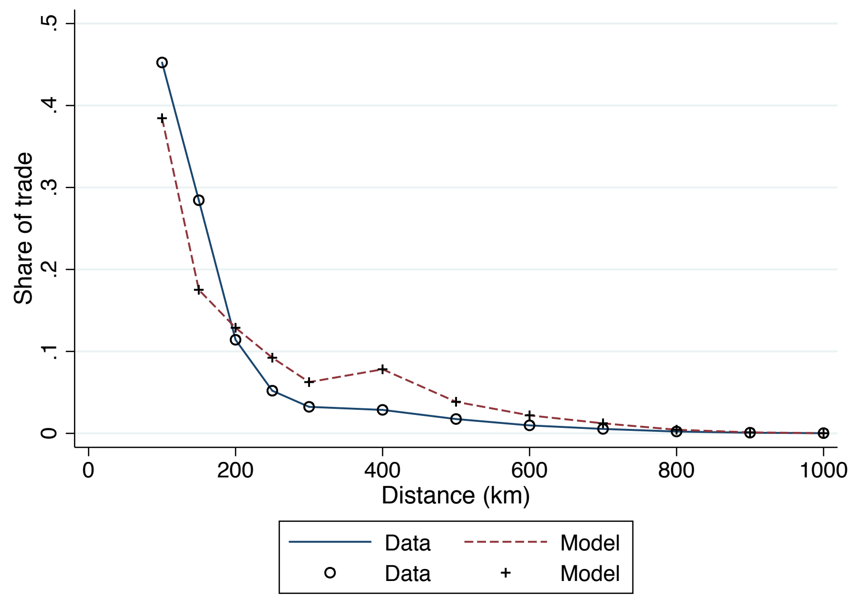
Given the initial transport network summarised by $\{T_{i,n}\}$and the value of the model parameters chosen above I solve for the spatial equilibrium defined by equations (7), (8),(9) and (10) of section 3. With the equilibrium endogenous variables $\{w_i, P_i, r_i, L_i\}$ I find the model simulated trade matrix between all German districts. Notice that this equilibrium takes the infrastructure network as given by the transport cost matrix $\{T_{i,n}\}$.

As a first check I show that the relation between trade flows and distance is very close in the data and in the model. I collect the total tons of goods shipped by distance bracket from manufacturing shipments and furniture shipments in the year 1938 within Germany.[40] I construct the share of shipments in real terms by distance bins in equilibrium using the calibrated model and compare the model's predictions with the data. Figure 6 plots the density of trade flows over distance in the data (continuous line) and in the model (dashed line). The very good fit of the model to the data is not surprising because I calibrate $\sigma = 7$ to match the elasticity of trade flows to distance but it is reassuring that such a good fit can be achieved by fitting only one parameter.

To check the model fit, I aggregate total trade by district into a different classification, traffic-districts (*Verkehrsbezirken*), for which I observe road shipments in the historical data. The data provides a measure of the total tons of goods received by road in any traffic-district from the rest of Germany and of total tons shipped to the rest of Germany. This information is available for 18 traffic-districts (that contain all 412 districts in Germany). I compare the predicted trade in the model with the total imports and total exports of each traffic-district in the data.

[40] Data collected from Statistical yearbook of the Deutches Reich (1940)

Figure 6: Model fit of trade flows over distance

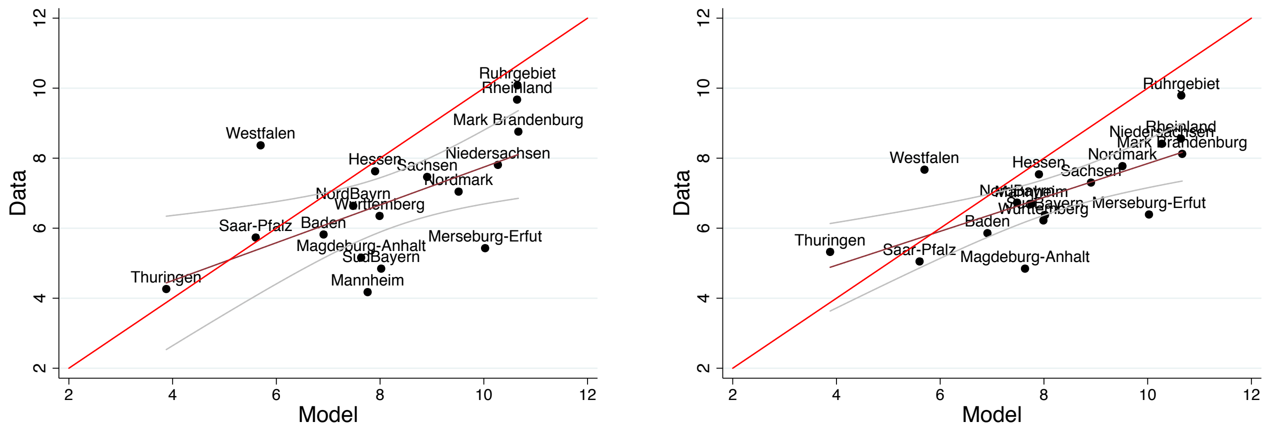


Notes: Share of total weight of good shipments by distance bins. The continuous line plots the density of goods shipments over distance in the goods traffic data while the dashed line plots the density of trade flows over distance in the model. Goods shipments only contain shipments by truck of manufacturing firms and furniture.

Figure 7 plots the goods traffic data against the model predictions. The correlation between the model and the data is corr=0.59 for total imports and corr=0.70 for total exports (the model explains 35% of the cross-sectional variation in imports and 50% of the variation in exports, as measured by the R-squared). Thus, the calibration presented in the previous sub-section does an excellent job in replicating trade flows across German districts before division. Notice that this is not a surprising fact, urban models of this kind have been successfully used to explain economic variables such as population and trade. Nevertheless, these results help me build confidence in the specific calibration chosen.

These two tests show that the model has the ability to explain the spatial equilibrium of Germany and captures well the trade flows observed in the cross-sectional data.

Figure 7: Model fit of domestic trade



A) Domestic Imports, Rsq= 0.35, corr=0.59 **B) Domestic Exports, Rsq= 0.50, corr=0.70**

Notes: Each dot represents one traffic-district, there are 18 in total. Data comes from the Statistical Yearbook of the Bundesrepublic, year 1940. The road shipment data is collected in tons and split up by tons imported and tons exported to the rest of German districts.

4.3 Model fit: Performance in changes after division

I now provide two additional test of the ability of the spatial model with endogenous infrastructure networks to explain economic outcomes. To this end, I exploit the unexpected appearance of a border between East and West Germany after the Second World War. The division of Germany happened as a result of the increasing tensions the United States and the Soviet Union. While the division was supposed to be temporary, it became permanent once the conflict between these two countries escalated.

The unexpected division of Germany can be used to test whether the structural model can capture the reaction of the economy to this division shock, that exogenously changed the Market Access and Centrality of all West German districts[41].

I perform two quantitative tests. First, I compare the district-level population change between 1950 and 1974 in the data with the model's prediction. Second, I compare the change in domestic trade flows across German states between 1950 and 1974 with the model's prediction. Notice that both these tests assess the performance of the model to make out-of-sample predictions, since I only used pre-division data for the calibration. To perform these tests, I simulate the division of Germany

[41] Redding and Sturm (2008) show that an economic geography model like the one I use in this paper can successfully capture the population response to the division shock of the 100 largest West German cities. I do a similar exercise including all districts and I extend the analysis to trade flows

by assuming that trade costs between East Germany and West Germany became prohibitive. Further details are provided in the next section.

Population changes First, I test ability of the model capture the change in the distribution of population after the division. Since the Second World War caused a dramatic loss of lives and a large reallocation of population I focus on changes between 1950 and 1980. Taking logs and first differencing equation (5) we get the following expression for the change in population in region i between t and t-1:

$$\Delta lnL_i = \frac{\epsilon\alpha}{(\sigma-1)}\Delta\text{ln MA}_i + \epsilon\Delta\text{ln v}_i + \epsilon(1-\alpha)\Delta\text{ln r}_i - \Delta ln\Phi - \Delta lnL \tag{20}$$

where MA stands for Market Access, $MA = \sum_j T_{ij,t}^{1-\sigma} E_{i,1938}/MA_{j,t}$. I follow Redding and Sturm (2008) and conjecture that the division of Germany can be summarized as a shock to Market Access. As measure of market access change I use three indicators. First, following Redding and Sturm (2008), I use the distance to the German interior border as a proxy for the division shock. Second, I build ΔMA_i as the difference between $lnMA_{i,1950}$ and $lnMA_{i,1938}$. I compute the market access measure $MA_{i,t}$ as the solution to the system:

$$MA_{i,t} = \sum_j \frac{T_{ij,t}^{1-\sigma} E_{i,1938}}{MA_{j,t}} \tag{21}$$

where $E_{i,1938}$, expenditure in the model, is replaced by $L_{i,1938}$ population in district i in year 1938 and kept constant for all Market Access calculations. Thus, the only difference between $MA_{i,1950}$ and ln $\text{MA}_{i,1938}$ is driven by the change in transport costs, to isolate the changes that come from the border change after the division. I compute a second measure of $\Delta\text{ln MA}_i^2$ that includes the new highway construction between 1950 and 1978. I define $\Delta\text{ln MA}_i^2 = lnMA_{i,1974} - \text{ln MA}_{i,1938}$ including the division shock and the new road construction between 1950 and 1974.

There are two empirical challenges to estimate the effect of market access changes on population, implied by equation 20. First, v_i and r_i, disposable income and rent are unobserved and will be contained in the error term. Therefore, if the change in Market Access is correlated with the changes in rents or disposable income at the region-level, we will estimate a biased effect of Market Access on population. To alleviate this concern I control for the distance to the internal German border, to take care of the effects that the closeness to the border could have had on rents and wages (in addition to the trade shock). Second, I add state fixed effects to control for state-level differences in economic development, specialization or state legislation.

The second concern is that the change in Market Access could be non-randomly affecting regions, creating a selection bias. This concern is of less relevance when we use $\Delta \ln \text{MA}_{1950,1938}$ since the changes in Market Access come from the division of Germany that was an unexpected and exogenous event. However, when we use the second measure of Market Access,$\Delta \ln \text{MA}_{1974,1938}$ part of the variation comes from the highway construction. As we know, governments may choose highway allocation based on economic fundamentals such as past or predicted internal migration. To deal with this endogeneity problem I instrument $\Delta \ln \text{MA}_{1974,1938}$ with $\Delta \ln \text{MA}_{Plan,1938}$ where I measure the change in transport costs using the (counterfactual) 1934 Plan. Since the 1934 Plan is previous to the division it is unlikely that it was designed to target any economic outcomes from the Post-division period.

I run the following regression at the district level:

$$\Delta ln \text{ Pop}_i^{80,50} = \beta_1 \Delta ln \text{ MA}_i + \beta_2 Dist2border + \delta_s + \nu_i \tag{22}$$

I use $\Delta Population_i^{80,50}$, the log-change in population between 1950 and 1980 in order to make sure we capture the response of population to the new highway construction. Since population mobility may be delayed I choose a wider time frame to look at the data. To test the fit of the model, I compare these estimation to a similar specification using model-generated data. In particular, I use predicted population changes between 1974 and 1950, $\Delta ln\widehat{Pop_i}^{74,50}$, as outcome variable. The results are reported in Table 2.

As we can see, the response of population to the division shock in the data (columns 1,2 and 3) is positive and of a very similar magnitude as the response generated in the calibrated model (columns 4 and 5).

Changes in trade flows The second test I conduct is to compare the predicted change in domestic trade flows between 1960 and 1989 with the changes in the data. The goal is to show that the calibration of transport costs generates the response of trade flows to transport costs comparable to the data. I collect historical on trade flows between west German states in 1960 and in 1989. Due to data constraints the earliest year I can use at the beginning of the post-division period is 1960.

The change in trade flows is computed as the growth rate of trade flows across German states (log-change)[42]. To assess the performance of the model in capturing changes in domestic trade flows, I compare the data with a model simulation. I use the model to predict the change in trade

[42] The data is in tons while the simulated data from the model is in nominal value of flows

flows between 1960 and 1980, by computing trade flows after the division (1960) and trade flows just before reunification (year 1989)[43]

Table 2: Out-of-sample Test: Change in Population distribution 1950 to 1980

	Data: $\Delta ln\ \text{Pop}_i^{80,50}$			Model: $\Delta ln\widehat{Pop_i}^{74,50}$	
	OLS	OLS	IV	OLS	OLS
	(1)	(2)	(3)	(4)	(5)
Δ ln $MA_{1950,1938}$	0.480***			0.874***	
	(0.135)			(0.219)	
Δ ln $MA_{1974,1938}$		0.182***	0.235***		0.317***
		(0.029)	(0.073)		(0.101)
Dist2border		0.001***	0.001***		
		(0.000)	(0.000)		
Constant	0.386***	0.057	0.035	0.201***	-0.055
	(0.014)	(0.054)	(0.059)	(0.055)	(0.078)
State FEs	Yes	Yes	Yes	No	No
Observations	312	312	312	312	312
R^2	0.251	0.282	0.280	0.100	0.040

Notes: Standard errors clustered at the Government-region level in parentheses.* significant at 10%, ** significant at 5%, *** significant at 1%.

As a measure of change in transport costs during the period I compute the change in ad valorem transport costs from every district-pair for the network in 1950 and the network in 1980. This variable, ΔTC, is always negative going from 0 to -2 (no change to 200% reduction). I measure transport cost improvements one decade earlier than the trade flows to allow for firms and consumers to adjust to the new infrastructure. Then, the changes in transport costs are aggregated to the state level by taking simple means to compute the state-to-state change in ad-valorem transport costs.

