From Periphery to Core: Economic Adjustments to High Speed Rail

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Abstract: This paper presents evidence that high speed rail systems, by bringing economic agents closer together, sustainably promote economic activity within regions that enjoy an increase in accessibility. Our results on the one hand confirm expectations that have led to huge public investments into high speed rail all over the world. On the other hand, they confirm theoretical predictions arising from a consolidate body of (New) Economic Geography literature taking a positive, man-made and reproducible shock as a case in point. We argue that the economic geography framework can help to derive ex-ante predictions on the economic impact of transport projects. The subject case is the German high speed rail track connecting Cologne and Frankfurt, which, as we argue, provides exogenous variation in access to regions due to the construction of intermediate stations in the towns of Limburg and Montabaur.

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1 Introduction

"A major new high-speed rail line will generate many thousands of construction jobs over several years, as well as permanent jobs for rail employees and increased economic activity in the destinations these trains serve."

US President Barack Obama, Apr 16th, 2009

With the rise of New Economic Geography (NEG) the spatial dimension in economic thinking has celebrated an impressive comeback during the recent decades.[1] Not least, the Nobel Prize being awarded to Paul Krugman in 2008 highlights how widely the importance of a deeper understanding of regional economic disparities has been acknowledged among economists. One of the fundamental outcomes of NEG models is that accessibility to regional markets promotes regional economic development due to the interaction of agglomerations forces, economies of scales and transportation costs.

Recent empirical research confirms that there is a positive relationship between regions' centrality with respect to other regions and their economic wealth (e.g. HANSON, 2005) and that there is evidence for a causal importance of access to regional markets for the economic prosperity of regions (REDDING & STURM, 2008). From these findings, a direct economic policy dimension emerges. Centrality is not exogenous to economic policy but, of course, depends on transport infrastructure. Therefore, by (public) investment into infrastructure, accessibility as well as economic growth can be promoted.[2]

The expectation that transport innovations would lead to sustainable economic growth has long since motivated public investment into large-scale infrastructure investment. The US interstate highway and aviation programs certainly feature among the most prominent examples of the 20th century. In the 21st century, promoted by sustainability requirements and congestion of highways and skyways, which further suffer from terrorism threats and security costs, high speed rail (HSR) systems are increasingly attracting

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[1] In many aspects NEG is building on the work of the early period of economic geography (e.g. CHRISTALLER, 1933; LÖSCH, 1940) adding formal models and spatial dynamics. The history of spatial economic thinking dates back to at least VON THÜNEN (1826).

[2] Other political dimensions related to NEG include the prospects of temporary subsidies and regulations having a permanent impact on the welfare of immobile factors (e.g. REDDING, STURM, & WOLF, 2007).

the attention of transport planners and policy makers. Various countries all over the world now plan to develop their own HSR networks, following the examples of Japan and some European countries such as France, Germany, and Spain, which started to develop HSR in the second half of the 20th century.

In the US, the Acela Express along the Northeast Corridor is evidence for the rise in significance of HSR, although these trains only facilitate an average speed of 240 km/h (150mph), a velocity that is relatively modest compared to European and Japanese systems. This line, however, is only the first step toward the development of a true inter-city HSR network across the US. THE US DEPARTMENT OF TRANSPORTATION (2009), recently announced its strategic plan, which would include completely new rail lines that feature velocities of possibly up to 400km/h (250mph). The plan already identifies US$8 billion plus US$1 billion a year for five years in the federal budget just to jump-start the development of the system.

Besides the requirement of more energy efficient transport in order to reduce carbon dioxide emissions and oil dependency, the key argument in favor of HSR transport builds on the idea that a faster connection between cities and regions will promote economic development. This is in line with the general theme emerging from spatial economics research, which predicts that more intense spatial interactions between economic agents drive internal returns and human capital spillovers and ultimately productivity through agglomeration economies. Evidence, however, on whether these expectations are met by the reality of existing HSR systems is hardly available.

The objective of this study is to use the example of HSR to investigate the role of regional accessibility in the realm of economic policy, thereby bringing NEG and transport economic research closer together. REDDING & STURM (2008) show that the spatial distribution of economic activity reacts to a major exogenous shock - Germany's division following WWII - as predicted by theory. We focus on an empirical assessment of whether a significant adjustment in spatial economic patterns can be found for a relatively limited shock to accessibility, or whether the respective forces are dominated by path dependency in the existing spatial configuration.[3]

One of the empirical challenges in identifying the impact of HSR results from the fact that rail lines are usually endogenous to economic geography. The strongest economic agglomerations are connected (first) as they naturally generate the largest demand. In other words, given that it is likely that the areas connected by HSR are those that do or are expected to perform best, it is difficult to establish the counterfactual of what would have happened in the absence of an HSR line and to disentangle its effects from the natural growth path. Second, if the largest agglomerations are connected, the marginal impact on accessibility of an HSR line, due to large home-markets and competing transport modes, may be too small to trigger measurable effects.

Ideally, we therefore want to investigate the impact of HSR on peripheral areas that do not experience a particular economic dynamic. These cases, however, are very difficult to find as the connection of such areas would naturally run counter to economic and financial viability. We find such a "natural experiment" in the case of the new high speed rail track connecting the German cities of Frankfurt and Cologne. The line is part of the Trans-European Networks and facilitates train velocities of up to 300 km/h. In the course of this new track, travel time between both metropolises was reduced by more than 55% in comparison to the old track and by more than 35% in comparison to car travel. Most important, the small towns of Montabaur and Limburg became connected to the new line.

The connection of these towns, which, arguably, represented peripheral locations, was the outcome of long and complex negotiations among authorities at the federal, state and municipality level, the rail carrier "Deutsche Bahn" and various activists groups. The resulting track was finally considered the best compromise in light of cost, speed, environmental and network considerations on the one hand, and heavy lobbying pressures of the involved federal states to maximize the number of stations within their territories,

[3] See for the role of initial conditions and historical accident in shaping the pattern of economic activity ARTHUR (1994), BALDWIN & KRUGMAN (1989) and DAVID (1985), among others.

on the other. As a consequence, Cologne and Frankfurt can now be reached within about a 40-minute train ride, making the location central with respect to two of the major regional economic agglomerations with a total population of approx. 15 million.

Altogether, our natural experiment offers the joint advantage of providing exogenous variation in access to markets, which facilitates the isolation of treatment effects from correlated effects, and being man-made and reproducible and, thus, of direct policy relevance. Since the new track is exclusively used for passenger service it is further possible to disentangle effects from increased labor mobility and human capital and information spillovers from the physical transport cost of tradable goods.

Our results highlight the potential of HSR to promote economic growth and are supportive for economic geography theories more generally. We argue that as a straightforward application arising from these findings, an economic geography framework can potentially be employed in order to simulate the effects of major transport projects as a basis for decision making.

2 Background

2.1 Transport Policy and Agglomeration Economies

There is, no doubt, a well-developed body of theoretical NEG literature explaining why economic activity tends to concentrate in regional agglomerations.[4] Increasingly, the respective ideas have been subject to empirical investigation. At least three major strands in empirical economic geography research are to be distinguished (HANSON, 2005). The first focuses on the location of production and exports, which according to KRUGMAN (1980) should concentrate in the close to large markets (DAVIS & WEINSTEIN, 1999, 2003; HANSON & CHONG, 2004; HEAD & RIES, 2001). Technology diffusion and the impact on trade and industry location, accordingly, represent the second backbone of empirical geography research (EATON & KORTUM, 1999, 2002). Finally, the role of access to regional markets as a determinant for economic wealth receives increasing attention.

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[4] See e.g. NEARY (2001), OTTAVIANO (2003) and OTTAVIANO & PUGA (1998) for an introduction to the literature.

Important contributions include REDDING & VENABLES (2004), HEAD & MAYER (2004) and HANSON (1996, 1997, 2005). HANSON (2005) examines the spatial correlation of wages and consumer purchasing power across US counties from 1970 to 1990. Using a HARRIS (1954) type nominal wage equation as well as an augmented version based on KRUGMAN (1991), he finds strong demand linkages between regions that are, as he notes, relatively localized. Significant correlations between nominal wage levels and market potential are also found for Europe, e.g. ROOS (2001), BRAKMAN, GARRETSEN, & SCHRAMM (2000, 2004a) for Germany, MION (2004) for Italy, NIEBUHR (2006) for West Europe and AHLFELDT & FEDDERSEN (2008) for a broader European study area. A common limitation of these studies is that, by focusing on cross-sectional variation in wage and income, results hardly allow for a causal inference on the effects of regional accessibility on regional economic development.

REDDING & STURM (2008) address this point by exploiting Germany's division and reunification as a source of exogenous variation in market access. They show that the adverse economic performance of West-German border regions during the period of division can entirely be explained by an unexpected loss of market access. Moreover, the estimated pattern of impact resembles the theoretical prediction derived from a simulation based on the HELPMAN (1998) model.

The economic policy dimension arising from these findings is immediately apparent given that regional accessibility is essentially shaped by transport infrastructure. From the empirical side a growing body of literature indicates that increasing accessibility due to improved transport infrastructure may have significant effects on urban and regional economic development (e.g. AHLFELDT, in press-a; AHLFELDT & WENDLAND, 2009; BOWES & IHLANFELDT, 2001; CHANDRA & THOMPSON, 2000; GATZLAFF & SMITH, 1993; GIBBONS & MACHIN, 2005; MCMILLEN & MCDONALD, 2004; MICHAELS, 2008). One of the few exceptions is AHLFELDT (in press-b) who, investigating the change in the mainline infrastructure in post-unification Berlin, does not find a significant accessibility impact on commercial and residential property prices.

It is worth regarding the potential contribution of a regional economic policy by means of transport infrastructure investment in the realm of the existing theories and evidence on city growth (see e.g. BOSKER *et al.*, 2008; DAVIS & WEINSTEIN, 2002).[5] The literature suggests that even large temporary shocks such as the allied strategic bombing during WWII on Japanese (DAVIS & WEINSTEIN, 2002) and German (BRAKMAN, GARRETSEN, & SCHRAMM, 2004b) cities as well as major natural disasters such as earthquakes (IMAIZUMI, ITO, & OKAZAKI, 2008) do not alter the regional distribution of economic activity permanently. These results are disappointing with regard to the prospects of temporary economic policies, e.g. subsidies, having a sustainable impact on regional economic development since the spatial configuration of economic activity seems to be strongly determined by processes of path dependency at best, if not location fundamentals. While (public) investment into the improvement of transport infrastructure also has a temporary character, the resulting increase in accessibility is permanent and, hence, more likely to have a sustainable impact by altering regions' quasi-fundamental location characteristics.

This paper extends the line of research opened by REDDING & STURM (2008) by analyzing a localized shock to regional accessibility arising from the inauguration of a high speed rail line connecting the German cities Frankfurt (Main) and Cologne. Given an overall well-developed transportation network, we investigate whether a) there are considerable economic effects to be expected according to a theoretical NEG framework and b) the predictions are confirmed by reality. The project under investigation offers a number of interesting features which will be discussed in more detail in the next section. First, we analyze a positive shock to the existing spatial equilibrium where much of the related work has focused on negative shocks such as loss of market access (REDDING & STURM, 2008; REDDING, STURM, & WOLF, 2007) or war destruction (BRAKMAN, GARRETSEN, & SCHRAMM, 2004b; DAVIS & WEINSTEIN, 2003). Second, the project is small enough to fall within the scope of what can still be considered a medium-scale project,

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5 Two basic views emerge in the literature. The first stresses an optimal (relative) city size that is persistent to shocks in the long-run due to location specific productivity and fundamental geography. The second allows for increasing returns, e.g. productivity increasing with city size. Temporary shocks, if strong enough to disrupt path dependency, may hence have a permanent effect on spatial economic pattern.

thereby facilitating a broader applicability of our conclusions. Last and most important, the path of the new rail line was mainly determined with respect to travel time between the core cities, taking into account primary geography, while the intermediate stops Montabaur and Limburg resulted from a complex political bargaining process among federal states. The improved connectivity along these stations therefore provides a source of variation in accessibility that is exogenous to the economic development in the area.