[43] The trade flows for the years 1960 and 1989 are generated by solving the spatial equilibrium of the model setting the total population to the 1960 (1989) and the highway network to the observed 1960 (1989) highways.

I run the following regression with historical data as well as with the model generated data:

$$\Delta lnTrade_{s,s'}^{1960,1989} = \mu_1 \Delta TC_{s,s'}^{1950,1980} + v_{s,s'}, \tag{23}$$

where s, s' are two states in West Germany and TC is the ad-valorem average transport cost computed along the least-cost path given the highway network.

Table 3 reports the relation between log-changes in trade flows and changes in transport costs. As we can see, the model is able to capture remarkably well the response of trade flows to reductions in transport costs when we account for the change in highways (column (1) vs column (2)). According to these results, a pair of states that benefited from a reduction in the ad-valorem transport cost similar to the mean (-1), saw an increase in trade flows of 19.5% in the data and of 14.5% in the model.

Table 3: Out-of-sample Test: Change in trade flows 1960 to 1989

Dep. Var: $\Delta log(Trade_{i,j})$	Data	Simulation
	(1)	(2)
Change in Transport costs (1980-1950)	-0.195***	-0.145**
	(0.0542)	(0.0613)
Constant	0.714***	0.295***
	(0.0597)	(0.0711)
Obs.	90	90
R-Squared	0.117	0.0435
Mean Change	-0.995	
St. Dev Change	0.51	

Notes: Robust HAC standard errors, are in parentheses.* significant at 10%, ** significant at 5%, *** significant at 1%. The Change in Transport costs is computed as the change in ad valorem transport costs from district to district, for the transport network in 1950 and the network in 1980. This variable is always negative going from 0 to -2. The changes in transport costs are aggregated by taking simple means to compute the state-to-state change in transport costs. The Data variable is log-change in tons shipped across each pair of states. The Model simulations use the log-change in nominal value of state-to-state trade.

These two additional tests show that the static model I build in section 3 performs strikingly well in predicting long-term changes in population and trade flows. Thus, the ability of the model to predict these responses of population to division and trade costs to transport improvements provides further confidence in the quantification of the model.

5 Results: Explaining the highway network

In this section, I examine whether the calibrated quantitative framework presented in the last two sections can explain the main pattern and changes of the highway network. This is one of the main contributions of the paper, showing that a quantitative spatial model can help us study infrastructure investment decisions by governments. I start by assessing the validity of the model to explain the level of highway investments across districts observed in the 1938 prewar Highway Plan (cross-sectional variation). The 1934 highway plan, though formally proposed by the Hitler government, was heavily inspired by engineering plans of german-wide networks proposed in the 1920s and 1930s. Next, I test whether the model can also account for the changes in highway construction, exploiting the large-scale shock to economic fundamentals caused by the division of Germany (time-variation).

5.1 Solving for the Optimal highway network

I use the model to compute the optimal infrastructure network given the German geography before the division. The model developed in section 3 embeds an endogenous choice of infrastructure in a standard spatial equilibrium framework. To solve for the optimal network, I recompute the initial trade costs matrix by assuming that no highway link has been built yet (the quality of all links is set to local roads). In addition, I calibrate the network-specific parameters of the model $\{\gamma, Z, c_i\}$.

Estimation of Infrastructure-related parameters The three parameters specific to my model that are crucial for the choice of infrastructure are γ, the returns to infrastructure investments, Z, the government's budget to invest on infrastructure and $\{c_i\}$, the district specific marginal construction cost. Recall that the budget constraint of the government is:

$$\sum_{i=1\ldots N} c_i \phi_i \leq Z, \tag{24}$$

where $\{\phi_i\}$ is the vector of infrastructure investment allocations. Because the initial underlying grid is based on the existing highways and roads in Germany these links will already be, to some extent, equally easy to build on. The model will never predict construction along very rugged terrain or across bodies of water. Thus, I choose $c_i = c, \forall i$ to simplify the computation problem. However, the ruggedness of the terrain or the existence of rivers could be introduced easily in the problem.

I discipline the two remaining parameters $\{\gamma, Z\}$ using the design of the 1934 highway Plan. The parameter γ, the returns on infrastructure investments, determines whether infrastructure investments have increasing or decreasing returns. Therefore, this parameter will shape the concentration of highway investments at the district level. I estimate γ to bring the degree of concentration of investments in the model as close as the concentration in the 1934 Plan. As a measure of concentration of investments I use the skewness of the distribution of highway kilometres in the 1934 highway plan. I estimate this parameter using Simulated Method of Moments (SMM) on a simulated 50-district economy where I discipline the productivity distribution using random draws from a distribution similar to the calibrated productivities in the previous section. This estimation yields parameter $\gamma = 0.84$. Further details are provided in section D of the Appendix.

The budget of the government, Z ,does not have a data counterpart in terms of units, but a measure of how much ad-valorem costs could potentially be reduced. To calibrate the budget meeasure, I use the distribution of highway kilometers by district allocated in the 1934 prewar Plan. Transport costs in the model are specified in ad valorem units, while investments in the plan are specified in kilometers. To make these measures comparable, I use the share of the budget/highway kilometers that a district receives. Plotting the shares in the model and in the data we can assess how similar are the distributions, specially, the number of districts that receive zero investments. I choose a measure for the initial budget in 1938, Z, that generates a similar distribution in terms of investments shares as the prewar plan. Figure A.5 in the appendix plots the investments shares in the model and in the 1934 Plan.

Finally, I impose $\phi_i \geq 1$ to ensure that the government is constrained by the original network and transport costs can only decrease with the choice of infrastructure. This also ensures that infrastructure that is given cannot be disinvested. I adjust the budget to account for the cost imposed by this lower bound restriction.

Given the productivity distribution, the initial transport network and transport costs and the calibrated and estimated structural parameters, I compute the infrastructure allocation that maximises aggregate welfare. The solution to the Government's problem is a 395 vector of the optimal district level investments that I can compare to the 1934 government plan.

Solution method Given the parameter values, the underlying transport network and the initial transport costs, I solve for the infrastructure allocation that maximises expected utility. The solution will be a vector of 395 infrastructure investments representing the spatial pattern of infrastructure investments.

The model does not feature congestion costs because transport costs are independent of the quantity shipped ($\frac{\partial T_{i,j}}{\partial X_{ij}} = 0$). This choice simplifies the solution method because given the network and the investment vector I can compute transport costs independently of the equilibrium allocation. However, the lack of congestion makes the government's problem not globally convex.[44] The short-come of modelling transport costs as constant on the quantity shipped (weakly convex) is that I cannot prove that the solution I find is the global optimum of the problem. In my set-up this is not a concern. The local optimum will be the best possible deviation from the initial network. This solution coincides with the problem the government has to solve: how to allocate limited resources to upgrade the highway network. On the contrary, the global optimum may be very far from the initial network and require a much more significant investment. Even without congestion the spatial problem of the economy is convex and features a unique and stable equilibrium (given the calibrated parameter values in the previous section). The transport costs are constant on the quantities traded and convex on the infrastructure investments which makes the problem (weakly) convex.

I can rewrite the problem as an optimisation of the expected utility in equilibrium over the infrastructure investment vector:

$$\underset{\{\phi_j\}_{j \in N}}{\text{Max}} EU^{eq} = f(w^{eq}(\Phi), P^{eq}(\Phi), r^{eq}(\Phi), L^{eq}(\Phi), T^{eq}(\Phi), \Phi), \tag{25}$$

where EU^{eq} is the equilibrium expected utility for a given infrastructure network and a given vector of infrastructure investments (Φ). The equilibrium expected utility is a function of the equilibrium wages, $w^{eq}(\Phi)$, equilibrium Price indices $P^{eq}(\Phi)$, equilibrium rents, $r^{eq}(\Phi)$, equilibrium population allocation, $L^{eq}(\Phi)$ and the equilibrium transport cost matrix, $T^{eq}(\Phi)$. To solve for the infrastructure allocation, I start the problem from the initial transport network (assuming all roads are local), and I search for the infrastructure allocation that maximises expected utility using an interior-point algorithm.

5.2 Explaining the 1934 Highway Plan

The solution of the model is the share of the investment budget that should be allocated to each district to maximise aggregate Welfare. I compare now ability of the model to capture highway investments in the 1934 highway plan. As mentioned in previous section, this prewar plan was heavily inspired by the 1920 and 1930 designs proposed by a group of engineers to build a german-

[44] See Fajgelbaum and Schaal (2017) for a detailed discussion about convexity in spatial networks

wide highway network following the economic geography of the time.

First, I convert the share of investment into highway kilometres by assuming that the number of kilometres built in the model is the same as the total kilometres in the 1934 Highway plan. Figure 8 plots the optimal number of kilometres per district in the model solution (upper figure) and the number of kilometres per district allocated in the 1934 highway plan (lower figure). The shading represents the units of investment predicted by the model or allocated in the plan in each district converted to kilometres.

The model is able to predict the main patterns of investment, such as the connections of the main German cities to Berlin (West to East and South to East links). We can also see that the model underpredicts investments at the border, because the baseline model abstracts from international trade and other geopolitical concerns that may have been driving infrastructure investments. I introduce international trade in the solution to the optimal investments post-division to understand the relevance of trade as a driver of infrastructure construction.

The model is also able to capture the relative importance of the different highway links. In figure A.6 in the Appendix we can observe the comparison between the model's prediction and the first highways that were built before division. The model's predicted intensity of investment coincides with the highway construction timing: the darkest links in the model, higher investment, were the first ones to be built showing that the districts with a high marginal benefit of highway investments according to the model were the districts that received these investments earlier in time.

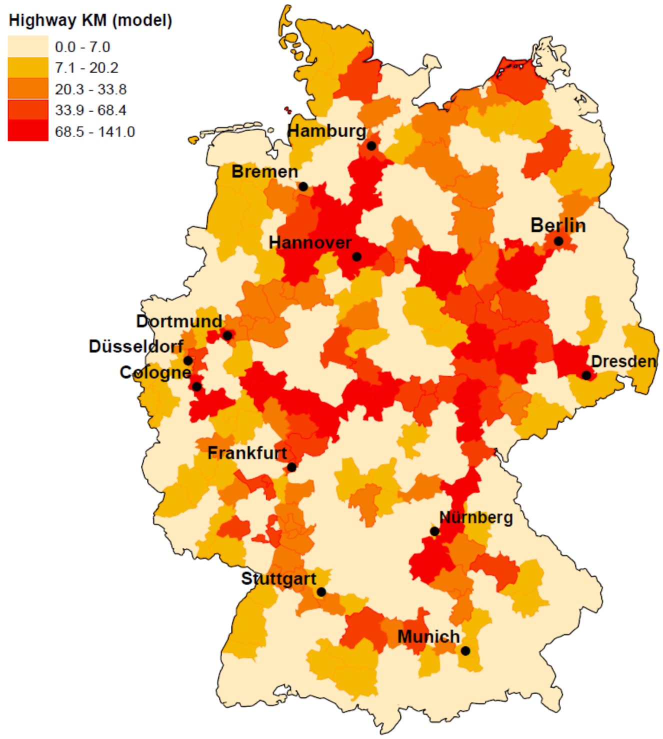
To test the predictive power of the model-generated investments I run the following regression, at the district level:

$$H_{i,Plan} = \alpha + \beta_1 H_{i,OPT} + X'\phi + u_{i,t}, \tag{26}$$

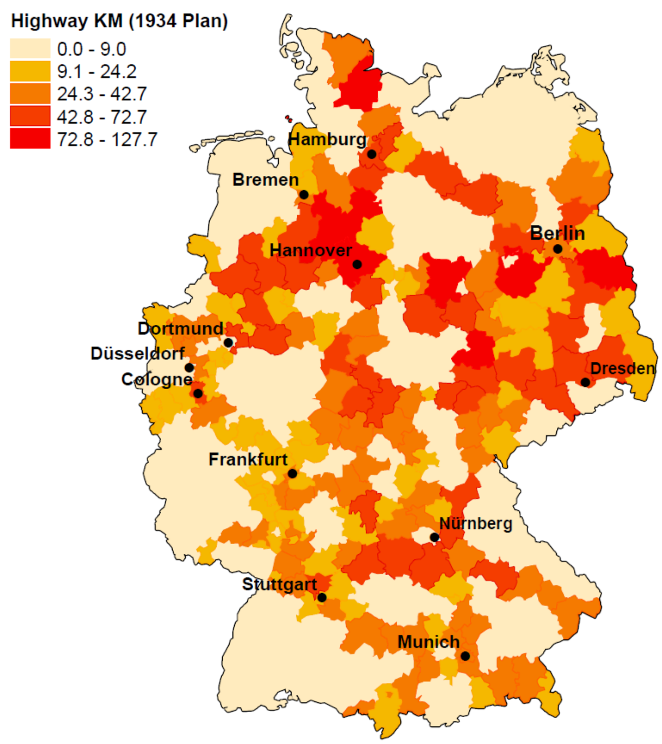
where $H_{i,Plan}$ is the total number of highway kilometres planned in district i and year 1934 and $H_{i,OPT}$ is the number of kilometres allocated to district i in the optimal network before division. The vector X' represents district-level controls, such as the distance to the border with Western Europe and the area of a district is squared kilometres. The coefficient of interest is β_1, that captures the relation between the model's predictions and the observed planned highway.

The identification of β_1 could be biased if there are district-specific characteristics that affect population and other fundamentals as well as highway investments before division. For example being close to a Port increases centrality of a region relative to the rest of the world and may have attracted population and trade as well as better infrastructure for decades. To control for some of the geography related time-invariant factors such as the ruggedness of terrain or proximity to the coast I

Figure 8: Simulated Infrastructure investments before the division shock



A) Model



B) 1934 Highway Plan

Notes: The shading represents the number of highway kilometres by district (darker, more kilometres). The upper panel displays the highway kilometres predicted by the model while the lower panel displays the highway kilometres allocated to each district in the 1934 Highway Plan.

run an additional specification that includes state-level fixed effects. It is clear that these controls will not dissipate the concern about the existence of omitted variables. Therefore, in the next section I exploit the change in economic fundamentals caused by the division of Germany to address some of these problems. Table 4 reports the results of this specification and table B.3 in the Appendix reports the results with standard errors clustered at Government regions (Regierungsbezirke).[45]

Table 4: 1934 Highway Plan : Cross-sectional variation

OUTCOME:	Highway km Plan (1)	Highway km Plan (2)	Highway km Plan (3)
Optimal highway km	0.4464***	0.3199***	0.3221***
	(0.0565)	(0.0492)	(0.0494)
Log Pop 1938		3.8921**	4.6429**
		(1.5242)	(2.0525)
Distance to the Border		0.0589***	0.0581***
		(0.0187)	(0.0219)
Elevation		-0.0035	-0.0162**
		(0.0046)	(0.0069)
Area (sqkm)		0.0114***	0.0118***
		(0.0022)	(0.0025)
Constant	10.2888***	-48.6655***	-43.7996
	(1.2235)	(18.5381)	(29.0911)
State FE	No	No	Yes
Observations	331	323	323
R^2	0.266	0.383	0.450
Mean Highway km	20		
SD Highway km	24		

Notes: Robust HAC standard errors, are in parentheses.* significant at 10%, ** significant at 5%, *** significant at 1%. Results for the 395 German districts aggregated into 331 micro-census regions. The dependent variable is the number of highway kilometres in the 1934 Plan for each district. *Optimal highway km* is the highway kilometres predicted by the quantitative model. Distance to West Border measures the distance from the district centroid to the German border with a western European country.

My results show that the model-generated optimal network can explain 26.5% of the cross-sectional variation in planned highway across German districts. The coefficient $\beta_1 = 0.44^{***}$ shows

[45] Clustering the standard errors at the Government region seeks to control for spatial correlation of errors. There are 30 Government regions.

the close relation between the predicted investments and the observed investments. This coefficient is reduced after introducing controls to $\beta_1 = 0.31^{***}$. The reduction in the coefficient shows that controlling for district specific factors such as population, distance to the border, elevation or area seems to be very important to assess the actual predictive power of the model. However, the model's predicted investment is still positive and significant. Finally, the coefficient remains stable after including state-level fixed effects specification in column 3. As expected, the coefficients on Area and Distance to Border are positive showing that the 1934 Highway Plan allocated more kilometres to larger districts and to districts closer to the interior of the country.

There are a few discrepancies between model and data. These discrepancies are clear when looking at the spatial distribution of investments in Figure 8. First, the model's measure of investment is smooth and thus the investment pattern is more gradual than the highway pattern. Second, the model fails to capture the investments near the Eastern border of Germany. In 1934, the German territories extended further East than nowadays borders and, thus, in figure 8 we observe several several planned highways that crossed the border with Poland, (former) Czechoslovakia and Austria. Finally, we do see that the plan invests heavily in the centre of the country while the model's solution is more radial.

It is also worth noting that comparing the district to district investment levels does not capture the network structure of highways. To capture the spatial nature of the data, I compare the changes in bilateral transport costs that each district would enjoy after the construction of the model predicted investments and after the hypothetical construction of the 1934 Highway Plan. I run the following regression,

$$\Delta T_{i,j}^{Plan-1938} = \beta_1 \Delta T_{i,j}^{OPT-1938} + v_{i,j}, \tag{27}$$

where $\Delta T_{i,j}^{Plan-1938}$=$TC_{ij}^{Plan} - TC_{ij}^{1938}$, the difference in bilateral transport costs between the network of 1938 and the construction of the 1934 Highway Plan, and $\Delta T_{i,j}^{OPT-38}$=$TC_{ij}^{Model} - TC_{ij}^{1938}$. The results of this regression, Table B.4 in the Appendix, shows that the model captures very well the change in transport costs that would have taken place if the 1934 Highway Plan had been built. This shows that the connections to which the model gives priority coincide, to a large extent, with the goals of the government.

In all, these results suggest that a model with endogenous infrastructure investments performs well in predicting the cross-section of highway investments.

5.3 Optimal highway construction after the division

As pointed out in the previous section, the existence of district-specific time-invariant factors such as geographical advantages or political importance poses a threat to identifying the predictive power of the model for the cross-section of highway investments. To address this threat, I exploit a large-scale exogenous shock to economic fundamentals: the German division. This exogenous shock allows me to test the model's predictions about new highway construction after the division shock. Focusing on the change in highway kilometres built between 1974 and 1950 controls for time-invariant characteristics affecting the stock of highways in that district. I will now explain how I simulate the division shock and solve for the optimal highway construction, after the division.

Simulation of the division shock Following the division of Germany in 1949, West Germany suffered an important shock to trade and population mobility following from the establishment of the inner German border. To understand how this exogenous shock to economic fundamentals affected the highway network I use the calibrated version of my model explained in the previous subsection.

I simulate the division shock by introducing a border friction, $\{B_{ij}\}$. The border friction multiplies the transport cost and is parametrised as follows:

$$B_{i,j} = \begin{cases} 1 & \text{if } i, j \text{ belong to West Germany} \\ > 1, & \text{in all other cases.} \end{cases} \tag{28}$$

In the numerical implementation I use the extreme assumption that $B_{i,j} = \infty$, by eliminating East German districts from the set of possible trade partners and location destinations.

Constrained choice of infrastructure After division the government's choice is restricted to upgrading the part of the network that remained in West Germany. The new government's problem is to upgrade the infrastructure in West Germany to maximise the aggregate welfare of West German districts. One important constraint for the choice of the government is the existing highways that had been built between 1934 and 1950 (Figure 3). About one half of the six thousand kilometres outlined in the 1934 Highway plan had been built before the division (two thousand kilometres were built in West Germany, while one thousand were built in East Germany). To capture this physical constraint I add to the government's problem in section 3 the following lower bound constraint:

$$\phi_j^{Postdivision} \geq \phi_j^{Predivision}. \tag{29}$$

This constraint will allow us to compare the constrained solution in the model with the constrained solution in the data. Finally, I assume that all other structural parameters remain unchanged. In this assumption, I follow Redding and Sturm (2008) that interpret the division of Germany as mainly a trade and labour shock. They provide strong evidence showing that other factors such trends in specialisation, the integration with the Western trade partners or the fear of further armed conflict were important but to a much lesser extent compared to the trade shock. Table B.2 in the Appendix summarises the calibrated and estimated values for all parameters.

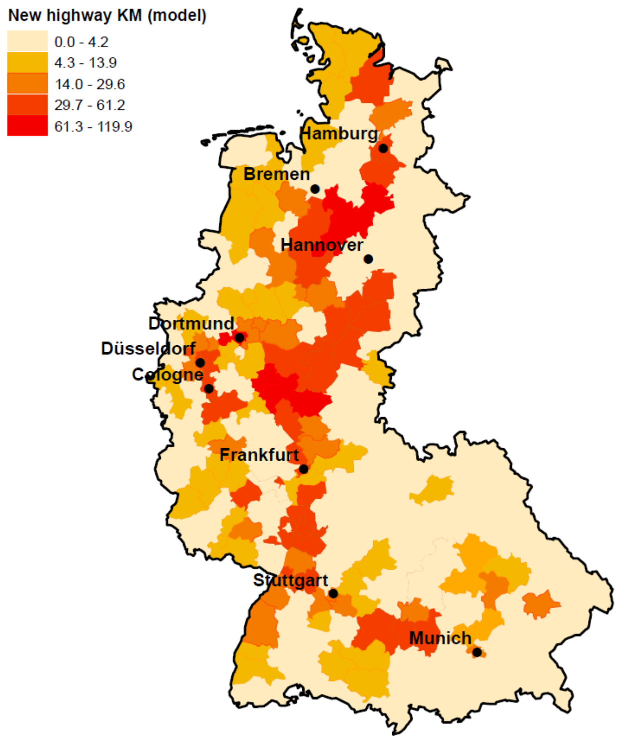
Optimal infrastructure after the division Figure 9 plots the spatial distribution of highway investments predicted by the model after the division of Germany. The shades represent the investment allocation predicted by the model, with darker shades representing higher investments. This optimal (constrained) network serves as a benchmark of the highway investments we would observe if the government's choice was driven by the change in economic fundamentals. The additional predicted investments, subtracting the built by highways (initial constraint), is the new highway construction.

As documented in section 2, about half of the new construction deviated from the original 1934 Highway plan. I compare the predictions of the model relative to the change in highways between 1950 and 1974 to show that the model can account for the time-variation of highways in the data.

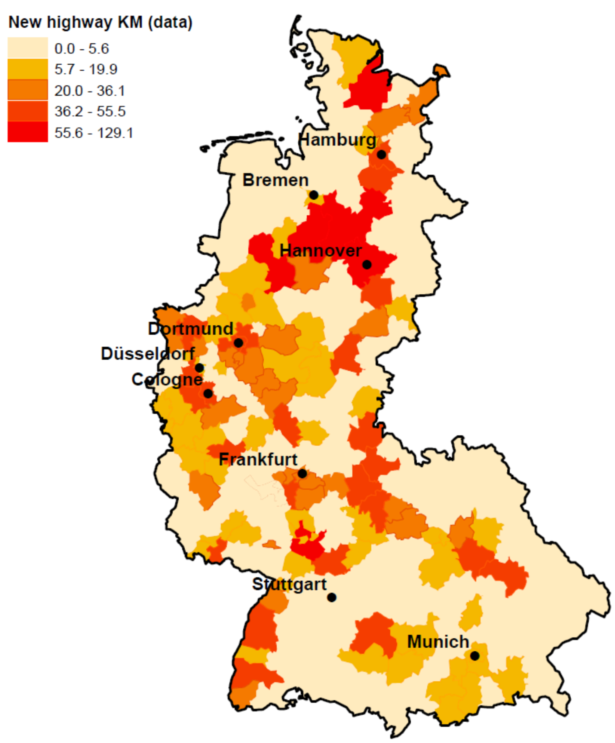
5.4 Explaining new highway construction

An empirical challenge that we face when analysing highway construction in the cross-section is that highway construction may be driven by district-specific factors affecting other fundamentals. For example, districts in the mountains have less population and trade less goods because of their remoteness and, at the same time, receive less highway construction because of the low demand or high construction cost. Thus, the elevation of the terrain creates a positive correlation between economic fundamentals and highway construction. These type of factors would induce a bias in the estimation of the predictive power of the model.

Figure 9: Simulated Infrastructure investments after division - Baseline



A) Model (Baseline)



B) Data (1974-1950)

Notes: The shading represents the change in highway kilometres by district (darker, more kilometres). The upper panel displays the changes predicted by the model while the lower panel displays the highway changes observed in the data (new highway construction between 1950 and 1974).

A good solution in the presence of time-invariant characteristics is to perform the using changes in the variable of interest. Therefore, to test the strength of the model in predicting the change in highway construction I use the change in highway investments. As a measure of highway change I will use $\Delta H_i = H_{i,1974} - H_{i,1950}$, the change in highway kilometres in district i between 1974 and 1950. The model counterpart of this empirical measure will be the $\Delta H_{OPT} = \Delta H_{Post}$, the district-level highway kilometres allocated after the division of Germany, from the remaining budget. This measure is the increase in highway construction on top of the already built highways that are included as a constraint for the government.

To test the predictive power of the model I run the following regression, at the district level:

$$\Delta H_{i,74-50} = \gamma_1 \Delta H_{OPT} + \nu_{i,t}, \tag{30}$$

where i denotes districts. The outcome measure, $\Delta H_{i,74-50}$ is the difference in highway kilometres in district i between 1974 and 1950. The main regressor ΔH_{OPT} is the allocation of the additional highway kilometres in the model, subtracting the initial investments realised by 1950. Because this is a first-differences specification I do not include district geographical characteristics or state fixed effects. This specification tests whether the predicted changes in highway investments in the quantitative model can explain the changes in highway construction observed in the data. Notice that the model-generated changes are purely driven by the simulation of the division shock, and therefore, only account for the economic factors affecting highway construction. The coefficient of interest is γ_1 that identifies the relation between the predicted changes and the observed highway reaction in the data. The results are reported in Table 5. The results with standard errors clustered at the Government region level are reported in table B.5 in the Appendix.

The estimated coefficients show that the model is also successful in explaining the changes in highway construction. We can think of these changes as the innovations implemented after the division shock. The predicted construction in the model explains 19% of the cross-district variation in highway changes (column 1) and has strong predictive power even controlling for distance to the border and the district's area. I find that an increase of one kilometre in the model after division predicts an increase of 0.41 kilometres in the data. This coefficient falls slightly when adding controls such as population in 1950 or distance to the border, but the coefficient stays positive and significant. In the last column I include allow for state-specific time-deviations (with state fixed effects) and the relationship between the model predictions and the observed changes remains positive and very significant.