2.2 The Cologne–Frankfurt HSR Line and the Case of Montabaur and Limburg

The high speed rail (HSR) line from Cologne (KK) to Frankfurt/Main (FF) is part of the priority axis Paris-Brussels-Cologne-Amsterdam-London (PBKAL), which is one of fourteen projects of the Trans-European Transport Network (TEN-T) as endorsed by the European Commission in 1994. In comparison with the old track alongside the river Rhine the new HRS connects the Rhine/Ruhr area (including Cologne) and the Rhine/Main area (including Frankfurt) almost directly, reducing track length from 222 km to 177 km.[6] The new track is designed for passenger transport only and allows train velocities up to 300 km/h. Due to both facts, travel time between the two main stations was reduced from 2h13 to 59min (BRUX, 2002). The construction of the rail track started in December 1995 and was finished by the end of 2001. After a test period the HRS line was put into operation in 2002. Total costs of the project were 6 billion Euros (EUROPEAN COMMISSION, 2005, p. 17).

The broader areas of Rhine-Ruhr and Rhine-Main have long been considered the largest German economic agglomerations. The rail lines connecting the two centers along both Rhine riverbanks were among the European rail corridors with the heaviest usage. They represented a traditional bottleneck since the early 1970s, when usage already exceeded capacity. The first plans for constructing an HRS line between Cologne and Frankfurt, consequently, date back to as far as the early 1970s. Since then, it took more than 30 years until the opening. A reason for the long time period was the complex evolution

[6] The straight line distance between Cologne Main Station and Frankfurt Main Station is 152 km.

process of infrastructure projects in Germany. Several variants at the left-hand and right-hand side of the Rhine were discussed during the decades of negotiations. Taking into account the difficult geography of the Central German Uplands, it was ultimately decided to construct a right-hand side connection that would largely follow the highway A3 in an attempt to minimize construction and environmental cost as well as travel time between the major centers. These benefits came at the expense of leaving relatively large cities like Koblenz and the state capitals Wiesbaden (Hesse) and Mainz (Rhineland Palatinate) aside.

Due to the federal system of the Federal Republic of Germany the states (*Länder*) have a strong influence on infrastructure projects that affect their territories (SARTORI, 2008, pp. 3-8). Three federal states were concerned with the subject project: North Rhine-Westphalia, Rhineland-Palatine, and Hesse. While Cologne lies in North Rhine-Westphalia and Frankfurt is located in Hesse, no stop was initially planned within the state of Rhineland-Palatine when the plans for the HSR track reached maturity. During a long lobbying process menacing a blockade of the planning and political decision process, the three federal states negotiated three intermediate stops along the HSR line, one in each of the concerned federal states. While Bonn/Siegburg and Limburg represented the shares of North-Rhine Westphalia, a new station in Montabaur ensured the connection of Rhine-Land Palatinate. It was also meant to ensure the connection of the hinterland of the state via an existing regional line.

These stops have been very controversial in terms, not least with regard to their economic viability. The cities of Montabaur and Limburg only exhibit approx. 12,500 and 34,000 habitants. Furthermore, the distance between these two small cities is just about 20 km and the high speed ICE train only needs 9 minutes between both stops, which is in contrast to the concept of high velocity travelling that has its comparative advantages at much larger distances.

3 Theoretical Framework

The discussion of how and why economic densities emerge has for a long time been dominated by the idea of two different forms of agglomeration economies. First, so-called *first nature geography* may be responsible for individuals' and firms' initial location decisions (BERLIANT & KONISHI, 2000; ELLISON & GLAESER, 1999; KIM, 1995, 1999).[7] Typical comparative advantages provided by certain locations include natural ports or navigable rivers, etc. Second, via intense interactions between producers at the same location, *urbanization* and *localization economies* eventually arise and generate additional benefits derived from so-called *second nature geography* (BERLIANT, PENG, & WANG, 2002; FUJITA & OGAWA, 1982; HENDERSON, 1974, 1977, 1988; JACOBS, 1969). An important factor for productivity gains derived from spatial proximity to other firms consists of knowledge spillovers due to formal and informal communication (IBRAHIM, FALLAH, & REILLY, 2009; MARIOTTI, PISCITELLO, & ELIA, 2010). Other benefits of locating in or close to dense economic agglomerations include access to intermediate goods, customers, and labor force, including an improved matching.

Recent NEG models have provided a formal framework to analyze some of these complex mutual interactions amongst regions. One established example is the multi-region extension of the model of HELPMAN (1998) developed by REDDING & STURM (2008, pp. 1771-1773).[8] This model determines the distribution of population or economic activity across regions from a tradeoff of agglomeration and dispersion forces. Thereby, agglomeration is caused by a combination of increasing returns, economies of scale, consumers' love of variety, and transport costs. Dispersion, on the other side, is modeled through a "congestion effect", where an increase in population raises the price of a non-traded amenity. The equilibrium population distribution balances these different forces. Any exogenous change in transport costs will lead to a new equilibrium.

According to the model, the economy is populated by a mass of representative consumers, L, who and are endowed with a single unit of labor which is supplied inelastically with zero disutility. Further, each consumer receives a location-specific nominal wage w_c. A fixed number of regions $c \in \{1,\ldots,C\}$ exist and there is full labor mobility between those regions.

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7 For a comprehensive overview of the nature of agglomeration economies see (ROSENTHAL & STRANGE, 2004)

8 For a more detailed exposition of the multi-region model, see the according Technical Appendix available at http://www.aeaweb.org/aer/data/dec08/20050315_app.pdf. A brief summary of the model can be found in Ploeckl (2010, pp. 6-8).

The production sector turns out a range of horizontally differentiated and tradable manufacturing goods, whereas labor is the sole factor of production. The differentiation of the tradable varieties takes the Dixit-Stiglitz form, i.e. there is a constant elasticity of substitution $\sigma > 1$ between varieties. The production process of each variety is characterized by a fixed cost, *F*, and a constant marginal cost, both in terms of labor. The tradable varieties are produced under monopolistic competition and are associated with iceberg transport costs. That is, $T_{ic} > 1$ units of a variety must be shipped from region *i* in order for one unit to arrive at location *c*.

Further, each region is endowed with an exogenous stock of a non-tradable amenity, H_c, which is supplied perfectly inelastically.

$$FMA_c \equiv \sum_i (w_i L_i)(P_i^M)^{\sigma-1}(T_{ci})^{1-\sigma} \tag{1}$$

$$CMA_c \equiv \sum_i n_i (p_i T_{ci})^{1-\sigma} \tag{2}$$

According to REDDING & STURM (2008, p. 1772), a labor mobility condition can be derived which links the equilibrium population of a city (L_c) to the two above defined endogenous measures of market access (FMA_c, CMA_c) and the exogenous local stock of the non-traded amenity:

$$L_c = \chi (FMA_c)^{\frac{\mu}{\sigma(1-\mu)}} (CMA_c)^{\frac{\mu}{(1-\mu)(\sigma-1)}} (H_c), \tag{3}$$

where χ is a function of the common real wage and model parameters.[9]

Taking logs on both sides of equation (3) yield:

$$\ln L_c = \ln \chi + \frac{\mu}{\sigma(1-\mu)} \ln FMA_c + \frac{\mu}{(1-\mu)(\sigma-1)} \ln CMA_c + \ln H_c \tag{4}$$

Assuming everything else is constant, the combined market access can be defined as a function of transport costs:

$$\ln MA_c(T_{ci}) \equiv \frac{\mu}{\sigma(1-\mu)} \ln FMA_c + \frac{\mu}{(1-\mu)(\sigma-1)} \ln CMA_c \tag{5}$$

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

Concluding the model implications, a positive shock to transport costs due to the new HRS line will shift market access and economic activity and trigger migration due to wage differentials until labor market clearing is achieved.

It should be noted, of course, that HSR in general and in our subject case in particular, are used for passenger transport only and does not lead to a reduction in the shipping costs of goods in a narrow sense. However, it could be argued that "selling" goods not only requires shipping goods from one place to another, but also establishing businesses and customer relations. These involve personal contacts and interactions and will be essentially promoted by a reduction in the cost of passenger transport and, thus, HSR. It is important to note that many of the existing studies that have attempted to estimate the spatial scope of regional economic integration in reference to the abovementioned NEG models find distance decays that are much larger than what would be in line with the physical (ice-berg) cost of goods transport (e.g. HANSON, 2005; MION, 2004; NIEBUHR, 2006). Similarly, REDDING & STURM (2008) find adverse effects of a loss of hinterland due to the German division to be concentrated within about 75 km of the former inner-German boundary. These localized effects point to the dominance of personal relations in business interactions. Anyway, in an empirical setting, a market potential indicator will capture the effects of urbanization economies in a broader sense. These will include productivity gains emerging from various forms of knowledge spillovers, which have been modeled as a function of market potential theoretically (FUJITA & OGAWA, 1982) and empirically AHLFELDT & WENDLAND (2010).

As with all transport infrastructures, however, the HSR line leads into two directions. There is, therefore, the possibility of a different causality that, in principle, could lead to a similar outcome in the long run. The new HSR effectively reduced commuting costs, at least if expressed in the opportunity cost of travel time. Following standard urban economics models, the equal utility constraint implies that a decrease in commuting costs will attract new residents to these locations with relatively low housing and living costs and high environmental quality. An increase in the resident population, in turn, increases the local labor access and consumer market and eventually could attract new businesses.

While in both cases the long-run implication are similar, there would be distinct trajectory paths to the new equilibrium, which can be identified from the data. If, in the first instance, a change in market access triggers a shift in productivity and labor market clearing occurs via costly migration, we would expect significant shifts in GDP and/or employment in the short run, and a more gradual adjustment in population. If the opposite was true, instead, population adjustments would dominate in the short run. Moreover, we would expect a significant increase in the share of out-commuters (relative to in-commuters). Last, if the market access hypothesis is true and the causality runs primary via an increase in productivity and a shift in economic activity, we would, at least temporarily, observe a significant increase in GDP per capita. Previewing our results, this is exactly what we find.

4 Data

Data were collected from several sources. We obtain NUTS3 level data from 1992 to 2006 on population, GPD and employment from EUROSTAT for a broad set of 1,335 European regions. Land value data is provided from the German Committee of Valuation Experts (Gutachterausschuss für Grundstückswerte) at the level of German counties (Kreise und kreisfreie Städte). In order to maximize the precision of our treatment variable, we model the change in market access due to the new HSR at the level of more than 3,000 municipalities within the core study area consisting of the German federal states of Hesse, North Rhine-Westphalia and Rhineland-Palatinate. Municipality level population is obtained from The Federal Office for Building and Regional Planning while data on in- and out-commuting, employment at residence and human capital indicators come from the Federal Employment Agency.

Car travel times refer to geographic centroids of municipalities and are approximated based on plain distance measures generated in GIS and an assumed average velocity of 75 km/h.Train times refer to the fastest train connection between the respective cities on December 8, 2008 (Monday) between 12 noon and 6 pm and were taken from the official website of the German rail carrier “Deutsche Bahn”. Note that for the city of Wiesbaden, which lies at a feeder line inaugurated with the new track, we found no improvements in connectivity to any city along the new track compared to road travel time so we omit the city and don’t discuss any effect for this city explicitly.

5 The Accessibility Shock

Before economic adjustments to the change in transport geography can be estimated, the effective impact on accessibility needs to be identified. There is a long tradition in New Economic Geography to represent access to regional markets as the distance weighted sum of population or *GDP*, which dates back to at least HARRIS (1954).

$$MA_{ht} = \sum_g GDP_{gt} \exp(-\alpha \times tt_{hgt}) \tag{6}$$

where MA_{ht} is market access for a given municipality h at time t, tt_{ght} stands for the travel time from municipality h to location g. Assuming a standard exponential cost function, the cost parameter α determines the weight of *GDP* of region g in the market potential. We note that travel time-based potentiality variables have recently been found to represent appropriate means to capture complex accessibility pattern in account of transport infrastructure (AHLFELDT, in press-a).

We interpret this basic indicator of economic geography as a broad indicator of centrality, encompassing the benefits of producer and consumer market access as well as various (knowledge) spillovers that drive productivity. An accessibility shock x_h that results from a transport innovation at time $t+1$ can be described by a change in the travel time matrix tt.

$$x_h = \log\left(\sum_g GDP_{gt} \exp(-\alpha \times tt_{hgt+1})\right) - \log\left(\sum_g GDP_{gt} \exp(-\alpha \times tt_{hgt})\right) \tag{7}$$

where tt_{ght+1} are the new travel times between each pair of locations h and g in the study area in the presence of the transport innovation, in our case the HSR line. In order to calculate this shock measure, a few assumptions need to be made. We strictly refer to the fastest land-based connection between two cities and assume that that accessibility patterns in the initial situation (t) are perfectly described by a full road travel time matrix. The rationale for leaving the rail network unconsidered in this period lies in the adverse average velocity of non-HSR in light of a dense highway network. Even a direct inter-city train journey between Frankfurt and Cologne took considerably longer than a car drive (2.13h vs. 1.55h). With the new HSR track, however, a highly attractive alternative in terms of travel time has been made available. Assuming that individuals stick strictly to the transport mode that minimizes travel time, the matrix describing the situation after the shock consists of either the road time necessitated for a journey or the combined network time for car drives to and from stations of departure and destination as well as the time necessitated for the train ride.[10]

$$tt_{hgt} = tt_{hgt}^{car} \tag{8}$$

$$tt_{hgt+1} = \min(tt_{hgt}^{car}, tt_{hrt}^{car} + tt_{rst+1}^{HSR} + tt_{hst}^{car}) \tag{9}$$

where *car* and *HSR* denote the transport mode, *r* is the HSR station closest to the origin in terms of travel time and *s* the same for the destination.

In order to calculate the accessibility shock according to specification (7), a transport cost parameter α needs to be defined. We set the parameter to a value of 0.02, which implies that spatial interactions diminish by 50% after about 35 min of travel time and are reduced to less than 1% after about 230 min. The choice of this parameter value is supported by two alternative approaches. Fist, we estimate a nominal wage equation which can be derived from structural relationships of general-equilibrium spatial models. A brief discussion is in the appendix:[11]

$$\log(w_i) = \alpha_0 + \alpha_1 \log\left(\sum_{j=1}^{J} Y_j e^{-\alpha_2 d_{ij}}\right) + \varepsilon_i \tag{10}$$

where w_i is nominal wage at NUTS3 region *i* measured in *GDP* per capita.[12] Equation (10) simply states that there is a (positive) relationship between nominal wage level and proximity to consumer and employment markets. By holding the regional price level constant due to constraints in data availability, the equation only captures the so-called backward linkages, which drive firms to concentrate where market access, e.g. purchasing power, is high, while the forward linkages related to the supply of goods and consumer goods remain unconsidered. Also, casual interpretation on the basis of the nomin-

[10] Of course, travelers are likely to use train connections instead of car drives for the journeys to and from stations. As we analyze the evolution of transport systems and the regional economic performance over time, the effects of transport infrastructure that does not change over time are differentiated out.

[11] For an analytical derivation of the wage equation from HELPMAN'S (1998) extension of the KRUGMAN (1991) model see e.g. HANSON (2005, pp. 3-6).

[12] Internal travel times tt_{ij} ad determined using the KEEBLE, Owens, & THOMPSON (1982) formula.

al wage equation is complicated by the endogeneity of market access (right-hand side) to GDP per capita (left-hand side). Still, the nominal wage equation should yield a useful estimate on the spatial scope of demand linkages (α_2). We estimate equation (10) for a broad European market area consisting of 1,335 NUTS3 (counties) regions *i* and *j*. Estimates are presented in Table A1 in the appendix. We also estimate a spatial error version of equation (10) as LM tests indicate the presence of spatial autocorrelation.[13]

Another way to determine the parameter (α_2) at which spatial interactions among regions discount in case of HSR, is to observe how the effective usage of rail systems diminishes in the lengths of journeys. The demand for heavy rail commuting serves as a benchmark. As a robustness test, therefore, we estimate a cumulative commuting density function on the basis of individual observations of commuters using heavy rail systems.

$$1 - F(n) = \sum\nolimits_{m>n} p(n) = \beta_1 e^{(-\beta_2 TIME_n)} + \varpi_n \tag{11}$$

As revealed in Tables A1, both approaches yield parameter estimates within the range of 0.02, which is more or less mid of the range of estimates derived from HARRIS (1954) type market potential equations available in the related literature mentioned in section 2.

Taking this cost parameter as a basis, the impact on accessibility as defined in specification (7) is illustrated in Figure 1 using spatial interpolation techniques. We use a hybrid data set of municipalities within the federal state of Hesse, North-Rhine Westphalia and Rhineland Palatinate and NUTS3 regions for the rest of Europe. As expected, the largest effects are observable for the areas close to the intermediate stops Montabaur and Limburg, which enjoy a much improved access to the Frankfurt Rhine Main region as well as to the Rhine-Ruhr region. For these municipalities, we find an increase in the market potential indicator of about 30%[14]. Obviously, effects diminish with distance to the stations

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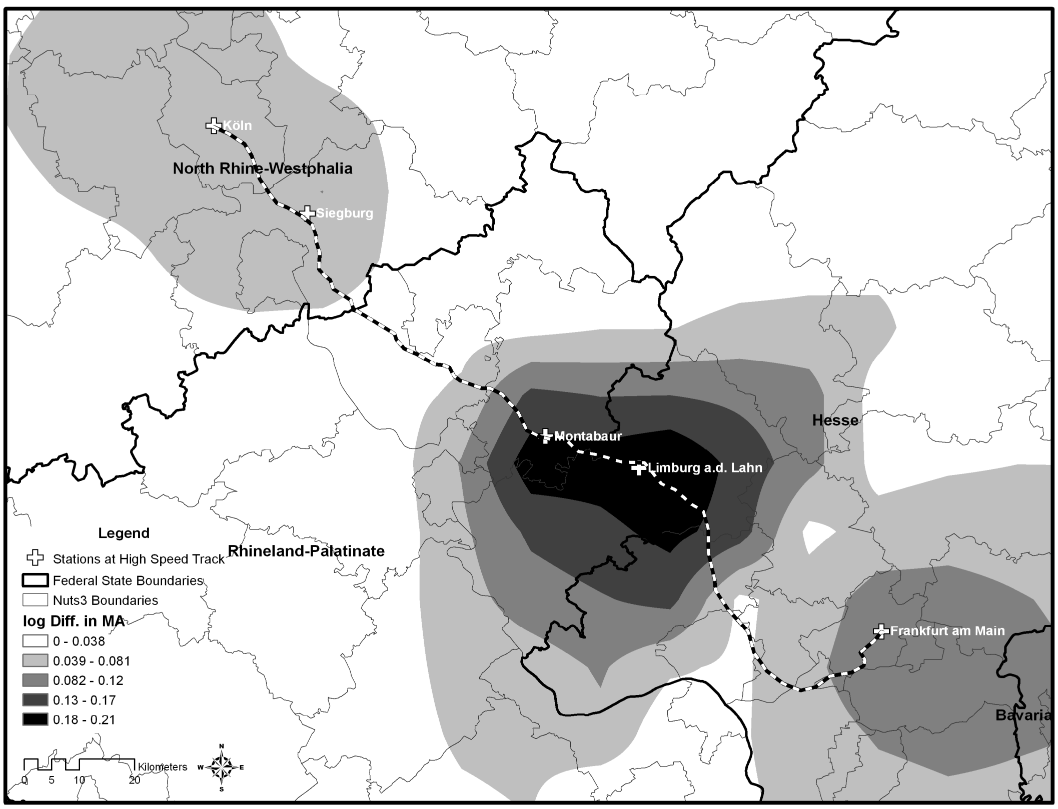
[13] A contiguity-based weights matrix is used. LM tests reject a spatial lag model in favor of an error-correction model (ANSELIN & BERA, 1996).

[14] The percentage effect (*PC*) corresponds to *PC* = (exp(*b*)-1)*100 where *b* is the respective log-difference. (e.g. HALVORSEN & PALMQUIST, 1980)

along the new track while, notably, the impact is larger for the Rhine Main region compared to Rhine-Ruhr. This is clearly due to the latter representing the much bigger agglomeration, therefore exhibiting a stronger impact on the regions at the other end of the track. Of course, the magnitude of results represents an upper-bound estimate of accessibility effects. It is assumed that all individuals are willing to switch to the train on the basis of travel time optimization, flight connections between Frankfurt and Cologne prior to the inauguration are ignored and there is no similar reduction in the physical transport cost of tradable goods.

Fig. 1 Accessibility impact



Notes: Own calculation and illustration. Map shows log difference in MA as defined in specification (7), spatially interpolated employing ordinary kriging with spherical semivariogram model. Classification according to the JENKS (1977) algorithm.

6 Empirical Analysis

6.1 Pre Tests

In the section above, the locations that are potentially affected by the shock have been identified. Whether economic adjustments took place within these areas as predicted by theory is subject to investigation in the remainder of this study. We essentially employ a two-part identification strategy, which in many respects follows AHLFELDT's (in press-b) approach to the evaluation of the impact of (mainline) accessibility changes.

In the first stage, we employ a flexible specification to identify the magnitude and the timing of the intervention. Besides the need to account for the complex spatial pattern of the accessibility shock, the identification strategy must cope with gradual adjustments, e.g. due to transaction costs in spatial arbitrage or the anticipation effects of investment. These are expected as firms, in their location decisions, consider the future stream of revenues and, hence, may seek first-mover advantages of moving close to a HSR line as soon as certainty about its inauguration is achieved.

In the second stage, we test whether improvements in accessibility significantly explain the economic growth during an adjustment period that is identified in the first stage. In an attempt to rule out alternative explanations, we control for various county characteristics, capturing geographical particularities, access to economic centers, construction related spending effects and initial economic conditions like per capita income or economic density, among numerous others. Special attention is also paid to the initial industry structure as well as industry turnover rates during the adjustment periods (churning).