The fact that the coefficient is far from unity, that we would expect if the model and the data were perfectly aligned, just tells us that the model predicts a stronger reaction to the division shock than the one observed in the data. This attenuated reaction could be driven by constraints or adjustment costs in the real world that are absent in the model. Furthermore, this estimated coefficient of 0.41 could be explained by the existence of other factors driving highway investments such as political interests.

Table 5: Change in highway construction

OUTCOME	Δ Kilometres (1974 – 1950) (1)	Δ Kilometres (1974 – 1950) (2)	Δ Kilometres (1974 – 1950) (3)
Optimal change in Kilometres	0.4101***	0.2307***	0.2350***
	(0.1106)	(0.0676)	(0.0719)
Log Pop 1950		3.9567**	3.7540*
		(1.7505)	(2.0213)
Distance to West Border		-0.0312***	-0.0326**
		(0.0109)	(0.0137)
Area (sqkm)		0.0037	0.0043*
		(0.0023)	(0.0024)
Elevation		-0.0038	-0.0078
		(0.0036)	(0.0064)
Plan 1934 km		0.3923***	0.3858***
		(0.0672)	(0.0701)
Constant	7.1523***	-43.1408**	-33.8805
	(1.2356)	(20.4614)	(26.9219)
State FE	No	No	Yes
Observations	258	257	257
R^2	0.188	0.441	0.447

Notes: Robust HAC standard errors, are in parentheses.* significant at 10%, ** significant at 5%, *** significant at 1%. Results for the 258 West German districts. The dependent variable is the change in highway kilometres between 1950, the end of the division and 1974. *Optimal change km* is the predicted increase in highway kilometres simulated in the quantitative model. highways built. Distance to West Border measures the distance from the district centroid to the German border with a western European country.

As we did before, I also measure the predictive power of the model looking at changes in the bilateral transport costs between all pairs of districts. I run a similar regression that correlates the change in ad-valorem transport cost between 1950 and 1974 with the model-implied change in ad-valorem transport cost under the assumption that the construction after 1950 follows the model solution:

$$\Delta T_{i,j}^{74-50} = \beta_1 \Delta T_{i,j}^{OPT-50} + v_{i,j}, \tag{31}$$

where $\Delta T_{i,j}^{74-50}$ is the change in bilateral transport costs between years 1950 and 1974, between districts i and j, and $\Delta \mathrm{T}_{i,j}^{OPT-50}$ is the change in bilateral transport costs between 1950 and 1974, assuming that construction in 1974 is equal to the model's prediction. Table B.6 in the Appendix, displays the results. The model does a very good job at predicting the change in transport costs during this period, explaining 97% of the change in transport costs. Most importantly, the model outperforms the 1934 prewar plan, that explains 92% of the variation. These estimates suggests that the model is able to anticipate which districts became relatively better connected after the division.

5.5 Discussion of results

Threats to Identification Given the estimation strategy presented above, the main concern that should be addressed to identify the explanatory power of the model are changes in other factors, in addition to geography, happening right after the division of Germany and affecting the returns to highway construction unevenly across the West German geography. Factors affecting all West German regions simultaneously such as the re-construction of cities after the Second World War or the decline in the importance of the railway as the main mode of transport for freight should not bias the estimates presented in the previous subsection. As long as the effect is constant across all regions, these changes create a level effect that would be differenced out in the proposed estimation strategy.

However, changes affecting West German regions in an uneven way could bias the estimation of the predictive power of the model. One of such factors is the process of European integration during which tariffs to international trade were eliminated between Belgium, Italy, Luxembourg, Netherlands and West Germany. This process started with creation of the European Economic Community in 1957 with the Treaty of Rome. To account for this, I extend the model to allow for international trade with other West European countries and solve for the optimal highway construction with both domestic and international trade. The details about the introduction of international trade in the calibration of the model can be found in section D of the Appendix. Figure A.7 in the Appendix plots the optimal change in highway construction as predicted by the model with international trade (above panel) and the observed change in highway construction between 1950 and 1974 in the data (lower panel).

The results from the model extended with international trade are reported in Table B.7, counterpart of table 5. The optimal highway investment in the model still has good predictive power for the actual change in highway construction but it predicts a smaller share of the variation in the data than the model without international trade (the R-squared of column 1 is 13.9% in the extended model compared to 18.8% in the baseline model). One explanation for why the model with international trade seems to be further away from the data could be that in the first years of the european integration process international trade was not so large in magnitude as a share of domestic activity. In the year 1982, around 85% of all tonnes-kilometres shipped in West Germany by road were domestic shipments while only 15% were cross-border (international) shipments. However, the political intention to integrate with other West European countries may explain a part of the shift of highway investments towards the Western border of Germany, even if the international trade magnitudes increased very gradually.

Additional factors that we could consider are changes in the industrial composition of West Germany or the shift of the capital from Berlin to Bonn. Extending the model to account for industrial policy or for the benefits of a change in the capital city goes beyond the scope of this paper. However, the interplay between infrastructure policy, industrial policy and the institutional setting is a promising avenue for future research. For example, Bai and Jia (2018) show how the loss and gain of regional capital status in China was accompanied by upgrades in the transport network. This change in status resultes in a gain or loss of centrality of a given city in the transport network, creating a link between the political and the economic status of the city.

Finally, part of the 1974 followed the 1934 prewar plan. As documented in section 2, while the first two thousand kilometres of highway built before the division followed the prewar plan, only half of the highways built after division were constructed following the plan. Further work could be devoted to understand why the West German government completed part of the 1934 design, rather than fully optimising the network. In the next session I quantify the economic impact of highway investments in two quantitative exercises. First I examine the gains from the partial reaction of the government to the shock, comparing the welfare level for the observed highway network with the counterfactual of building the highway plan as it was designed in 1934. Second, I quantify the cost of the constraint imposed by the initial two-thousand kilometres built before the division.

6 QUANTITATIVE EXERCISES: ECONOMIC IMPACT OF HIGHWAYS

In this section, I quantify the aggregate gains of reshaping the infrastructure network. I use the structural model to evaluate the welfare gains from different policy-relevant counterfactuals.

The first question we seek to answer is whether the choice of highways affected the economic gains from infrastructure investments. Can governments improve welfare substantially by placing infrastructure in a sensible way (taking into account the economic geography of the country) or is infrastructure beneficial for the reduction of transport costs it generates, leading to large gains even across different spatial allocations? To understand this I take a data-driven approach: I quantify the gains in welfare accomplished by the considerable reshaping of the highway network that took place during the first decades of the division (as documented in the previous section).

The second question I examine is whether the past infrastructure choices persistently affects economic variables, due to the existence of path-dependence. Infrastructure projects are long-lived and, therefore, unexpected changes in the economic geography of a country may reduce the value of the infrastructure network if it becomes obsolete. The construction of the first part of the 1934 Highway plan and the subsequent division of Germany is an extreme, but clear, example. In these cases, we would like to know how large are the costs of path-dependence from past infrastructure construction and how costly is it to overcome these loses.I use the structural model to solve for the optimal unconstrained highway network for West Germany, without taking into account construction before the division. I quantify the cost of path-dependence by comparing the optimal constrained highways, predicted by the model, with the alternative solution of the optimal unconstrained highway network. Both these exercises can help us understand how important is the decision on where to place infrastructure investments and the different trade-offs that may appear.

6.1 THE GAINS FROM RESHAPING INFRASTRUCTURE

To understand how important is the placement of infrastructure I compare the observed highway network in 1974 with the 1934 highway plan that can serve as counterfactual of a suboptimal network. Comparing the actual highway network in 1974 with the 1934 Plan has two advantages: First, the counterfactual comes directly from the data, from the digitised historical map. Second, both networks are of the same length, in terms of highway kilometres. Differences in aggregate measures come purely from the reallocation of construction across districts. I use the model as a measuring tool to compute welfare gains from the construction of the 1934 Highway Plan as well as of the 1974 highway network. Details about the construction of the model counterpart 1934 and

1974 network can be found in section D in the Appendix.

I take as baseline the 1934 Highway Plan that is the highway network that would have been built if the economic fundamentals in Germany had remained constant after 1949. In compare the gains of building the observed 1974 network in two cases, the baseline model with no international trade and the extended model that allows for trade with Western European countries. The results are reported in Panel A and B of Table 6.

The government's reshaping of 1600 kilometres increased welfare by 1.07% relative to building the 1934 Highway Plan with no adjustments. The gains in terms of real income were of 0.65% compared to the level under the construction of the 1934 Highway Plan. Panel A shows that the gains in Welfare and income are driven by a reduction in the Price level and lower average Transport costs. It is important to notice that these gains are annual increases in aggregate outcomes, that West German would enjoy every year. Furthermore these gains come purely from the reallocation of the highway network keeping the budget fixed. The gains from the observed reshaping of infrastructure are even larger if we consider the potential trade flows with European neighbours, with the gains increasing to 1.86% in terms of Welfare and 2.02% in terms of income. How much better could the government have performed? According to Panel B, investing on infrastructure as predicted by the model would have increase Welfare by 7.5% and real income by 5.659%. The gains from reshaping

Table 6: Effect of reshaping the highway network

	Compared to Initial 1934 Highway Plan
Panel A: Highways 1974 - baseline	% Change
Welfare	**+1.07**
Real Income	+0.65
Panel B: Highways 1974 - int. trade	% Change
Welfare	**+1.86**
Real Income	+2.02
Effects on trade - baseline	
Openness (Intra-district trade)	**+ 14**
Effects on inequality	
Inequality (Variance of real GDP across regions)	- 7

infrastructure can also be found when looking at other indicators such as trade openness by district and inequality.

6.2 The cost of path-dependence

Finally, this set-up allows me to quantify the aggregate cost of path-dependence. The construction of the German highway network started in the 1930s when the division could not be imagined. In this additional exercise I compare the welfare level of the optimal constrained network, that includes the 2000 initial highway kilometres, with the unconstrained network. Table 7 reports the Welfare and real income gains from building the constrained and the unconstrained network, taking the 1974 highways as reference. The difference between Panel A and Panel B tells us about the cost of path-dependence. My counterfactual exercise suggests that the construction of 2000 kilometres before the division of German had a cost of 1.6% of the 1974 Welfare level and of 1.675% in terms of 1974 real income. The cost comes from the sunk nature of the initial 2000 highway kilometres. However, it is important to notice that these quantification is relevant for West Germany and does not take into account the re-unification of Germany in 1989.

Table 7: The cost of path-dependence

	Compared to observed Highways in 1974
Panel A: Constrained optimal network	
Welfare	**7.512**
Real Income	5.659
Panel B: Unconstrained optimal network	
Welfare	**9.119**
Real Income	7.344

6.3 Discussion of results

Finally, let us put in perspective the different welfare and real income gains associated with the different counterfactual networks. The quantifications so far were considering the aggregate gains of different highway network allocations of the same length. As we could see, there are considerable gains from different infrastructure investment patterns.

What are the aggregate economic gains of infrastructure construction? Taking as baseline the 1974 highway network, I find that eliminating all highways would cause Welfare to fall by 13.8% and real GDP by 8%. As we mentioned before, if we change the 1974 Highway network by the 1934 Highway Plan, Welfare to fall by 1% and real GDP by 0.65%, thus by about 10% of the total gains from building the 1974 highway network. This shows that the government's response to the division increased the gains from highway construction by a large magnitude. However, the gains could have been larger, going from the 1974 highways to the Optimal constrained network would increase welfare by 12.2% and real GDP by 8%. Figure A.8 and A.9 in the Appendix plots the level of aggregate gains for all the counterfactual networks for the before division period, upper panel, and for the post division period, lower panel.

The magnitudes found in this quantification depend on the calibration of the parameters of the model. The last exercise I do is to put bounds on the reshaping gains by looking at different values of two very important parameters: the trade elasticity σ and the returns to highway investments γ[46]. Table 8 summarises the results. As we can see, the estimates reported below may fall or increase slightly but it seems clear that there are positive welfare gains from reshaping infrastructure and negative costs of path-dependence, since the intervals are far away from zero.

Table 8: Welfare Gains: Bounds

Welfare Gains	Min	Max	Bounds for $\gamma = \{0.5, 1\}$ σ=7	Bounds for $\sigma = \{6, 8.5\}$ γ=0.84
Reshaping highways	0.68	1.44	(0.84, 1.11)	(0.81, 1.32)
Path dependence	0.69	1.62	(0.97, 1.52)	(1.31, 1.60)

7 Conclusion

Understanding how the placement of infrastructure affects the economic gains from infrastructure investments is essential for policy-makers to take informed decisions. However, the endogeneity between infrastructure investments and economic outcomes is an important challenge to common empirical and quantitative methods. The reduced-form approach of exploiting exogenous variation in infrastructure construction is appealing to estimate local effects but cannot be employed to

[46]For σ I consider the extremes of the confidence interval estimated when calibrating the trade elasticity using trade flows. For γ I consider 0.5 and 1, following Fajgelbaum and Schaal (2018)

quantify the aggregate effects of infrastructure projects.

In this paper I take a structural approach to this problem by building a quantitative spatial trade framework with endogenous infrastructure investments. In the model, a government decides how to allocate investments across regions to maximise aggregate welfare. This framework allows me to characterise the optimal infrastructure network, calibrate the model using historical data and estimate the key structural parameter, the returns to highway investments, taking into account the endogeneity of infrastructure.