In order to increase homogeneity within the sample, we restrict the study area to the German federal states Hesse, Rhineland-Palatinate and North Rhine-Westphalia throughout our empirical analyses. This restriction would come at the expense of a potential underestimation of the true treatment effect if the area as a whole received an economic boost from the new HSR track. Before analyzing the local impact, we therefore compare the economic performance of our study area to the remaining counties in former West-Germany. We take the evolution of population, GDP, employment and wage (measured as GDP/capita) as a benchmark (y_{it}).

$$\log(y_{it}) = \vartheta_i + \varphi_t + \sum_{1993}^{2006} \tau_u STUDY_i \times YEAR_u + \varepsilon_{it} \quad (12)$$

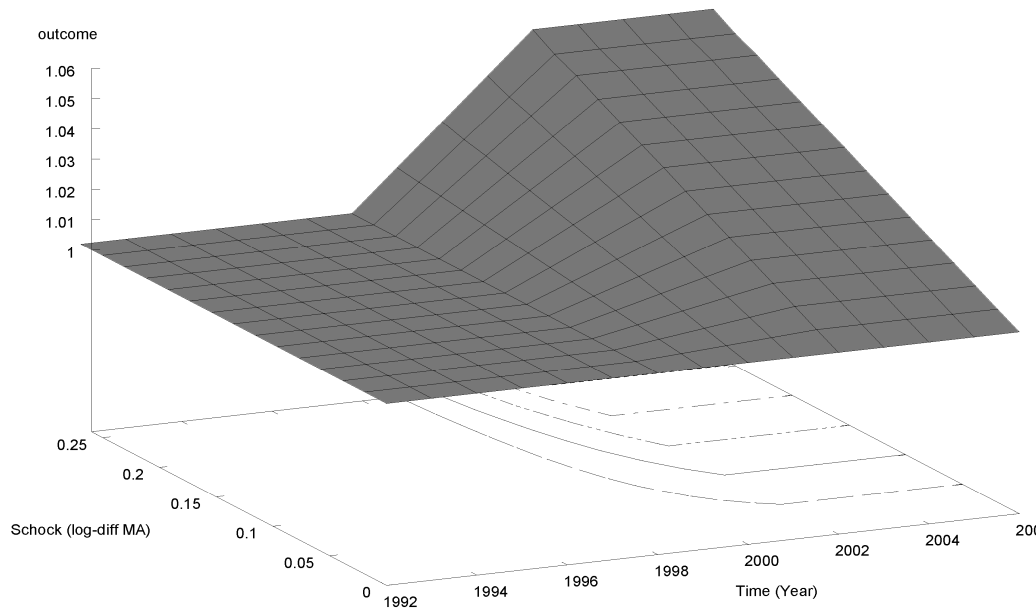
where ν_i and φ_t capture location and time effects and *STUDY* is a dummy denoting counties *i* within our designated study area. Parameters τ_u yield an index of the change in the difference between means for the study area and the rest of West-Germany in year *u* relative to the base year 1992 and effectively. Effectively, specification (12) produces a series of *u* difference-in-difference estimates. Results presented in Table A2 in the appendix reveal that, relative to the rest of West-Germany, our study area underperformed throughout our observation period along a more or less linear trend. This finding holds for population, GDP, GDP per capita and employment and indicates that the transport innovations, if at all, had a rather localized economic impact and did not shift the level of economic wealth for the study area as a whole. A restriction to the study area in the remainder of our analysis, hence, seems appropriate.

6.2 Detecting Discontinuities

Our empirical strategy aims at identifying the treatment effects which regions receive that are subject to the shock modeled in section 5. Difference-in-difference (DD) (BERTRAND, DUFLO, & MULLAINATHAN, 2004) strategies or regression discontinuity designs (RDD) (IMBENS & LEMIEUX, 2008) are established approaches to identify treatment effects that occur at particular locations. A common strategy in these kinds of quasi-experimental designs is to compare locations that receive a treatment to a control group that is not affected by a shock, but is otherwise comparable. Ideally, the treatment effect from a quasi-experiment can be identified from a discrete setup, i.e. the shock is modeled discretionarily both with respect to location (treatment vs. control) as well as time (before and after the shock).

In our case, too, we are confronted with a two-dimensional identification problem. A discrete approach toward the subject intervention, however, is likely to fall short, mainly for two reasons. First, we cannot rule out the possibility of a gradual adjustment around an intervention date *t*, e.g. due to anticipation and spending effects during construction and/or transaction cost in spatial arbitrage. Second, and even more fundamentally, the treatment is not discrete in terms of space. Locations *i* are affected distinctly by the change in market access and we therefore expect the economic response to vary with the degree to which access to markets actually changes *(x_i)*. Figure 2 depicts a potential economic response (on the z-axis) at time *t* (on the x-axis) for locations ordered according to the intensity of the shock they experience (on the y-axis). Our preferred indicator in these terms is the (log)-change in market access (*MA*) (see Figure 1).

Fig. 2 Outcome variable surface



Source: Own illustration.

Within an adjustment period, there a transformation to a new spatial equilibrium where locations systematically benefit the higher their relative increase in market access is. If the change in accessibility is zero, outcome variables presumably are not affected at all so that the respective regions serve as a control area. In principle, there might be either a) a discontinuity in the outcome variable surface along the treatment *x* at the time of inauguration *t*; b) a more gradual adjustment towards and/or after *t* c) a distribution along *x* that remains stable over time if the increase in market access had no economic impact at all or, in empirical terms, the impact was too small to statistically reject the null-hypothesis. Thus, even if significant adjustments take place, it will not be known a priori when the adjustment process starts and ends. We note that in the realm of the transport economics literature some studies have modeled continuous treatments (AHLFELDT & WENDLAND, 2009; GIBBONS & MACHIN, 2005), while others have allowed for gradual adjustments (MCMILLEN & MCDONALD, 2004). Only a few studies, however, have taken complex continuous patterns with respect to space and time into deeper consideration (AHLFELDT, in press-b).

As noted by Dachis, Duranton & Turner (2009), an outcome variable "surface" (y) along the dimensions i (location) and t (time) can be described by a Taylor series expansion.

$$y_{it} = y(0,0) + \frac{\partial y}{\partial x} x_i + \frac{\partial y}{\partial t} t + \frac{1}{2} \frac{\partial^2 y}{\partial x^2} x^2{}_i + \frac{1}{2} \frac{\partial^2 y}{\partial t^2} t^2 + \frac{\partial^2 y}{\partial x \partial t} x_i t + O(3) \tag{13}$$

It depends on three major components. First, variation that depends solely on location; second, variation that depends solely on time; and third, variation that depends on an interaction of both. Clearly, we are mostly interested in the latter component, i.e. the adjustment in the spatial economic equilibrium over time, which is precisely the component displayed in Figure 2. In order to detect such an adjustment empirically, we translate equation (13) into the following regression-based identification strategy:

$$\log(y_{it}) = \vartheta_i + \varphi_t + \sum_{1993}^{2006} \gamma_u x_i \times YEAR_u + \varepsilon_{it} \tag{14}$$

As in specification (12) a set of location fixed effects v_i captures the proportion of the variation in the response surface that is solely attributable to location, hence

$$v_t = \sum_{k=1}^{\infty} \frac{1}{k!} \frac{\partial^k w}{\partial x^k} x^k{}_{it} \ , \tag{15}$$

and year effects φ_t capture the respective proportion attributable solely to time, hence

$$\varphi_t = \sum_{k=1}^{\infty} \frac{1}{k!} \frac{\partial^k w}{\partial t^k} t^k{}_{it} \ . \tag{16}$$

Basically, these effects capture any time-invariant characteristics of location and all macroeconomics shocks that are common to the entire study area. The remaining variation is assumed to be related to location-specific trends that can be evaluated with respect to a treatment measure x and a random error term (ε). The interactive component of time and the locations specific shock measure in specification (14) is captured by allowing the treatment effect to freely vary over time. In the simplest form x_i is a dummy variable denoting an area that is subject to a particularly strong change in market access, which is interacted with a vector of $YEAR_u$ dummies. Specification (14) then yields a series of coefficients γ_u that denote how the differential between this treatment area and the rest of the area, which serves as a control, changes over time for a given response variable *y*. As we omit the base year (1992) treatment, this specification, similar to specification (12), tests for a significant change in the treatment effect relative to the base year.

Our preferred treatment measure x_i, however, is modeled in terms of (log)change market access as derived in section 5. We argue that with this treatment measure, specification (14) yields a pretty strong test on the causal effect of the accessibility treatment as it not only compares areas that are subject to treatment to control areas, but also relates the degree to which locations are affected by the shock to their economic performance over time. At the same time the flexibility of our specification ensures that any underlying relative trends as well as potential anticipation or adjustment processes will be revealed. An adjustment as illustrated in Figure 2 would be reflected by constant (insignificant) γ_u coefficients before the effects of the shock become effective, raising point estimates during an adjustment period and, constant (significant) coefficients once the new equilibrium is achieved.

While specification (14) controls for time-invariant location characteristics by means of location fixed effects, it ignores the potential existence of long-run location-specific trends that are correlated with, but not caused by the change in accessibility. We therefore introduce an interactive term of the treatment measure (x_i) and a yearly trend variable ($TREND_t$), while omitting the 2006 *YEAR*-treatment (x_i) interactive, in specification (17) to test for significant deviations from a hypothetical linear relative growth path. We argue that a gradual (linear) long-run adjustment would be little support for an intervention effect. Instead, a significant (positive) economic adjustment should be reflected by a negative deviation from the long-run path before effects become effective and/or a positive deviation afterwards.

$$\log(y_{it}) = \vartheta_i + \varphi_t + \theta\, x_i \times TREND_t + \sum_{1993}^{2005} \gamma_u x_i \times YEAR_u + \varepsilon_{it} \qquad (17)$$

Note that the LM test for serial correlation in a fixed effects model (BALTAGI 2001, pp. 94-95) clearly rejects the hypothesis of no serial correlation. We therefore use an arbitrary variance-covariance matrix as recommended by BERTRAND, DUFLO & MULLAINATHAN (2004) in all estimations.[15]

The highest level of geographic detail for which most of the data considered in our analyses are available refers to the county level (NUTS3/"Kreise und kreisfreie Städte"). In order to maximize precision we first calculate market access (*MA*) indicators as defined in (6) for the level of municipalities *h* before aggregating them to county *i* level, weighted by population *P*.

$$MA_{ti} = \sum_h MA_{th} \frac{P_h}{P_i} \tag{18}$$

This method is preferred over the alternative of connecting counties' geographic centroids directly as it accommodates the within county population distribution. Substituting equation (18) into (7) and defining (*t+1*) and (*t*) as the situations after and before the new HSR track was available, our preferred treatment measure (x_i) takes the following form:

$$x_i^a = \log\left[\sum_h \frac{P_h}{P_i} \sum_g Y_g \exp\left(-\alpha_2 tt_{hgt+1}\right)\right] - \log\left[\sum_h \frac{P_h}{P_i} \sum_g Y_g \exp\left(-\alpha_2 tt_{hg}\right)\right] \tag{19}$$

Note that in order to avoid endogeneity problems we use 2002 GDP (*Y*) and population (*P*) in both periods so that the entire variation in the treatment variable is driven by changes in travel times between the two periods. By definition, this variable takes positive values for locations that receive treatments and a value of zero for all control areas.

As an alternative treatment variable, we define a more traditional indicator variable, which denotes the three counties adjacent to the HSR stations Limburg and Montabaur. As discussed, these intermediate stations are the result of political negotiations rather than a comprehensive economic rationale. This indicator variable thus denotes the area where, following the rationale laid out in the theory section, we would expect the largest causal impact from the new HSR track.

$$x_i^b = \begin{Bmatrix} 1 \text{ for "Rhein Lahn Kreis", "Rhein Sieg Kreis", "Westerwaldkreis"} \\ 0 \text{ otherwise} \end{Bmatrix} \tag{20}$$

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[15] The LM test statistic is $t_b = \sqrt{NT^2/(T-1)}(\hat{v}'\hat{v}_{-1}/\hat{v}'\hat{v}$; asymptotically distributed as $N(0,1)$.

A third treatment variable is defined, which will be used to instrument the market access shock measure (x^a) at a later stage of the analysis. It combines the features of being continuous on the one hand and restricted to the catchment area of the intermediate stations on the other by considering the (log) change in the minimum travel time to the nearest economic core defined as either Frankfurt (*ttF*) or Cologne (*ttK*). Travel time reductions are illustrated in Figure A1 in the appendix. As expected, increases in accessibility are achieved along the intermediate stops on the HSR track and concentrated around the middle stop "Montabaur".

$$x_i^c = \log\left[\sum_h \frac{P_h}{P_i} \min(ttF_{ht+1}, ttK_{ht+1})\right] - \log\left[\sum_h \frac{P_h}{P_i} \min(ttF_{ht}, ttK_{ht})\right] \tag{21}$$

Adjustment Processes

Figure 3 illustrates the point estimates ($\hat{\gamma}_u$) and the corresponding 90% confidence intervals from a series of specification (14) (left column) and (17) (right column) type regressions. They use our preferred continuous treatment measure, the log-change in market access (x_i^a). Results depicted in the first row, which refer to GDP as a response variable, indicate a positive adjustment in GDP levels after 1998. A new plateau is reached by 2002, the year when the new line was put into operation. Treatment effects are significantly different from zero (at the 10% level) from 2000 onwards. A minor increase, also statistically significant, is revealed for 1996, the first year of construction (left column). The adjustment period from 1998 to 2002 becomes even more evident once treatment effects are tested against a linear (relative) long-term trend (right column). These findings are in line with considerable investment taking place in anticipation to an expected increase in location productivity due to an availability of an HSR line. In contrast to the minor effects in 1996, the identified major adjustment remains persistent after 2002.

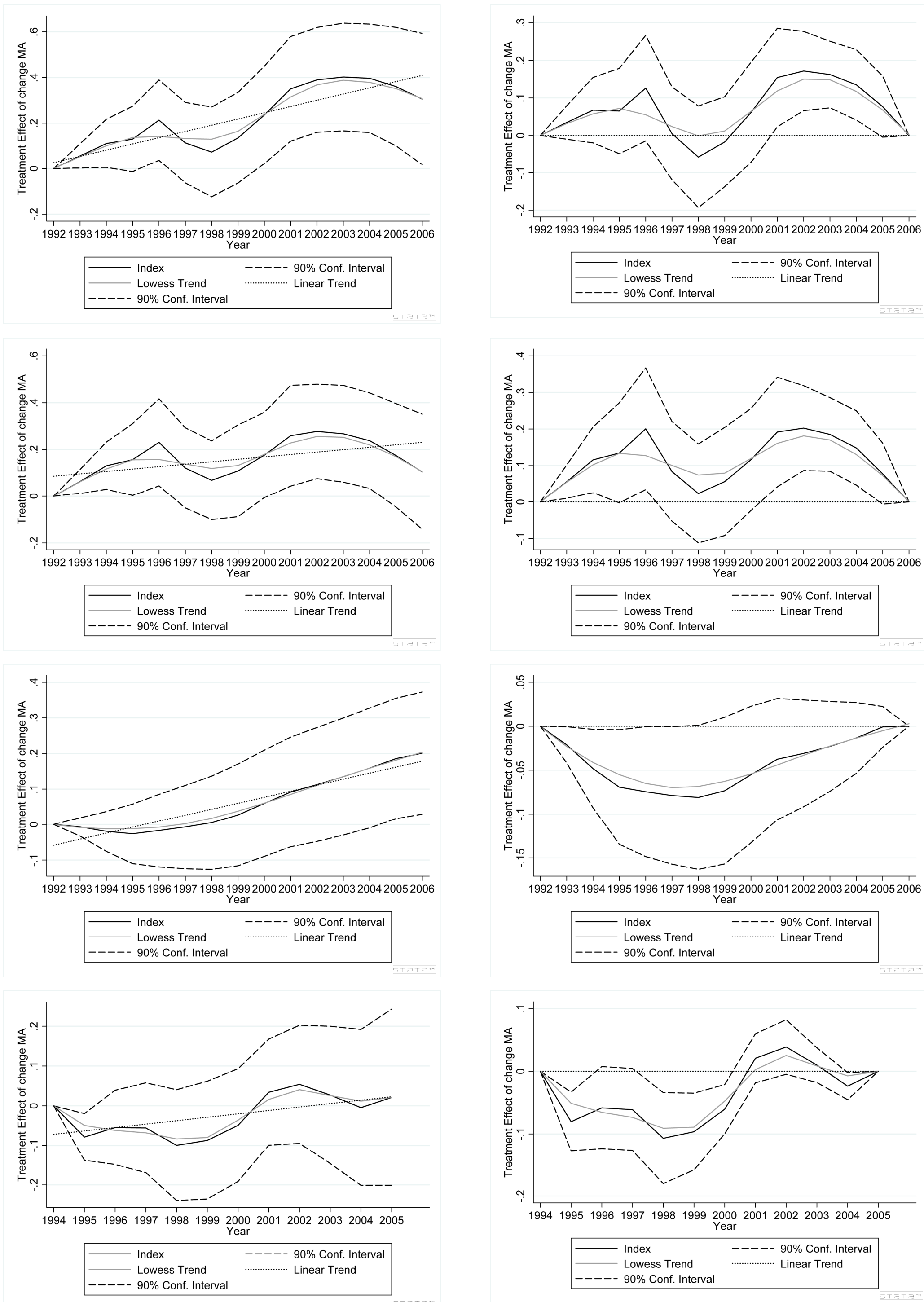
These findings are largely confirmed using GDP per capita as the outcome variable (row 2). The adjustments are somewhat weaker, owing to an increase in population after 1998 (see row 3), which, however, is clearly more attenuated than for GDP. These findings support the prediction that an increase in GDP per capita and, hence, wages, initiates worker migration. A pronounced adjustment is also evident in terms of workplace employment (row 4). Following an adverse performance prior to 1998, treatment areas experience an evident positive shift during the same 1998 to 2002 adjustment period.

While treatment effects relative to the base year (left) do not satisfy conventional significance criteria throughout the study period, the statistically significant deviations from the long-run (relative) trend (right) support the presence of a significant adjustment.

As discussed, an HSR connection potentially attracts new residents directly as a result of reduced commuting times. Clearly, if the HSR attracted new residents who could now commuted to the economic centers (or already present residents who switched to more attractive, but remote jobs), one would expect an increase in the proportion of out-of-town commuters of the resident workforce after the rail line opened. Estimated treatment effects shown in Figure A2 in the appendix (row 1), however, indicate that, if at all, the effects are very small and cannot be rejected from being zero. Similar estimates for the proportion of into-town commuters of the local workforce (workplace) point to a negative long-term trend, hardly exhibiting evidence of a discontinuity. A similar finding holds for land values, revealing that the price of the immobile factor land did not systematically increase where accessibility had been improved. One potential explanation is an elastic supply of land. Municipal authorities reacted to an increase in demand by granting permissions to develop new land, often within new industry zones close to the HSR stations, e.g. the "ICE-Park" in Montabaur.

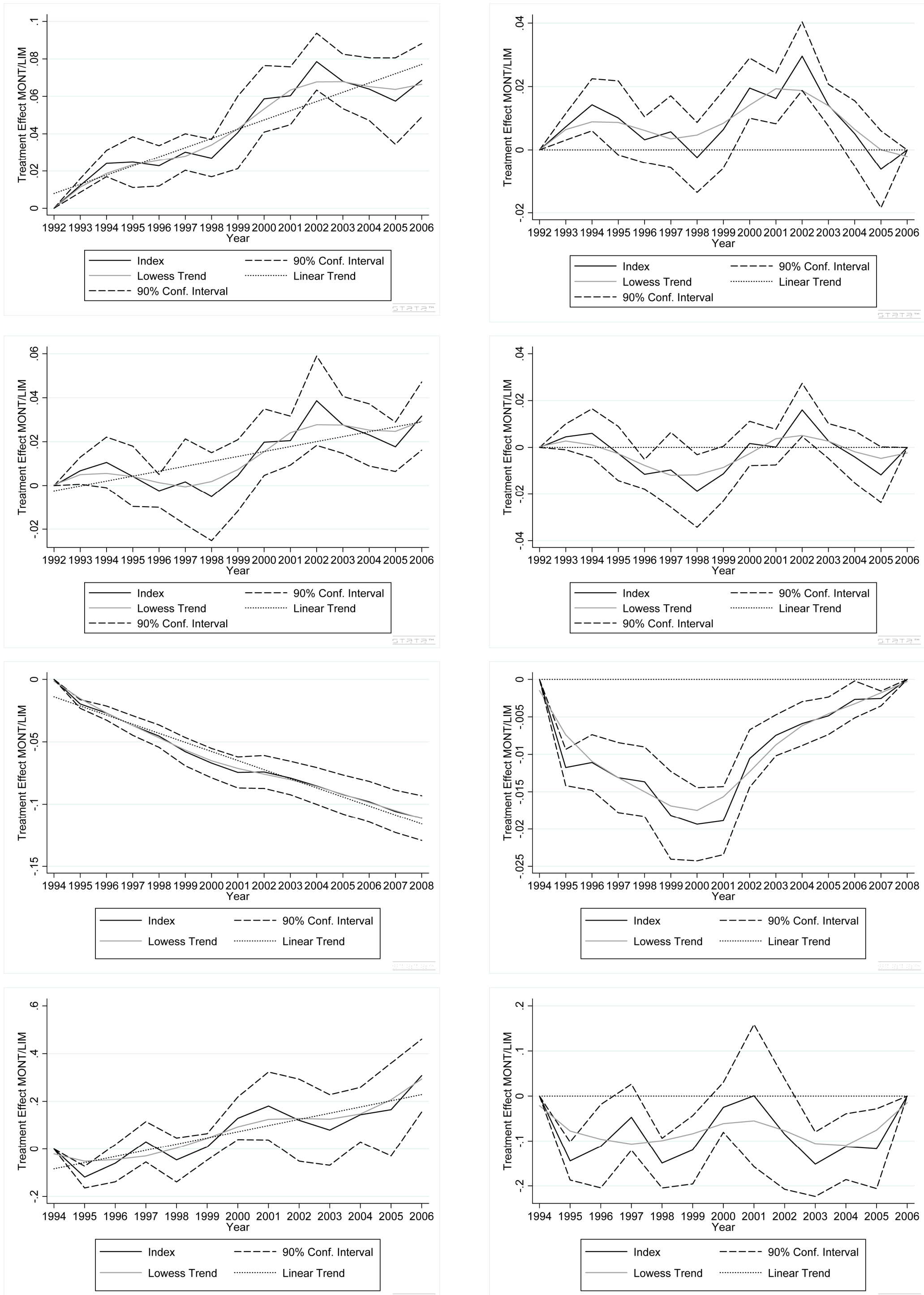
Altogether, our discrete treatment measure (x_i^b) generally yields similar results. As shown exemplarily for GDP (row 1) and GDP per capita (row 2) in Figure 4, similar (positive) adjustments are found for the period from 1998 to 2002. One result, however, is particularly notable. While the share of out-of-town commuters of total workforce (by place of residence) continuously declined over time, there is evidence for a reduction in the rate of decline after the HSR had been opened and, in particular, a shift in the inauguration year 2002. Given the pronounced adjustment in GDP per capita in Figure 4, the commuting effect, besides being limited to a narrow area around the new stations, seems to, if at all, account for a relatively small proportion of economic adjustment.

Fig. 3 Market Access Treatment (x^a)



Notes: Figure illustrates time-varying treatment effects according to specification (14) (left column) and (17) (right column). Treatment variable is log-difference in market access (x^a). Outcome variables by row: 1) GDP, 2) GDP/capita, 3) population, 4) employment (workplace).

Fig. 4 Discrete Treatment (x^b)



Notes: Figure illustrates time-varying treatment effects according to specification (14) (left column) and (17) (right column). Treatment variable (x^b) defined according to (20). Outcome variables by row 1) GDP, 2) GDP/capita, 3) share of out-commuters at employment (residence), 4) standard land values.