I use the calibrated model to study the economic impact of highway construction in the context of the division of Germany. The division of Germany provides an ideal set-up to test the ability of the model to predict highway construction after the division and to estimate the gains from reshaping the network in response to the shock. Using newly digitised data, I document that half of the highway kilometres built after the division, between 1950 and 1974, deviated from the initial prewar Highway Plan. I find that the reallocation of these investments (one third of the network) led to increases of 1.08% of welfare and 0.64% of real income annually, keeping the budget fixed. In the extended model with international trade, the gains are even larger: the new 1974 highway network increased welfare by 1.8% and real income by 2%. Finally, I measure the cost of path-dependence and show that reshaping the full network could have increased welfare by 1.62% and real income by 1.5%.

The magnitude of these reshaping gains is large relative to current estimates in the literature. For example Asturias et al. (2014) find gains of 2.7% of real income from the construction of the Indian highway network of almost six thousand kilometres and Fajgelbaum and Schaal (2017) find welfare gains of between 0.9% and 1.5% from reshaping the totality of nowadays Germany's highway network.

There are two main differences between my paper and other studies. First, I examine the gains from reacting to a change in economic fundamentals. My findings suggest that the economic impact of infrastructure is larger in this case than when evaluating the impact of infrastructure investments in the presence of stable economic fundamentals. Second, my results are estimated from the construction of the initial part of the highway network. It is likely that returns to investments decrease as infrastructure is accumulated. However, these differences make my results particularly relevant for countries that are going through structural reforms or large policy changes and for countries building the first stages of the infrastructure network. Making use of a quantitative framework like the one developed in this paper can help governments quantify the expected gains across different investment allocations.

There are several related questions that need to be addressed in relation with infrastructure choice more generally. First, what other factors shape the investment decisions of governments? The importance of political factors can be estimated with a framework of endogenous infrastructure that includes economic fundamentals and political incentives. Second, how does the optimal network decision change with the introduction of additional mechanisms such as intermediate input usage, heterogeneous agents or international trade? Finally, what is the optimal infrastructure policy to address different spatial settings such as fast-urbanising countries or deeply integrated free-trade areas? Expanding this framework in the mentioned directions is left for future research.

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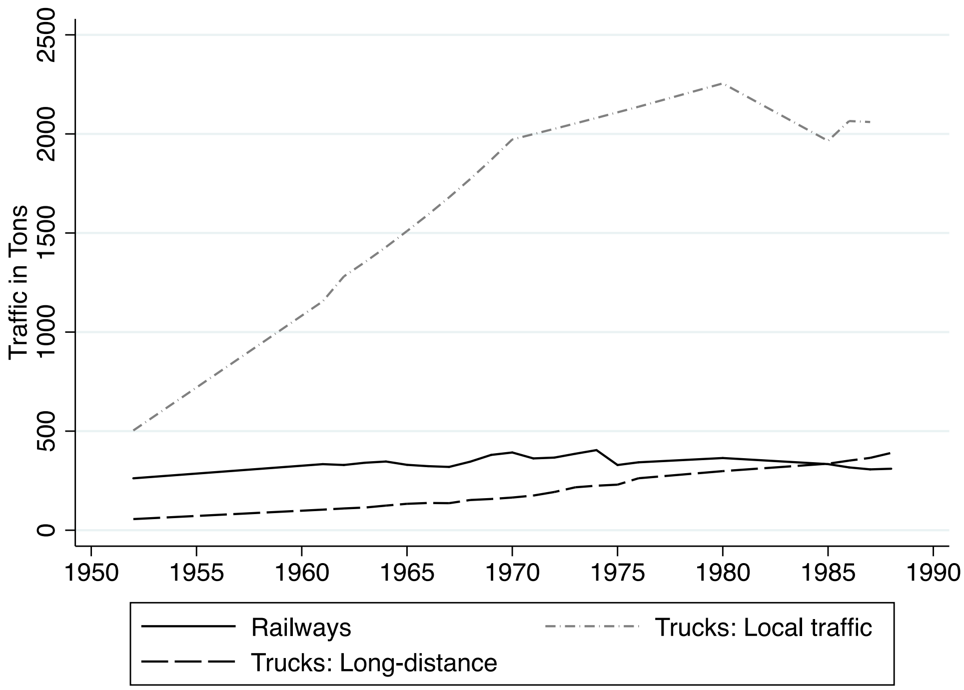
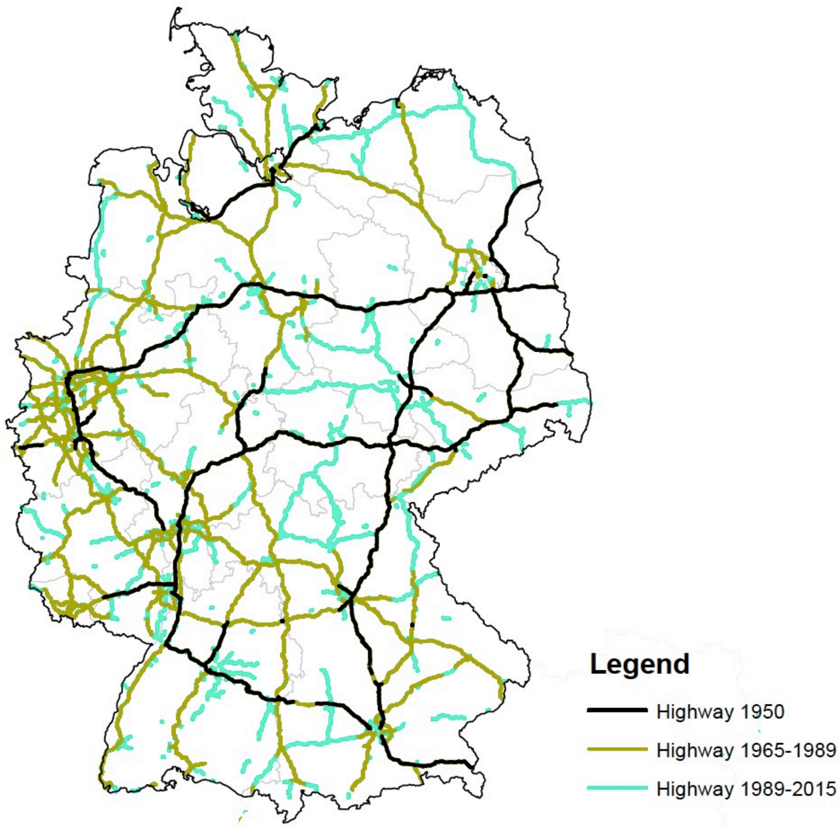
A Additional Figures

Figure A.1: Goods traffic by transport mode



Note: Values are for West Germany, collected by author from Statistical Yearbook of the Bundesrepublik, multple years. Values for missing years are interpolated.

Figure A.2: Evolution of the German highway network



Notes: German highway data collected from Michelin Atlases of the years 1950, 1964, 1975, 1980 and 1989 digitised by the author.

Figure A.3: Construction and Planning of the Highway Network

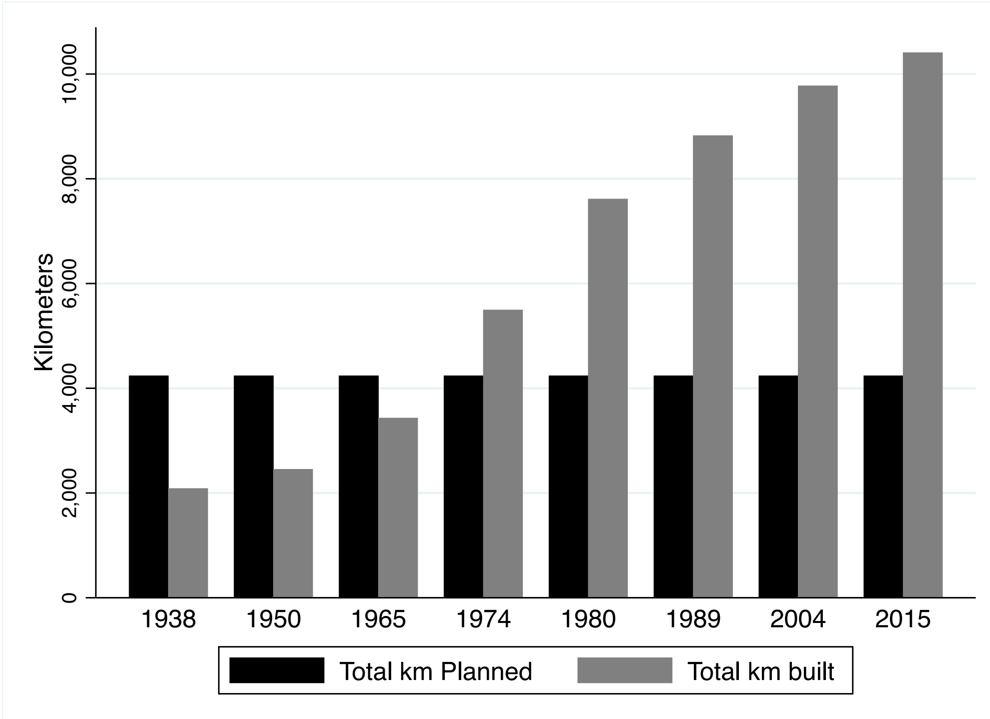
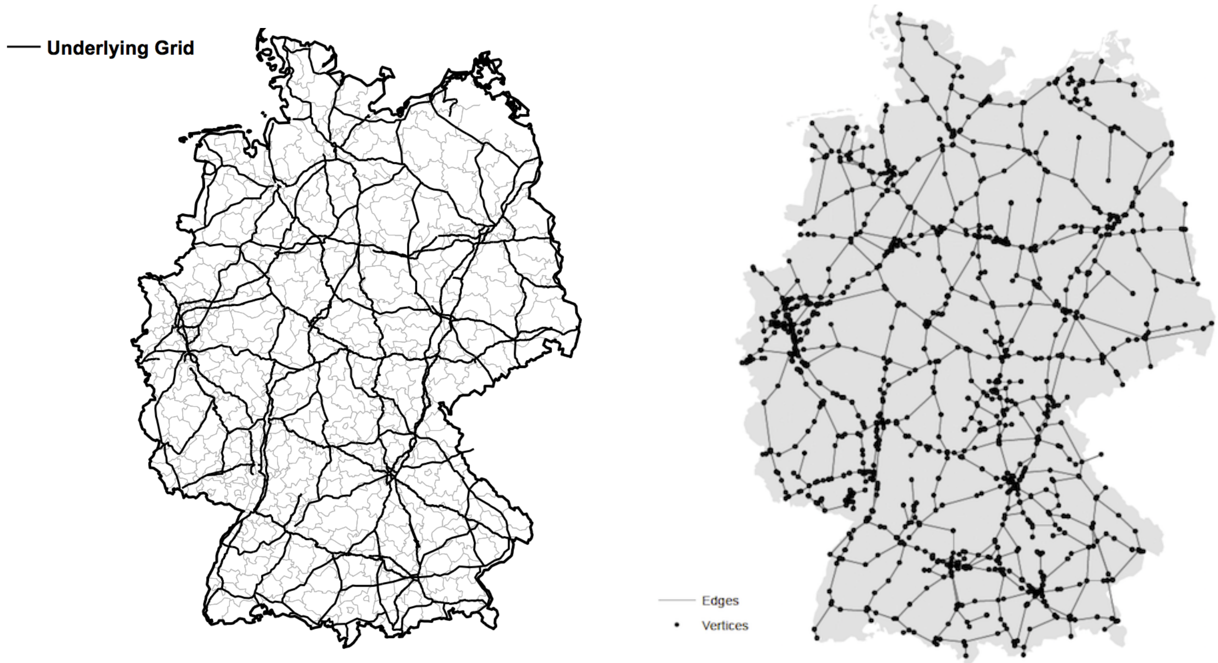