Treatment Estimates

The results presented so far are indicative of positive adjustments in the level of economic activity within the 1998-2002 adjustment period. In order to explicitly test for a significant level shift in GDP caused by the HSR line, we employ a hybrid of specification (14) and a more traditional DD/RDD approach. Therefore, we generate a dummy variable (*POST*) that denotes the period after the inauguration in 2002 and interact it with the treatment measure to estimate the average treatment effect (δ). A set of individual treatment (x_i) *YEAR* interactive terms for 1999-2001 accounts for the identified adjustment period. In addition to time and county effects we further introduce a full set of individual county specific *TREND* (yearly) variables in order to avoid the error term being correlated with our indicator variable in light of unobserved location specific trends, which could bias our treatment estimates.

$$\log(y_{it}) = \vartheta_i + \varphi_t + \sum_i \Omega_i TREND_{it} + \sum_{\mathrm{n}} \sum_{1999}^{2001} \gamma_{un} x_i^n \times YEAR_{un} + \sum_n \delta_n x_i^n \times POST_t + \varepsilon_{it} \qquad (22)$$

The subscript *n* denotes treatment measures (a-b) defined in equations (19)-(20) and will be introduced individually as well as jointly into our empirical models. The coefficient on our indicator variable can be interpreted as a traditional difference-in-difference estimate, which differentiates the response variable across location (treatment/control) and time (pre/post).

$$\log(y_{i,POST=1}) - \log(y_{i,POST=0}) = \delta_n x_i^n \qquad (23)$$

The treatment coefficient can be interpreted as a kind of market access elasticity in case the market access treatment (x_i^a) defined in (19) is used.

$$\delta_a = \frac{\log(y_{i,POST=1}) - \log(y_{i,POST=0})}{\log(MA_{it+1}) - \log(MA_{it})} \qquad (24)$$

If we employ the discrete treatment measure (x_i^b), instead, the treatment coefficient yields the change in the outcome variable of the treatment group relative to the control group. The coefficient can be interpreted in percentage terms (*PD*) according to the standard interpretation in semi-logarithmic models.[16]

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[16] $PD = (\exp(\delta)-1)*100$ (HALVORSEN & PALMQUIST, 1980)

$$\delta_b = \left[\log\left(\bar{y}_{i,POST=1}\right) - \log\left(\bar{y}_{i,POST=0}\right)\right]^{x_i^b=1} - \left[\log\left(\bar{y}_{i,POST=1}\right) - \log\left(\bar{y}_{i,POST=0}\right)\right]^{x_i^b=0} \quad (25)$$

The results presented in Table 1 reveal positive and significant treatment effects for both treatment measures when included individually without controlling for locations specific trends. Accordingly, a 1% increase in market access leads to a 0.27% increase in GDP (1). Within the three counties closest to the intermediate stations Montabaur and Limburg, a positive treatment effect of close to 5% is found (2). If county trend effects are included, the estimated market access elasticity falls slightly to 0.21, with the precision of the estimate sharply failing to satisfy conventional significance criteria (p-value 0.131) (4). The treatment coefficient for the discrete measure is somewhat more sensitive to the control for individual trends as the treatment effect is reduced to 2.7% (5). Notably, the estimated treatment effects are roughly in line with the level shifts visible in Figures (3) and (4) (first rows, left columns). If both treatment effects are estimated simultaneously it is notable that the MA elasticity estimate remains almost unchanged while the discrete treatment is rendered virtually to zero (6).[17]

In sum, our results provide compelling evidence for an increase in economic activity within areas that gained in access to regional economies following with the availability of the new HSR line. We find considerable anticipation effects that have previously been reported by MCMILLEN & MCDONALD (2004) in the realm of rail innovations. If unobserved location specific long-term trends are accounted for, our preferred market access-based shock measure entirely explains the economic response to the new HSR within the area of primary interest.

[17] Note that the MA treatment is estimated highly statistically significant in all models if robust standard errors are not clustered on counties.

Tab. 1 Treatment Effects (GDP)

	(1)	(2)	(3)	(4)	(5)	(6)
MA Treatment	0.271*		0.212	0.217		0.213
(x^a)	(0.118)		(0.169)	(0.143)		(0.214)
Discrete Treat.		0.047**	0.022		0.027**	0.001
(x^b)		(0.010)	(0.023)		(0.006)	(0.028)
Year Effects	Yes	Yes	Yes	Yes	Yes	Yes
County Effects	Yes	Yes	Yes	Yes	Yes	Yes
Anticipation Effects: (x^a)	Yes	-	Yes	Yes	-	Yes
Anticipation Effects: (x^b)	-	Yes	Yes	-	Yes	Yes
Trend Effects	-	-	-	Yes	Yes	Yes
Observations	1725	1725	1725	1725	1725	1725
R-sq. (within)	0.84	0.84	0.84	0.94	0.94	0.94

Notes: Dependent variable is log of GDP in all models. Robust standard errors (in parenthesis) are clustered on counties. **/*/+ indicate significance at the 1/5/10% level.

6.3 Determinants of Growth

Taking the results from the subsection above as given, this section investigates whether alternative explanations for the observed economic adjustments can be ruled out. Precisely, our baseline specification tests if the (log)change in market access impacts significantly on *GDP* (y) growth from 1998 (t) to 2002 ($t+1$), conditional on a vector of control variables (Z).

$$\log(y_{it+1}) - \log(y_{it}) = \phi\,[\log(MA_{it+1}) - \log(MA_{it})] + \textstyle\sum_v \Psi_v Z_{iv} + \sum_j \xi_j + \varepsilon_i \qquad (26)$$

where MA_{it+1} and MA_{it} are defined as in (6) and (18), ϕ provides an elasticity estimate of the market access impact, and ξ_j are federal state (Bundsländer) fixed effects that account for institutional heterogeneity. In the vector Z, we include a range of 1998 county characteristics (log of GDP, log of GDP per capita, log of GDP per area, shares of industry sectors, etc.) so that specification (26) effectively corresponds to an extended version of standard empirical growth models. The specification also shares similarities with the approach employed by AHLFELDT & WENDLAND (2009), who show that the first difference estimate satisfies quasi-experimental conditions. Considering a control group (C) of locations that remain unaffected by the shock to market access, parameter ϕ provides a difference-in-difference estimate that distinguishes between time as well as control and treatment (T) locations.

$$\phi\;[\log(MA_{it+1}) - \log(MA_{it})] = [\log(y_{it+1}) - \log(y_{it})]^{T} - [\log(y_{it+1}) - \log(y_{it})]^{C} \qquad (27)$$

We note that a simple correlation coefficient between growth in GDP and (log) change in market access takes the value of 0.23 and satisfies significance criteria at the 1% level. Conditional estimates on the impact of the change in market access according to specification (27) are presented in Table (2). A simple regression of GDP growth on (log) change in MA yields an elasticity coefficient of about 0.3 (1). This estimate is slightly larger than suggested by the results discussed so far, but it is brought back into the same range of slightly more than 0.2 once state fixed effects are introduced (2).

In column (3) we introduce a set of variables related to the economic activity in the initial period (1998). Besides the log of GDP, we include the log of GDP per capita to control for convergence growth and the log of GDP per surface area as a measure of economic density and urbanization. We further extend the set of controls by geographic control variables in column (4). We introduce the log of altitude and the log of the shortest distance to a navigable river as proxies for natural (dis)advantages and log of distance to Frankfurt, log of distance to Cologne and log of market access from the pre-HSR period (*t*) as indicators of economic centrality. In order to maximize precision, all geographic variables are calculated at municipality level and aggregated to county level using population weights as described for MA in specification (18). Column (5) extends the set of explanatory variables by the share of mining, services and manufacturing at county level GVA in 1998 in order to account for a potentially heterogeneous competitiveness of industry sectors and their impact on economic prosperity. In the last column (6), we eventually introduce GDP growth from 1992 to 1998 (measured in log-differences) in order to control for unobservable characteristics that are correlated with the regional long-term growth paths. Results, however, show that the pre-trends are virtually uncorrelated with growth during the subject period, leaving the coefficient estimate of interest nearly unaffected.

Evidently, all estimated elasticity parameters in Table 2 fall within a relatively small range that is close to the results from the section above. Even the estimates based on the most demanding specifications still indicate that a 1% increase in market access yields a 0.25% increase in GDP. Although the explanatory power of our accessibility variable is modest, the estimated coefficients generally satisfy conventional levels of statistical significance. Even the weakest estimate (4) almost satisfies the 10% criteria (p-value 0.105), despite a fairly limited number of observations. This is particularly remarkable as, with the exception of the log of GDP (1998) per area, none of the controls achieves similar significance levels in any model.

Tab. 2 Conditional correlation of GDP growth and MA change

	(1)	(2)	(3)	(4)	(5)	(6)
Log Diff MA	0.311**	0.218**	0.296**	0.208	0.246+	0.247+
(1998-2002)	(0.093)	(0.068)	(0.111)	(0.127)	(0.139)	(0.140)
Log Diff GDP						0.011
(1992-1998)						(0.114)
State Effects		Yes	Yes	Yes	Yes	Yes
GDP Controls			Yes	Yes	Yes	Yes
Geo Controls				Yes	Yes	Yes
Ind Controls					Yes	Yes
Observations	114	114	114	114	114	114
R-squared	0.05	0.10	0.21	0.28	0.3	0.3

Notes: Dependent variable is log difference (2002-1998) in GDP in all models. GDP controls include log of GDP (1998), log GDP (1998) per capita and log of GDP (1998) per area. Geo controls include log of altitude, log of distance to the nearest navigable river, log of market access (pre), log of distance for Frankfurt and log of distance to Cologne. Industry controls include share of mining at GVA (1998), share of services at GVA (1998) and share of manufacturing at GVA (1998). Robust standard errors are in parenthesis. **/*/+ indicate significance at the 1/5/10% level.

Endogeneity

A typical concern when investigating the economic effects of transport infrastructure is that the event of a new infrastructure being built is not an entirely exogenous event, i.e. new roads or rails are likely to be constructed to accommodate economic growth. Besides affecting the causal interpretation of the market access coefficient, results will be biased if the treatment variable is correlated with the error term. As discussed, the areas exposed to the largest increase in market access are around the new stations "Montabaur" and "Limburg", which resulted from a long process of political bargaining rather than particular local economic conditions. We further argue that for the whole track, the timing of the construction can be considered exogenous. It is important to note that the track had been under discussion since the 1960s. The initial decision to build the track dates back as far as to 1969. During the 1970s, however, following sever opposition of numerous activist groups and lengthy negotiations among stakeholders the track was even temporarily excluded from the Federal Transport Infrastructure Plan. Negotiations continued during the 1980s, particularly concerning the exact route. When the Minister of Transport finally decided that the track would be developed on the eastern side of the Rhine in 1989, this decision was made with little regard to the expected economic prospects of the subject region during the end of the 1990s, but rather perceived as the outcome of a lengthy policy game that had finally come to an end. The final route largely follows an existing highway in an attempt to minimize construction and environmental costs.

On these grounds there is little reason to believe that the shift in market access was not exogenous to the performance within our study and the identified adjustment period from 1998-2002. We will provide further evidence that the impact of our market access treatment variable is indeed exclusive of the adjustment period in section 6.2 at a later stage. To further reject endogeneity concerns we, nevertheless, employ an IV strategy with instruments for the market access treatment that satisfy the following conditions: a) being correlated with the market access treatment, b) only using variation provided by the "exogenous" intermediate stations, c) only impacting on economic growth via a shift in access to markets, which is the identifying assumption.

We find these instruments in the two other treatment measures introduced in section 6.2. Log-difference in minimum travel time to the closest economic core following the inauguration of the new track (x_j^c), see equation (21) and Figure A 1) and the discrete treatment measure for counties adjacent to the intermediate stations (x_j^a) are clearly correlated with the shock and only make use of the proportion of variation in accessibility that we assume to be "purely exogenous". Second stage 2SLS estimates are presented in Table 3. First stage results are in Table A3 in the appendix. Compared to the baseline results in Table 2, columns (2) and (5), the results change only marginally. The treatment effect is even slightly larger and estimated at higher levels of statistical significance. Altogether, it seems fair to state that endogeneity concerns can be rejected in the subject case.

Tab. 3 GDP growth and MA change 2SLS

	(1)	(2)
Log Diff MA	0.319*	0.296*
	(0.125)	(0.144)
State Effects	Yes	Yes
GDP Controls		Yes
Geo Controls		Yes
Ind Controls		Yes
Observations	114	114
R-squared	0.09	0.30

Notes: Endogenous variable is log difference (2002-1998) in GDP in all models. GDP controls include log of GDP (1998), log GDP (1998) per capita and log of GDP (1998) per area. Geo controls include log of altitude, log of distance to the nearest navigable river, log of market access (pre), log of distance for Frankfurt and log of distance to Cologne. Industry controls include share of mining at GVA (1998), share of services at GVA (1998) and share of manufacturing at GVA (1998). Log. Diff MA is instrumented using the changes in travel times to economic cores defined in equation €. Fist stage results are presented in Table A€. Robust standard errors are in parenthesis. **/*/+ indicate significance at the 1/5/10% level.

Treatment heterogeneity

In order to evaluate a potential heterogeneity in the market access treatment effect we extend our baseline specification by an interactive term of our market access treatment variable and a dummy variable D_e that denotes counties within the upper 50 percentile of a variable of interest e.

$$\log(y_{it+1}) - \log(y_{it}) = \phi\,[\log(MA_{it+1}) - \log(MA_{it})]$$
$$+\varrho\,[\log(MA_{it+1}) - \log(MA_{it})] \times D_{is} + \textstyle\sum_v \Psi_v Z_{iv} + \sum_j \xi_j + \varepsilon_i \qquad (28)$$

Parameter ϱ provides an estimate on the difference in the market access elasticity for counties with above median characteristics and the rest. Arguably, this is a simple test on treatment heterogeneity, but it seems appropriate in light of limited observations. The following criteria are considered in Table 4: population size (1), GDP per capita (2), population density (3), and whether a county possesses a local industry with an above average proportion of manufacturing (4) or services (5) at GVA.

Based on the results, we cannot reject the hypothesis of a homogenous treatment effect. If at all, the fact that the introduction of the services interactive (5) reduces the magnitude and the estimation precision of the market access treatment variable might be indicative of the local industry mix influencing the reception of the accessibility shock. We note that in unpublished robustness checks no treatment heterogeneity was revealed if the market access treatment variable was interacted with continuous variables. At best there was weak evidence for more urbanized areas (higher population density) showing a slightly larger stronger adjustment to the shock.

Tab. 4 Treatment heterogeneity

	(1)	(2)	(3)	(4)	(5)
Log Diff MA	0.247+	0.243+	0.248+	0.250+	0.185
	(0.138)	(0.141)	(0.142)	(0.149)	(0.268)
Log Diff MA x D	0.034	0.047	-0.035	-0.023	0.076
	(0.233)	(0.232)	(0.255)	(0.268)	(0.268)
Heterogeneity	Pop	GDP/cap	Pop/area	Manufact.	Services
State Effects	Yes	Yes	Yes	Yes	Yes
GDP Controls	Yes	Yes	Yes	Yes	Yes
Geo Controls	Yes	Yes	Yes	Yes	Yes
Ind Controls	Yes	Yes	Yes	Yes	Yes
Observations	114	114	114	114	114
R-squared	0.3	0.3	0.3	0.3	0.3

Notes: Endogenous variable is log difference (2002-1998) in GDP in all models. GDP controls include log of GDP (1998), log GDP (1998) per capita and log of GDP (1998) per area. Geo controls include log of altitude, log of distance to the nearest navigable river, log of market access (pre), log of distance for Frankfurt and log of distance to Cologne. Industry controls include share of mining at GVA (1998), share of services at GVA (1998) and share of manufacturing at GVA (1998). Robust standard errors are in parenthesis. **/*/+ indicate significance at the 1/5/10% level.

Construction and substitution effects

It is evident that the identified adjustment period falls into the construction period, which started in 1995 and ended in 2001. One might therefore be concerned that the revealed economic stimuli could be partially driven by spending effects related to the construction of track beds, including bridge and tunnel works. As some of the counties through which the tracks were built benefited from the HSR in terms of accessibility, an estimate of the treatment effect could be upwardly biased if GDP growth was significantly promoted by construction works. A similar concern regarding the efficiency of the treatment estimate is related to potential substitution effects along the old rail connection between Cologne and Frankfurt. The opening of the shorter and faster HSR line came at the expense of a lower train frequency on the old mainline, which runs along the western Rhine riverbank. A negative substitution effect for counties along the western

Rhine riverbank would affect the control group and could, thus, upwardly bias the treatment effect of the new rail line.

In order to control for the related effects we define two dummy variables that denote all counties that lie along the newly developed HSR track (*Construction*) or along the old western Rhine riverbank rail track (*Substitution*). These variables will capture any otherwise unobserved shocks that are common to these groups and facilitate an unbiased accessibility estimate in light of systematic construction and/or substitution effects.

Results presented in Table 5 do not support the existence of construction related spending effects that are idiosyncratic to counties along the HSR track beds. To the contrary, results reveal that, conditional on the accessibility treatment and macroeconomic controls, the respective counties over the four-year study period experienced economic growth rates that were on average about 3.3 percentage points below the rest of the study area. Spending effects due to construction works were either small and/or overcompensated by crowding-out effects. The estimated market access elasticity even slightly increases to 0.32, significantly estimated at the 5% level (2). Estimated substitution effects along the old rail connection are very close to zero and do not pass conventional significance criteria. At the same time the estimated market access elasticity is left almost unaffected (2). Results do not change notably when both effects are controlled for simultaneously (3). We conclude that the estimated impact of market access on economic growth within our treatment area is unlikely to be driven by construction or substitution effects.

Tab. 5 Construction and substitution effects

	(1)	(2)	(3)
Log Diff MA	0.316*	0.246+	0.323*
	(0.138)	(0.139)	(0.139)
Construction	-0.033*		-0.035*
	(0.015)		(0.018)
Substitution		0.002	-0.008
		(0.016)	(0.017)
State Effects	Yes	Yes	Yes
GDP Controls	Yes	Yes	Yes
Geo Controls	Yes	Yes	Yes
Ind Controls	Yes	Yes	Yes
Observations	114	114	114
R-squared	0.33	0.3	0.33

Notes: Endogenous variable is log difference (2002-1998) in GDP in all models. GDP controls include log of GDP (1998), log GDP (1998) per capita and log of GDP (1998) per area. Geo controls include log of altitude, log of distance to the nearest navigable river, log of market access (pre), log of distance for Frankfurt and log of distance to Cologne. Industry controls include share of mining at GVA (1998), share of services at GVA (1998) and share of manufacturing at GVA (1998). Construction is a dummy variable denoting all counties along the new HSR track. Substitution is a dummy variable denoting all counties at the western Rhine riverbank along the old rail connection between Cologne and Frankfurt. Robust standard errors are in parenthesis. **/*/+ indicate significance at the 1/5/10% level.

Industrial turnover (churning)

The economic structure of cities and regions is essentially determined by the composition of their local industries, which potentially influences economic growth. In an attempt to control for alternative determinants of GDP growth, our conditional estimates control for industry composition in the initial year (1998) of the identified adjustment period. Besides the relative shares at output of different industries per se, however, the relationship between economic performance and the change in the sectoral composition of local industries has received increasing attention in regional economics. DURANTON (2007) shows that the "churning" of industries occurs across cities and develops a theoretical framework, which predicts that cities which are mobile along the city hierarchy due to endogenous industry relocations eventually form a concave city size distribution in the steady-state. Building on his pioneering work FINDEISEN & SÜDEKUM (2008) develop an excess churning index (*ExcChurn*) as an indicator for industrial turnover, which they find to be correlated with the rise and fall of cities along the city hierarchy. We replicate their index – with the notable difference that we build on sector GVA instead of employment – in order to evaluate whether industrial turnover can be rejected as an alternative explanation for the identified growth effects within our treatment areas.[18] In addition, we shed light on whether the new HSR line itself promoted industrial turnover within our study area.

$$ExChurn = \frac{1}{T}\left(\sum_t \sum_z \frac{|GVA(z,i,t+1) - GVA(z,i,t)|}{GVA(i,t)}\right) - \frac{1}{T}\left(\sum_t \frac{|GVA(i,t+1) - GVA(i,t)|}{GVA(i,t)}\right) \quad (29)$$

where $GVA(z,i,t)$ is the GVA of industry z in county i at time t. We consider the T=4 years during the subject adjustment period (t=1998, 1999, 2000, 2001). Notably, the index basically consists of two terms. The first component provides an index of the yearly average industry turnover in a county, while the second reveals the yearly average change in the counties' total GVA. The index strictly takes larger values the more some sectors in a city gain at the expense of others. FINDEISEN & SÜDEKUM (2008) provide a more extensive discussion on the properties of their index. Table 6 compares our results for the two components of the excess churning index to the existing evidence for France, the USA and West-Germany. It is evident that compared to the USA and France, average turnover occurs at a relatively lower rate in Germany, and at an even lower rate within our study area, although our estimates are pretty close to those provided by FINDEISEN & SÜDEKUM (2008). The distribution of the excess churning rates within our study area also resembles their findings for West-Germany closely (see Figure A3 in the appendix).

Tab. 6 **Churning in France, Germany and the USA**

	Churn	∆Emp (∆GVA)	*Churn*/∆Emp (∆GVA)
USA	8.26%	4.10%	2.01
France	11.40%	5.20%	2.19
West-Germany	4.98%	2.29%	2.17
Study area	4.27%	2.53%	1.69

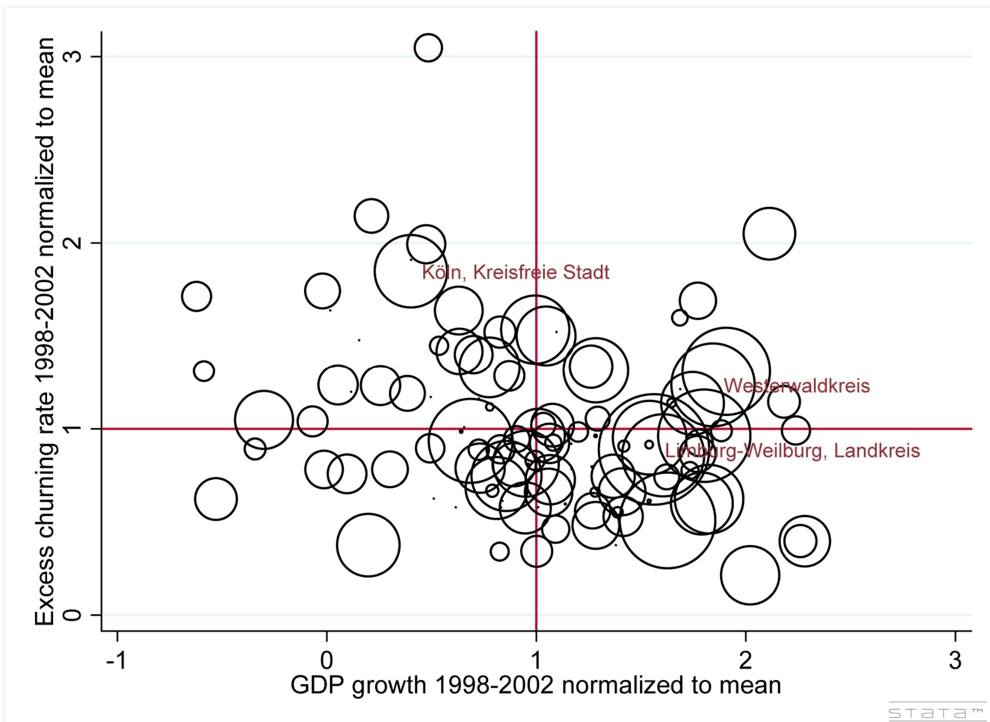
Notes: Values obtained from own calculations (study area), DURANTON (2007) (USA, France) and FINDEISEN & SÜDEKUM (2008) (West-Germany).