Figure A.4: Representative transport network and corresponding graph

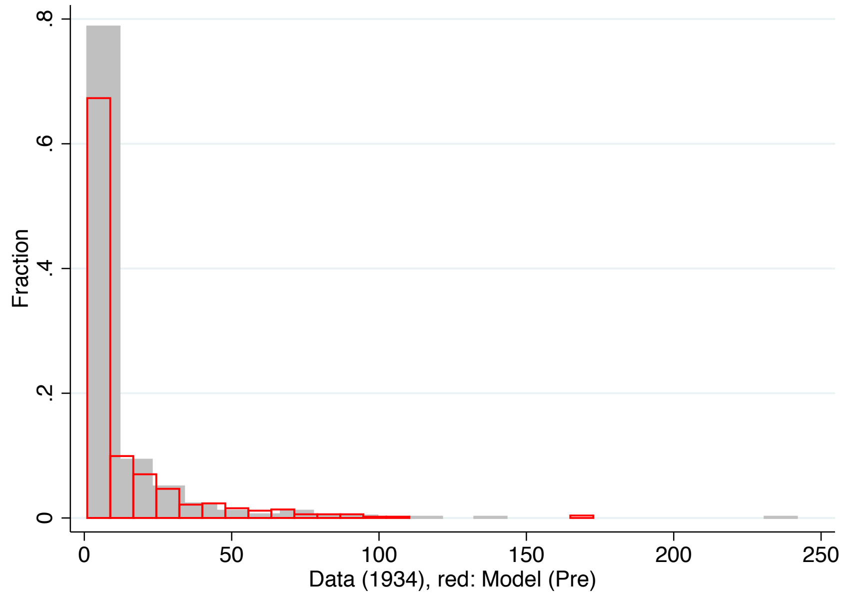


A) Chosen network

B) Graph

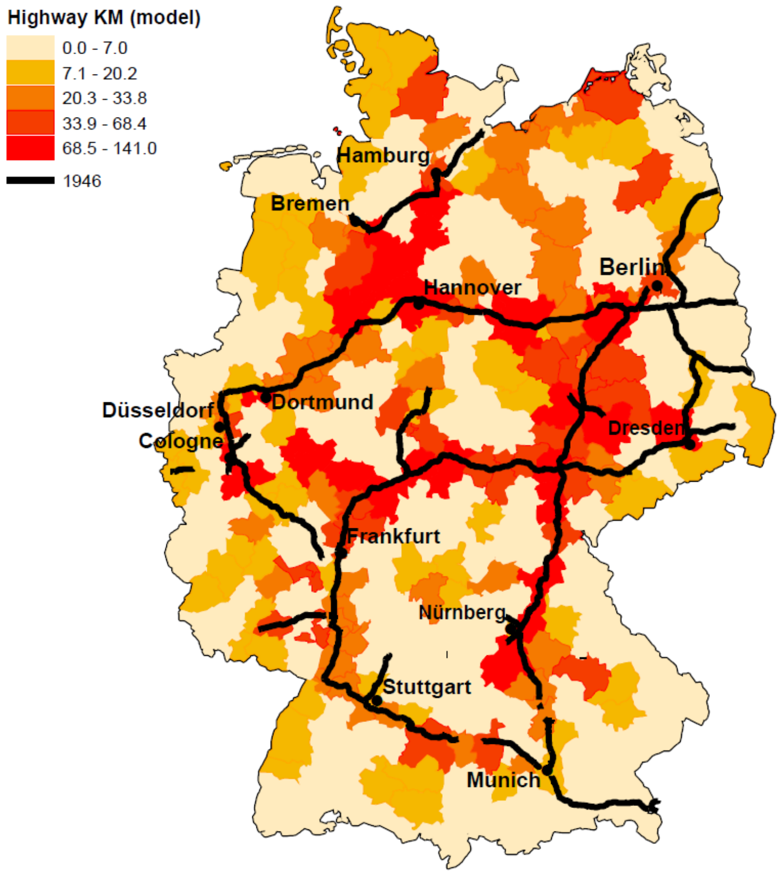
Notes: Panel A shows the roads that I choose to build the grid. This network connects all districts while the number of links remains small. Highways are the darkest lines, federal highways are the intermediate lines, and local roads are the thinnest lines. Panel B shows the discretisation of the network in panel A. Each dot represents a vertex, and each line represents an edge of the network.

Figure A.5: Share of investments by district: model vs data



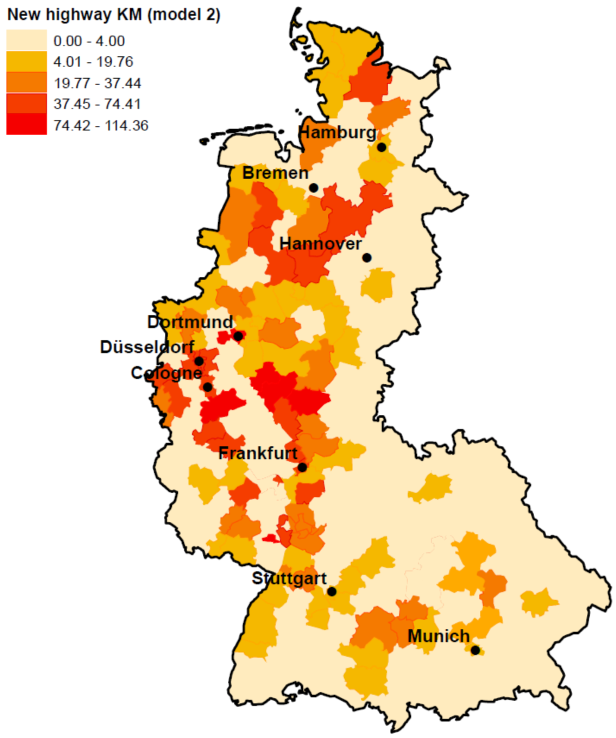
[47]: The figure plots the share of investment in each district of the total budget (model) and of the total length of the prewar Plan (1934 plan). The model is depicted in red, while the data from the plan is depicted in grey.

Figure A.6: Simulated Infrastructure before the Division shock - Timing of Construction

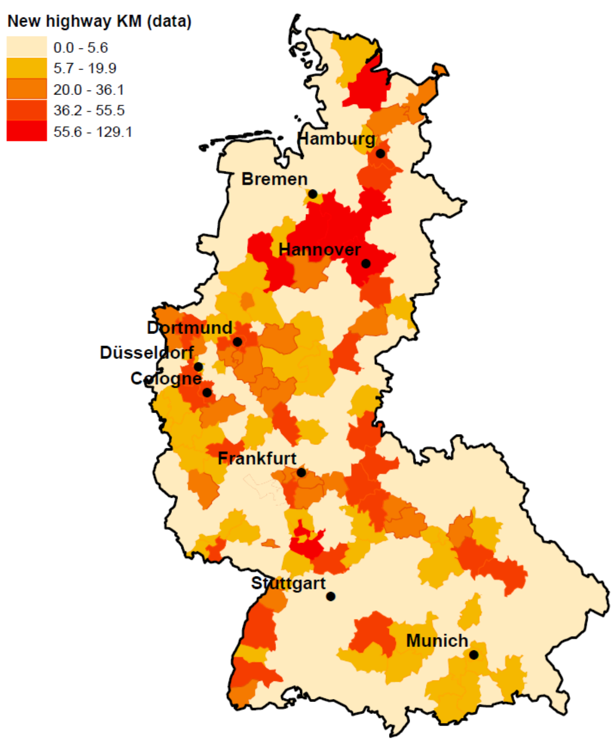


Notes: The shading represents the investment allocation by district, in terms of kilometres. The model predicts the optimal allocation of the investment budget to each district, as a share of the budget. I convert the share of investment into highway kilometres by assuming that the total number of kilometres built in the model is the same as in the 1934 Highway plan. The black lines represent the highways that had been built by 1946.

Figure A.7: Simulated Infrastructure investments after Division - International trade



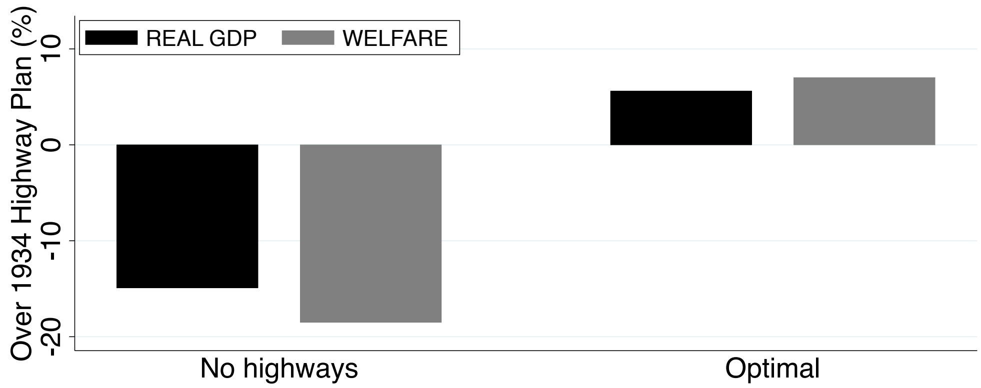
A) Model (International trade)



B) Data (1974-1950)

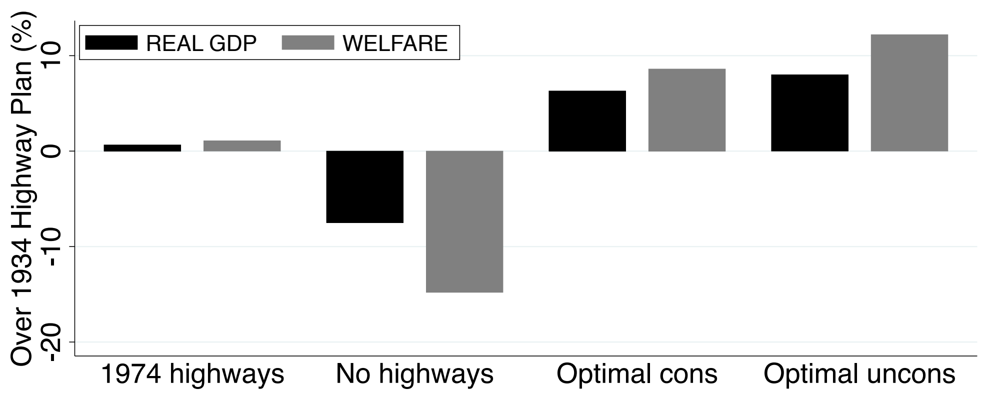
Notes: The shading represents the change in investment allocation by district. The upper panel displays the changes predicted by the model while the lower panel represents the highway changes observed in the data (new highway construction between 1950 and 1974). Darker shades indicate higher highway construction.

Figure A.8: Gains from Infrastructure Investments



Before Division

Figure A.9: Gains from Infrastructure Investments



After Division

B Additional Tables

Table B.1: Elasticity of trade flows to distance

Outcome: Log (Road shipments in tons)	(1)	(2)
	DATA 1938	MODEL ($\sigma = 7$)
Log(Distance)	-2.8674***	-2.7808***
	(0.2381)	(0.3762)
Constant	28.7349***	35.9057***
	(1.4651)	(2.3151)
Observations	13	13
R^2	0.929	0.832

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

Notes: Standard errors, are in parentheses. Regression run using total tons shipped by truck by manufacturing firms over 13 distance brackets (from less than 50km to more than 1000km). Model regression using simulated trade data given parameter values and infrastructure in 1938 aggregated over the same distance brackets

Table B.2: Choice of Parameters

Parameter	Description	Source/Target	Value
From Literature			
ε	Shape parameter of Fréchet	Monte et al. (2015)	3
α	Share of tradables	Redding, Sturm (2008)	0.7
1938 Germany			
$\{A_i\}$	Productivity parameter	Match population 1938	
$\{H_i\}$	Land supply	Area in sqkm	
σ	Elasticity of substitution	Trade elasticity 1938	7
Infrastructure			
γ	Returns to highway investments	Concentration in 1934 Plan	0.84
Z	Budget of Government	Average km in Plan	1.5*regions
c	Marginal cost	-	1
Division Shock			
$B_{i,j}$	Cost of Border East Ger.-West Ger.	Prohibitive trade costs	∞

Notes: Further details about the calibration and estimation of the parameters can be found in section 4 in the main text and in section D of this Appendix.

Table B.3: 1934 Highway Plan : Cross-sectional variation

OUTCOME:	Highway km Plan	Highway km Plan	Highway km Plan
	(1)	(2)	(3)
Optimal highway km	0.4496***	0.3213***	0.3285***
	(0.0675)	(0.0566)	(0.0583)
Pop 1938		3.8656**	4.6497*
		(1.6137)	(2.3317)
Distance to the Border		0.0576**	0.0578**
		(0.0244)	(0.0241)
Elevation		-0.0033	-0.0169
		(0.0080)	(0.0104)
Area (sqkm)		0.0115***	0.0117***
		(0.0027)	(0.0021)
Constant	10.2302***	-48.3552**	-44.0867
	(1.7620)	(20.3512)	(34.0212)
State FE	No	No	Yes
Observations	331	323	323
R^2	0.265	0.381	0.451
Mean Highway km	20		
SD Highway km	24		

Notes: Standard errors clustered at Government Region level, are in parentheses.* significant at 10%, ** significant at 5%, *** significant at 1%. Results for the 331 German districts. The dependent variable is the number of highway kilometres in the 1934 Plan for each district. *Optimal highway km* is the highway kilometres predicted by the quantitative model. Distance to West Border measures the distance from the district centroid to the German border with a western European country.

Table B.4: 1934 Highway Plan : Change in Transport Costs

OUTCOME	Transport cost 1934 Plan (1)	Transport cost 1934 Plan (2)	Transport cost (1934 Plan) (3)	Δ TC (Plan-1938) (4)
1938 Transport costs	0.5272***		0.2954***	
	(0.0012)		(0.0022)	
Optimal Transport costs		2.2899***	1.1600***	
		(0.0052)	(0.0097)	
Δ TC Optimal				0.6016***
				(0.0014)
Constant	0.2592***	-1.4559***	-0.7011***	-0.2166***
	(0.0032)	(0.0071)	(0.0085)	(0.0019)
Observations	77246	77246	77246	77246
R^2	0.724	0.713	0.767	0.716
Mean dep. var	1.62			
SD dep. var	0.512			

Notes: Standard errors, are in parentheses.* significant at 10%, ** significant at 5%, *** significant at 1%. . Results for the 395 German districts aggregated at the micro-region level. The dependent variable is the level of bilateral Transport costs under the counterfactual construction of the 1934 Highway Plan or the change in bilateral transport costs between 1938 and the construction of the 1834 Plan. $OptimalTransportCosts$ is the ad-valorem transport cost computed under the optimal investment predicted by the model. $1938TransportCosts$ measures ad-valorem transport costs under the 1938 network. $\Delta TCOptimal$ is the difference between Optimal and 1938 transport costs.

Table B.5: Change in highway construction: Highway kilometres

	Δ Kilometres (1974 – 1950) (1)	Δ Kilometres (1974 – 1950) (2)	Δ Kilometres (1974 – 1950) (3)
Optimal change in Kilometres	0.4101***	0.3628***	0.3295***
	(0.1180)	(0.0896)	(0.1019)
Distance to West Border		-0.0184	-0.0196
		(0.0132)	(0.0199)
Area (sqkm)		0.0087***	0.0096***
		(0.0028)	(0.0028)
Constant	7.1523***	1.4961	
	(1.7108)	(3.7236)	
State FE	No	No	Yes
Observations	258	258	258
R^2	0.188	0.243	0.475

Notes: Standard errors clustered at Government Region level, are in parentheses.* significant at 10%, ** significant at 5%, *** significant at 1%. Results for the 258 West German districts. The dependent variable is the change in highway kilometres between 1950, the end of the Division and 1974. *Optimal change km* is the predicted increase in highway kilometres simulated in the quantitative model. highways built. Distance to West Border measures the distance from the district centroid to the German border with a western European country.

Table B.6: Change in Highway construction: Transport Costs

OUTCOME	Transport cost 1974 (1)	Transport cost 1974 (2)	Δ TC (1974-1950)	Δ TC (1974-1950)
Δ Transport Cost Model	0.7368***			
	(0.0004)			
Δ Transport Cost 1934 Plan		0.9768***		
		(0.0009)		
Constant	-0.0384***	-0.0746***		
	(0.0006)	(0.0010)		
Observations	96721	96721		
R^2	0.970	0.923		
Mean dep. var	1.75			
SD dep. var	0.45			

Notes: Standard errors, are in parentheses.* significant at 10%, ** significant at 5%, *** significant at 1%. . Results for the 312 West German districts aggregated at the micro-region level. The dependent variable is the change in bilateral ad-valorem transport cost between 1950 and 1974. $TransportCostsOptimal$ is the ad-valorem transport cost computed under the optimal investment predicted by the model. $TransportCosts1950$ measures ad-valorem transport costs under the 1950 network and $TransportCosts1934$ under the (counterfactual) construction of the 1934 Highway Plan. $\Delta TCOptimal$ is the difference between Optimal and 1950 transport costs while $\Delta TCPlan$ is the difference between Transport costs in the 1934 Plan and 1950.

Table B.7: Change in highway construction: Model with International Trade

OUTCOME	Δ Kilometres (1974 – 1950) (1)	Δ Kilometres (1974 – 1950) (2)	Δ Kilometres (1974 – 1950) (3)
Optimal change in km	0.3352***	0.2026***	0.2065***
	(0.0875)	(0.0551)	(0.0595)
Log Pop 1950		4.6325***	4.3295**
		(1.7236)	(1.9214)
Distance to West Border		-0.0263**	-0.0266**
		(0.0112)	(0.0135)
Area (sqkm)		0.0038	0.0043
		(0.0026)	(0.0026)
Elevation		-0.0022	-0.0053
		(0.0037)	(0.0064)
Plan 1934 km		0.4118***	0.4077***
		(0.0707)	(0.0743)
Constant	7.9858***	-52.3630***	-39.9075
	(1.0721)	(20.1133)	(25.8030)
State FE	No	No	Yes
Observations	258	257	257
R^2	0.139	0.436	0.442

Notes: Robust HAC standard errors, are in parentheses.* significant at 10%, ** significant at 5%, *** significant at 1%. Results for the 258 West German districts. The dependent variable is the change in highway kilometres between 1950, the end of the Division and 1974. *Optimal change km* is the predicted increase in highway kilometres simulated in the quantitative model. highways built. Distance to West Border measures the distance from the district centroid to the German border with a western European country.

C Theoretical Appendix

C.1 A model of trade with endogenous infrastructure investments: No housing

In this section I describe in detail the model presented in section 3. The model features costly trade across many domestic districts, $i = 1...N$, endowed with an exogenous productivity, A_i. There is a measure L of workers that move across districts according to their own heterogenous preferences. This model builds on the family of widely used quantitative spatial models reviewed by Redding and Rossi-Hansberg (2017) and is specially close to Redding (2016). The main contribution of my theoretical framework is to embed the spatial equilibrium framework in the decision of a Government whose goal is to choose the optimal infrastructure investments to maximise aggregate welfare. The consumption, production and location decisions of consumers and workers are standard. The model, however, features a realistic geography where transport costs are determined as the solution to the problem of shipping across a grid of districts at the minimum cost.

Preferences The preferences of each worker are given by two components. First, a heterogenous preference taste (b), that represents how much a given worker values a given location (Redding (2016)). Second, a consumption component (C) that can be represented by a canonical CES demand system, with every agent choosing the level of consumption of each of the varieties available with a constant elasticity of substitution across varieties of σ. Specifically, the utility function of an agent ω living in district n is given by:

$$U_n = b_n(\omega)\left(\frac{C_n}{\alpha}\right) \tag{32}$$

where $C_n = \left[\sum_j^N \sum_\nu^M c_{jn}(\nu)^{\frac{\sigma-1}{\sigma}}\right]^{\frac{\sigma}{(\sigma-1)}}$, is the consumption basket chosen by workers living in district n, $c_{jn}(\nu)$ is the consumption of a worker that lives in district n of variety ν produced in district j[48]. M is the number of available varieties in the economy. The price index associated with the tradable varieties aggregator C_n is $P_n = \left[\sum_j^N \sum_\nu^M p_{jn}(\nu)^{1-\sigma}\right]^{\frac{1}{(1-\sigma)}}$, where $p_{jn}(\nu)$ is the price in district n of variety ν produced in district j. The taste component $b_n(\omega)$ is an idiosyncratic taste preference. Each worker draws a vector of N realisations $\{b_n(\omega)\}_{n=1...N}$ from a Frechet distribution that governs the individual preferences for each district:

$$G_n(b) = [Pr(b_n(\omega) \leq b)] = e^{-b^{-\epsilon}} \tag{33}$$

where ϵ is the shape parameter governing the dispersion of tastes across workers for each location. A large ϵ implies a low dispersion (low standard deviation). Less dispersion means that the idiosyncratic preferences are more equal across districts for all workers. In this case a small difference across districts will trigger big movements in population. In the limit, $\epsilon \rightarrow$ all workers behave identically. They become indifferent between locations and the model collapses to the *perfectly mobile labour* case because all districts are perceived as equally desirable and tiny changes

[48]Notice that workers living in n face the same consumption prices and earn the same wage so they make the same consumption choices

in wages trigger large population reallocations. When $\epsilon \to 1$, highest dispersion, workers are very heterogeneous in their taste. This means that large differences in district-level outcomes are needed to make workers move from their preferred choices. In this type of models the labour supply in a district is upward slopping in the wage.

To keep the number of parameters of the model low and due to data limitations I abstract from consumption of housing in the model. The existence of heterogenous preferences will act as a dispersion force through wages and, under certain parameter values, the existence of the equilibrium will be unique and stable.

Production Production uses labour as only factor of production, happens within firms and takes the form of monopolistic competition. There is a fixed cost to pay to start production, F, but once a firm enters the market it will produce a differentiated variety. The existence of the fixed cost and free entry ensures that each variety will only be produced by one firm. This means that each district will produce a specific and unique set of varieties that will equal the sum of varieties produced by the firms in that district. All varieties are produced with the same technology that is district-specific, A_i. From the firm's profit maximisation we know that a firm producing a variety v in location i will set a price $p_i = \mu \frac{w_i}{A_i}$ where μ is the mark-up charged over the price $\mu = \frac{\sigma}{\sigma - 1}$. Notice that the price is constant across varieties produced in the same district. As we can see, each agent in the economy is endowed with one unit of labor that is supplied inelastically to produce A_i units of the district-specific varieties. I assume there is only one sector in the whole economy. The existence of free entry in each location drives down profits to zero and will pin-down the size of a firm in each district:

$$q_i^F(v) = \frac{F * A_i}{(\mu - 1)} = A_i(\sigma - 1)F \tag{34}$$

As we can see more productive districts will have larger firms because they will be able to cover the fixed cost more easily. Given the scale of each firm and the local labour supply, the labour market clearing condition pins down the number of varieties (equal the number of firms) in each district:

$$M_i = \frac{L_i}{\sigma F} \tag{35}$$

Again, we see that larger districts will produce a larger number of varieties. Therefore, the productivity of a district determines the scale of its firms and the size of a district determines the number of varieties locally produced. Finally, we can re-write the optimal price index of tradables P_i in terms of the local price and the number of varieties produced in each district, taking into account that all varieties in a given location have the same price and substituting the number of varieties in each district:

$$P_n = \frac{1}{\sigma F}\left[\sum_{j}^{N} L_j p_{jn}^{1-\sigma}\right]^{\frac{1}{(1-\sigma)}} \tag{36}$$

The price index in a district will depend on the local prices of imported varieties with larger regions exporting a larger share and therefore having a higher weight on the price index.

Location and Consumption choices Given the specification of preferences, we can write the indirect utility function of worker ω in district n as

$$v_n(\omega) = \frac{b_n(\omega) w_n}{P_n} \tag{37}$$

Since indirect utility is a monotonic function of the idiosyncratic preference draw, it has a Frechet distribution too:

$$G_n(u) = Pr[U_n \leq u] = e^{-\Psi_n u^{\epsilon}} \tag{38}$$

where $\Psi_n = (\frac{v_n}{P_n})^{\epsilon}$. $G_n(u)$ is the distribution of indirect utility realisations in district n.

Each worker chooses the location that maximises her indirect utility. Using the properties of the Frechet distribution we find that the probability that a worker chooses to live in district n:

$$\pi_n = Pr[U_n \geq max\{U_s; s \neq n\}] = \int_0^1 \underbrace{\prod_{s \neq n}[1 - G_n(U)]}_{Pr(U_s<u), s\neq i} \underbrace{dG_n(U)}_{\text{cdf } U_n} = \frac{(\frac{w_n}{P_n})^{\epsilon}}{\sum_k (\frac{w_k}{P_k})^{\epsilon}} \tag{39}$$

The fraction of workers that choose to live in district n coincides with the probability that any given worker chooses n:

$$L_n = \frac{(\frac{w_n}{P_n})^{\epsilon}}{\sum_{k=1}^{N}(w_k/(P_k))^{\epsilon}} L \tag{40}$$

As we can see ϵ is the elasticity of the labour share in any district to changes in real income income in that district w_n/P_n. Workers are more likely to choose districts with a relatively high real income.

Consumption is determined by the CES preference structure over varieties. The demand for variety v produced in district i and consumed in district n is:

$$x_{i,n}(v) = \frac{p_{i,n}^{1-\sigma}}{P_n^{1-\sigma}} w_n L_n \tag{41}$$

where $P_n = \frac{1}{\sigma F}(\sum_k L_k p_{k,n}^{1-\sigma})^{1/(1-\sigma)}$ is the price index of consumption goods in district n and $w_n L_n$ is the total expenditure in district n. Because each district produces a different set of varieties, the demand in district n for goods produced in district i (import share) will be:

$$X_{i,n} = \frac{L_i}{\sigma F} \frac{p_{i,n}^{1-\sigma}}{P_n^{1-\sigma}} w_n L_n \tag{42}$$

A district will import less goods from more expensive destinations (high p_i) and will import more goods from other districts, relative to domestic consumption, if it is more expensive (has a high Price index P_n). The above expression displays the Home market effect from the Krugman (1980) model: A larger district (high population) will produced a larger share of varieties and therefore export larger shares to other districts (notice that trade share X_{in} is increasing in L_n).

Finally, applying the same steps as before, we can compute the expected utility for each worker ex ante that is equal to the utility of the economy as a whole, ex post:

$$E(U) = \Gamma\left(\frac{\epsilon}{\epsilon - 1}\right)\left(\sum_{1}^{N}(w_n/(P_n))^{\epsilon}\right)^{1/\epsilon} \tag{43}$$

Geography The set of N districts can be thought of as located in a two-dimensional grid where each square represents a different district and we let the population be concentrated in the centre of the square. A more complex geography will be introduced in the calibration exercise. I define the size of district i, D_i, as the length of side of the square representing the region. We assume, as mentioned, that all the population is located in the centroid of the district and all the production happens there.

Given the dispersion of production and population across the grid, there are ad-valorem type of transport costs associated with the consumption of non-locally produced varieties. The price of variety i consumed in district n is given by:

$$p_{i,n} = p_i B_{i,n} T_{i,n}(D, \Phi) \tag{44}$$

The transport friction $T_{i,n}(D, \Phi)$ depends on two variables: $\{D\}$ and $\{\Phi\}$. The vector $\{D\}$ represents the size of each district in geographical terms while $\{\Phi\}$ represents the level of infrastructure in each district. Finally, the vector $\{B\}_{i,n}$ denotes the border friction between districts i and n that will be defined by:

$$B_{i,n} = \begin{cases} 1 & \text{if } i, n \text{ are within the same border} \\ > 1, & \text{if } i, n \text{ are separated by a border} \end{cases} \tag{45}$$

Transport Costs The transport cost that has to be paid to move a good produced in district i to be consumed in district n will be given by the minimum possible transport cost that can be realized when shipping between i and n. Therefore, the transport cost matrix will be the collection of the transport costs along the least cost path between each district pair. This set-up is similar to assuming the existence of some shadow transport sector that is driven by profit-maximization, and thus, ships goods at the minimum costs (see Fajgelbaum and Schaal (2017)). The transport cost minimization problem will consider both geography, D, that determines the distance that has to be covered in a given trip, and the quality of infrastructure, Φ, that will determine how costly (fast) can we cover this distance. While geographic distances are exogenous, infrastructure is *endogenous*, and can be upgraded to reduce transport frictions. A further simplifying assumption I make is that the quality of infrastructure is homogeneous within a district[49]. These two variables, distance and infrastructure quality, define the cost of shipping some good across district i as follows:

$$\text{Cost of transiting}^i = \frac{D_i}{\phi_i^{\gamma}} \tag{46}$$

where I use ϕ_i to denote the district-level infrastructure and Φ to denote the vector of infrastructure allocations. I assume that $\phi_j \geq 1$, so that the transport cost cannot be larger than the geographical cost but will be always bounded above by the physical geography[50]. The elasticity of the ad-valorem transit cost to the infrastructure investments is denoted by γ, that is model-specific and I assume it to be $\in (0, 1)$. This restriction ensures that there are decreasing returns to infrastructure and that the marginal benefit of infrastructure investments is concave.

As we can see, a higher quality of infrastructure will reduce the size of a district in terms of the ad valorem cost that is incurred in the transit. The elasticity of the shipping cost across district i to a marginal change in the level of quality of infrastructure Φ_i is $-\gamma$. In the quantitative exercise $\{\Phi\}$ is the quality of the road (highway, state highway or local road) and will affect shipping cost because

[49]In the real world a district may have one very high quality highway and one very low quality road. Therefore, we may think of ϕ_i as the average quality of the infrastructure stock in district i. Fajgelbaum and Schaal (2017) adopt the decision of defining the quality of infrastructure for every link but this implies solving the optimal investment for every link rather than keeping the district as the unit of analysis

[50]This is a very reasonable assumption in the context of land-shipping because there is always some residual way to go from one region to another even in the absence of roads (i.e. across the fields)

of the different maximum speeds at which each road can be transited.

Optimal path matrix The solution to the least cost path problem to connect each district-pair will depend on distance, D, and the quality of infrastructure, Φ. For some given geography and a given level of infrastructure investment in each district this solution can be expressed using an optimal path matrix. This matrix indicates whether district i is a transit district for all the other district-pairs along their optimal cost path. It is similar to the *transition matrix* in the network literature as it indicates how to transition from one node of the network to any other. The element $\Pi^i_{o,d} \in \Pi^i$ indicates whether district i is relevant for the determination of the cost of shipping from district o to district d and is defined as:

$$\Pi^i_{o,d} = \begin{cases} 1, & \text{if } i \text{ is a transit district in } \textit{the path between o and d} \\ 0, & \text{if } i \text{ is not a transit district in } \textit{the path between o and d} \end{cases} \tag{47}$$

I can now define the transport cost $T_{o,d}$ between any two districts o and d as

$$T_{o,d} = \left[\sum_i \Pi^i_{o,d} \frac{D_i}{\phi_i^\gamma} \right] \tag{48}$$

where ϕ_i is the infrastructure level in district i and it reduces the travelling time across district i with an elasticity of $-\gamma$. This expression means that the cost of shipping a good from o to d will be the sum of the geographical distance scaled by the infrastructure quality of all the districts that have to be transited to reach destination d from origin o. Given that we have defined $\{ \Pi^i \}$ as the optimal path matrix this implies that we can also express the transport friction between o and d as $T_{o,d} = min_k(T(p^k_{o,p}))$ where $T(p^k_{o,p})$ is the transport cost of shipping a good from o to d along path k.

Finally, I adopt a normalisation common to all trade models by assuming $T_{i,i} = 1$, equivalent to assuming free intra-district trade and normalising the cost of trading out of the district by the internal shipping cost.

C.2 Spatial equilibrium

The spatial equilibrium is given by the clearing of the goods market at the equilibrium wages and the clearing of the labour market so that the expected utility for all workers is equalized. The goods market clearing implies that the income of each district has to equalise the total exports of that district (assuming trade is balanced):

$$w_i L_i = \sum_j \frac{L_i}{\sigma F} \left(\frac{\sigma}{\sigma - 1} \frac{w_i}{A_i} b_{i,j} T_{i,j} \right)^{1-\sigma} (P_j)^{\sigma-1} w_j L_j, \forall i \in N \tag{49}$$

where the Price index in each region will be:

$$P_i^{1-\sigma} = \sum_j \frac{L_j}{\sigma F} \left(\frac{\sigma}{\sigma - 1} \frac{w_j}{A_j} b_{j,i} T_{j,i} \right)^{1-\sigma}, \forall i \in N \tag{50}$$

The utility equalisation condition will hold when the labour share in each district n is given by:

$$\frac{L_n}{L} = \frac{(\frac{w_n}{P_n})^{\epsilon}}{\sum_{n=1}^{N} (w_n/(P_n))^{\epsilon}} \tag{51}$$

The labour market clearing implies that the sum of labour in each district will add up to the total number of workers: $\sum_n \frac{L_n}{L} = 1$. These conditions determine the equilibrium value of wages, labour shares and the equilibrium welfare given by expected utility E(U), equation 43. As shown in Allen and Arkolakis (2014) the condition for the existence and uniqueness of the spatial equilibrium will hold if the elasticity of expected utility to the labour share in a district is negative, this is, if the dispersion forces are stronger than the agglomeration forces of the model. Specifically, the condition for existence and uniqueness of the equilibrium with imperfect mobility of labour is

$$\sigma \left(1 - \frac{1}{1 + \frac{1}{\epsilon}} \right) > 1 \tag{52}$$

I calibrate the parameters so that the equilibrium is unique and stable.

D Quantification details

D.1 Quantification of the model before Division

Initial transport network We have 3 types of roads in Germany in 1938: Highways, Federal Highways and Local roads. To construct the initial transport grid I choose the smallest set of edges and vertices that allows me to represent the underlying geography of Germany to transport goods. First I select the set of vertices to represent the 412 German districts I observe in the data. I choose as the vertex of the district the centroid of the path of any highways that transits the district. If there is no highway in the district I use the centroid of the federal highway inside the district. If there are no highways or federal highways I use the centroid of the local road. Second I build the set of edges

Table D.1: Cost of time and distance of truck shipping (France, 1978)

	Highway (Autobahn)	Federal Highway	Local road
Speed (km per hour)	80	60	40
Cost of distance (Euros)	85.8	89.8	97.18
Cost of time (Euros)	5.4	5.4	5.4

that connects the vertices that represent the population centres. To do this I select all highways and federal highways that existed in 1938. I add the set of local roads needed to connect the remaining vertices that do not have highway access.[51]

Finally, I export the network to use in my quantitative analysis. The resulting network is composed of 1071 junctions (nodes), collected into 412 districts) and around 1200 edges (links) that can be exported as two vectors: one containing the links and one containing the cost of transiting each link (called weight in the networks literature).

Initial transport costs To compute the initial transport cost matrix I follow Combes and Lafourcade (2005) transport cost function. The function is derived to account for the cost of shipping one truck full of goods in France in the decade of 1978. The transport cost specification for shipping a truck between i and n is:

$$t_{i,n} = \text{Distance cost} \times \frac{\text{speed}_{i,n}}{\text{length}_{i,n}} + \text{Time cost} \times \frac{\text{speed}_{i,n}}{\text{length}_{i,n}}. \tag{53}$$

The table below represents the speed and costs assumed by Combes and Lafourcade (2005) that I use in the computation. I use this function to compute the cost of shipping one truck worth of goods for each link in the network using the length in kilometres along the underlying German network in 1938. I assume links with local roads can be transited at 40 kilometres per hour, link with federal highways at 60 kilometres per hour and links with autobahns at 80 kilometres per hour. Even if there was no speed limit in Germany for highways trucks can rarely go faster than 80 km/h. I use the Network Analyst toolbox in ArcGIS to construct the network that is then exported to MATLAB.

I compute cost of transit in each link using the above function and the actual kilometres. I use

[51] To select this edges I choose the least cost path to connect each of the 57 districts that are not transited by a highway or a federal road to the closest district with federal highway using the ”Closest facility Tool” in ArcGIS that allows you to extract the path chosen to connect facilities (federal highway points) to incidents (district centroids). Local roads are used as the default way to more around to prevent any transport costs to be zero. Instead of manually recovering the local road network in 1938 I use the 2004 digitised map of local roads and enabled a truck to move through these links at 40 km per hour.

the least-cost path algorithm to compute the matrix of initial transport costs in euros. To convert this measure to ad-valorem quantities I normalise the computed cost in euros by 28,000 euros that is the average cost of a truck full of German goods in the year 1995. This computation uses the average export price per ton from Germany to France. This normalisation ensures that the transport cost matrix expresses the cost of shipping one unit of the average German good across any district pair in ad-valorem terms.

D.2 Optimal infrastructure network

Estimation of parameter γ I estimate γ to match the skewness of investments in the 1934 highway plan. Skewness is a measure of the concentration of a distribution. Matching this moment ensures that the concentration of highway investments in the model is aligned with the data. I use the Simulated Method of Moments for the estimation. I simulate 100 times the optimal choice of infrastructure in a representative 50-district economy with 100 different random draws of the vector of district-specific productivities. I compute the skewness of these investments and estimate the value of γ that minimises the sum of squared differences between average skewness in the model and skewness in the data. Skewness in the data is 1.5. For the simulation I specify the productivity distribution as a Pareto distribution with shape parameter $\alpha_p = 1.6$, estimated from the calibrated productivity distribution for Germany, scale parameter $\sigma_p = 1$ and location parameter $\theta_p = 0$.This procedure yields an estimate of $\gamma = 0.84$.

D.3 Optimal infrastructure network with International Trade

To introduce international trade post-Division I consider trade with Belgium, France and Netherlands. I assume that trade with the rest of the world is only possible through the West German districts located in the border with these countries for which some highway had been designed in the prewar Highway Plan or for which some local road existed.

To model the new trading opportunities I choose to increase the population of the bordering regions with a share of the foreign population, so that access to these bordering regions allows a firm to sell products to the domestic population and to the foreign population as well. I assume that trade is possible with the whole population in the foreign countries but I compute a cost of trading with these foreign population equal to the average distance between the German border and the main foreign cities/capital city (for Belgium and Netherlands). I reduce the accessible population by a share to account for this distance cost. This simplifying assumption of considering trade opportunities as an increase in the size of regions at the border allows me to follow the same calibration strategy as before: I re-calibrate the productivity vector to match the new population distribution where the bordering regions have been allocated extra population coming from the foreign countries. The rest of the calibration procedure is the same as described previously.

D.4 Counterfactual exercises

Taking the highway network to the model To construct the model counterpart of the 1974 highway allocation I follow two steps. First, I compute the district share of highway kilometres. This is obtained by dividing the total highway kilometres in a district by the total highway kilometres built in 1974 in West Germany. Then, I multiply the highway share by the total budget allocated in the model to the Post-Division network, as follows:

$$\phi_i = 1 + share_{74} * (Z - 312), \tag{54}$$

where I subtract 312 from Z because that is the lower bound imposed by the requirement that highway investments cannot increase the transport costs and

$$share_{74} = \frac{\text{Highway km}_{i,1974}}{\sum_i^N \text{Highway km}_{i,1974}}. \tag{55}$$

In the same way, I build the counterpart of the 1934 plan as

$$\phi_i = 1 + share_{Plan} * (Z - 312), \tag{56}$$

E Data Appendix

Highway data The highway network data (Autobahns) collected for the empirical exercise is of two types. First, I digitise the highway network plan of 1934 from historical documents. From the digitised data I construct a district level measure of the number of kilometres that the 1934 highway plan allocated to each district. Besides, I collect data of the actual highway network (only Autobahn) in Germany (both East and West Germany) for the years 1938, 1950, 1965, 1974, 1980 and 1989. This information is obtained from different road atlases and historical maps and geo-referenced using the software ArcGIS. Once the maps and atlases are digitised I manually collect the data to construct the highway network in each period. Additionally, I collect and geo-reference the pattern of federal roads in 1950 and 1965. Federal roads (Bundesstrase) are decided by the central government but are not restricted-access roads like the Autobahns and the network was developed earlier than the highway network. Finally, the network of local roads is imported from the EuroGlobal map by *Eurographics* that provides harmonised European open geographical data covering 45 countries and territories in the European region and is freely available. The website address of Eurographics is https://eurogeographics.org.

Economic outcomes As economic outcomes, I use population data by decade at the district level from the historical census. I also collect employment level at the district level from the historical census, available for some aggregated sectors.

Additionally, I collect traffic of goods by road for 18 aggregated traffic districts in Germany. The traffic data is collected in tons and reported in an aggregated way (Total tons of goods sent to the rest of Germany and received from Germany). The traffic data is collected from the "Statistisches Jahrbuch fr das Deutsche Reich". I use data from the year 1938, the closest to the beginning of the construction of the highway network. The scanned photocopies of the annual editions of the "Statistisches Jahrbuch fr das Deutsche Reich" are available at http://www.digizeitschriften.de/dms/toc/?PID=PPN514401303.

Finally, I collect and digitise traffic of goods by road between West German states. This data is available only after 1960 (most recent data I found was 1966). The traffic data is collected in tons and reported in an aggregated way (Total tons of goods sent to each state and received from each state in West Germany). This traffic data is collected and digitised from the "West Germany Road freight transport 1945- Statistics Serials" (Der Fernverkehr mit Lastkraftfahrzeugen: Zusammengefasste bersichten zur Gterbewegung).

Geographic variables As controls, I collect a series of measures related to the geography of Germany such as area of districts and distance to relevant points such as the inner German border. First, I measure the distance from each district to the closest point of the inner German border, to the closest point to the external West German border and West Berlin. I calculate these distances from the centre of each district to the geographic feature of interest over a straight line. Furthermore, I compute the distance to West Berlin through the transport network in 1950. Finally, I collect the district area in square kilometres.