Figure 5 provides a classification of counties within our study area with respect to their growth and excess churning rates relative to the sample means. The market access treatment is revealed by the size of the markers that stand for individual observations. Notably, there is a concentration of counties with a large treatment in the right section

[18] We use GVA data obtained from EUROSTAT on the seven industrial sectors construction, manufacturing, mining, trade & retail, banking and public services.

that indicates above average growth rates. No positive correlation, instead, is evident between the market access treatment and the industrial turnover, reflected by the excess churning rate. The only county which at the same time exhibits high turnover rates and a considerable increase in market access is the city of Cologne. Most of the other cities that gained in access through the HSR line such as "Westerwaldkreis" and "Limburg-Weilburg", where the discussed intermediate stations are located, show average turnover rates.

Fig. 5 Growth, Churning and change in MA



Notes: Own illustration. GDP growth measured in log differences. Excess churning rate are defined in (29). The size of the dots reflects the change in MA as defined in (19).

Conditional estimates provided in Table 7 confirm that industrial turnover does not explain the treatment effects in our study area. Compared to the previous Tables, the estimated market access elasticity remains virtually unchanged and is still estimated at a satisfying 10% level of significance, at least. Interestingly, there is a significantly negative (conditional) relationship between industrial turnover and growth rates, which according to classification scheme developed by FINDEISEN & SÜDEKUM (2008), is indicative of a dominance of "structural change losers" in the sample. These cities are in a process of industrial transformation, but the gains from rising sectors are (still) not large enough to compensate for losses from the declining sectors. Many of the traditionally coal & steal dominated cities in the Ruhr area in North Rhine-Westphalia (NRW) fall into this category.

It is important that the qualitative implications of industrial turnover were different outside NRW, e.g. because if counties belonged to the reinvention cities that grow due to structural change, the sign of the estimated turnover coefficient would vary within our study area. If we did not allow for heterogeneity, the variable would hence not appropriately capture the turnover effect at the locations where the increases in market access are largest (these areas lie outside of NRW) so that the estimated market access elasticity could be biased. In order to allow for this kind of heterogeneity, we include an interactive term of the excess churning index with a dummy variable denoting counties in the federal state of North Rhine-Westphalia (NRW). As evident from column (3), however, there is no significant heterogeneity in the impact of turnover on county growth across NRW and the rest of the study area. The estimated effects for the excess churning index and the market access treatment are correspondingly only marginally affected.

A related interesting subject is whether a shock to market access significantly affects turnover rates. Table A4 in the appendix provides results for a series of regressions of the excess churning index on the log of population as a measure of city size, our MA treatment variable and numerous control variables. While our results confirm the basic negative relationship between turnover and city size shown by FINDEISEN & SÜDEKUM (2008), no significant impact of market access treatment on the excess churning index can be established.

Given that industrial turnover depends on city size and industrial composition, a potential endogeneity problem arises in Table 7. A Durbin-Wu-Hausman augmented regression test yields a relatively small p-value (0.11) for residuals obtained from an auxiliary regression of *ExChurn* on the log of population and a full set of exogenous variables, which indicates that OLS estimates may not be consistent. We therefore instrument *ExChurn* in a 2SLS procedure with the log of county population and sector shares (mining, services, and manufacturing) at GVA in 1998, omitting industrial controls in the first stage (column 4). We also omit the log of GDP from GDP controls due to collinearity with log of population that serves as an instrument. The identifying assumption is that the size and industrial composition of a county in the initial period only impacts on subsequent *GDP* growth via impacting on industrial turnover. While the coefficient on the excess churning index is considerably reduced and no longer indicates a significant impact on growth, the estimated coefficient of our primary variable of interest remains virtually unchanged.[19]

Tab. 7 Growth and MA conditional on churning

	(1) (OLS)	(2) (OLS)	(3) (OLS)	(4) (2SLS)
Log Diff MA	0.230*	0.291+	0.289+	0.274*
	(0.094)	(0.147)	(0.152)	(0.129)
ExChurn	-0.015*	-0.012+	-0.017*	-0.005
	(0.006)	(0.007)	(0.007)	(0.012)
ExChurn x NRW			0.007	
			(0.012)	
State Effects	Yes	Yes	Yes	Yes
GDP Controls		Yes	Yes	Yes
Geo Controls		Yes	Yes	Yes
Ind Controls		Yes	Yes	
Const & Subst Controls		Yes	Yes	Yes
ExChurn instrumented				Yes
Observations	114	114	114	114
R-squared	0.16	0.36	0.36	0.30

Notes: Dependent variable is log difference (2002-1998) in GDP in all models. ExChurn is defined in equation (29). NRW is a dummy denoting all counties that lie in the federal state of North Rhine-Westphalia. GDP controls include log of GDP (1998), log GDP (1998) per capita and log of GDP (1998) per area. GDP controls exclude log of GDP in column (4). Geo controls include log of altitude, log of distance to the nearest navigable river, log of market access (pre), log of distance for Frankfurt and log of distance to Cologne. Industry controls include share of mining at GVA (1998), share of services at GVA (1998) and share of manufacturing at GVA (1998). Const and subst controls are two dummy variables denoting a) all counties along the new HSR track. And b) all counties at the western Rhine riverbank along the old rail connection between Cologne and Frankfurt. First stage results to column (4) 2SLS estimates are in Table A4, column (5). Robust standard errors are in parenthesis. **/*/+ indicate significance at the 1/5/10% level.

6.4 Persistency

In this, the last, sub-section of our empirical analysis, we investigate whether the economic adjustments identified above remained persistent, i.e. whether the new HSR led to a permanent shift in economic activity. A simple test on the hypothesis that the new HSR

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[19] First stage results are in Table A4, column (4).

line had a singular impact within the adjustment period is provided in Table 8, where we repeat selected Table (2) type estimates for one period prior (1995-1998) and one period after (2002-2006) the adjustment period (1998-2002).

The results clearly confirm that the positive treatment effect is limited to the identified adjustment period. Our MA treatment variable (x^a) yields negative and insignificant coefficient estimates in both periods before (1-3) as well as after (4-6) the adjustment period. On the one hand this is indicative of the new HSR representing a shock to the level of economic activity rather than inducing a sustainable positive long-run growth trend. On the other hand, the coefficients in columns (3) and (4), by not being statistically distinguishable from zero, also suggest that economic gains are not dissipated in the subsequent years.

Tab. 8 Conditional correlation before and after adjustment

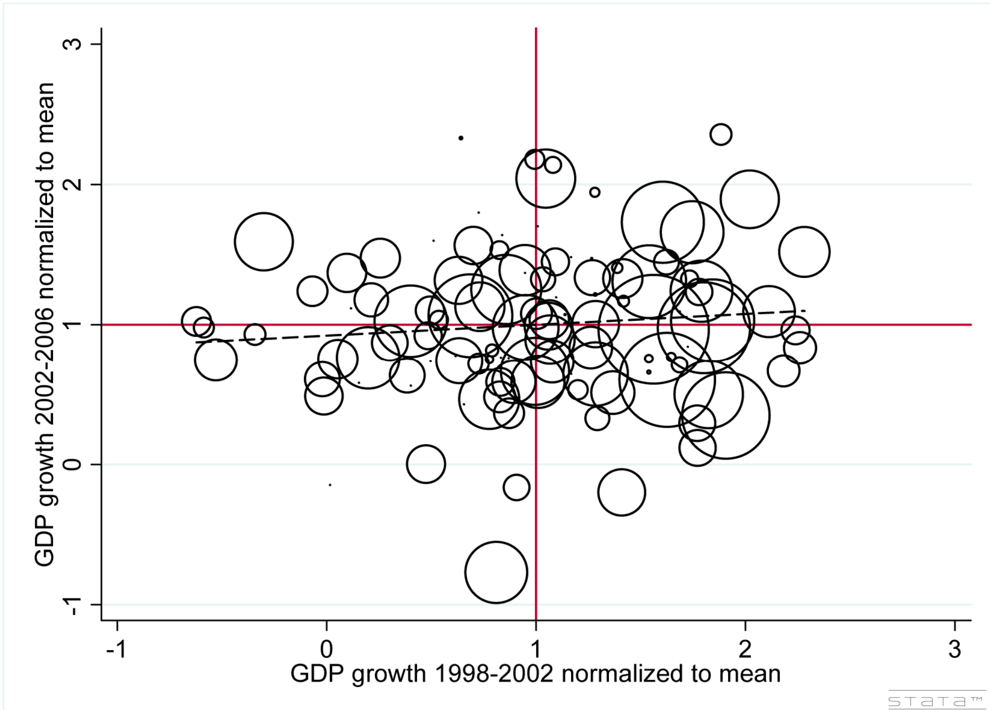
	(1)	(2)	(3)	(4)
Log Diff MA	-0.053	-0.139	-0.092	-0.141
(x^a)	(0.086)	(0.126)	(0.091)	(0.102)
Period	1995-1998	1995-1998	2002-2006	2002-2006
State Effects		Yes		Yes
GDP Controls		Yes		Yes
Geo Controls		Yes		Yes
Ind Controls		Yes		Yes
ExChurn		Yes		Yes
Observations	114	114	114	114
R-squared	0	0.31	0.01	0.28

Notes: Endogenous variable is log difference (1995-1998) in GDP in models (1-3) and (2002-2006). GDP controls in columns 1-3/4-6 include log of GDP (1995/2002), log GDP (1995/2002) per capita and log of GDP (1995/2002) per area. Geo controls include log of altitude, log of distance to the nearest navigable river, log of market access (pre), log of distance for Frankfurt and log of distance to Cologne. Industry controls include share of mining at GVA (1996/2002), share of services at GVA (1996/2002) and share of manufacturing at GVA (1996/2002). Lagged log- differences in GDP refer to 1992-1995 in models (1-3) and 1998-2002 in models (4-6). ExChurn is defined as in equation (29). Robust standard errors are in parenthesis. **/*/+ indicate significance at the 1/5/10% level.

This finding has important implications both from theoretical as well as applied economic policy perspectives. As discussed in Section 2, the literature has provided surprisingly little support for temporary shocks having permanent impacts on the spatial distribution of economic activity. Even following large shocks like war devastations during WWII in Japan and Germany, economic activity was found to re-converge relatively quickly to the prior spatial configuration (BRAKMAN, GARRETSEN, & SCHRAMM, 2004b; DAVIS & WEINSTEIN, 2002). These findings were interpreted in support of location fundamental theories, which state that the long-run distribution of economic activity is largely determined by primary geography. Taking newer economic geography theories as a basis, which emphasize increasing returns as a driving force of spatial concentrations (see e.g. FUJITA, KRUGMAN, & VENABLES, 1999), the straightforward conclusion has been that the existence of multiple equilibria in industrial location is a rather theoretical one. As a result there has been some disappointment regarding the potential for a sustainable promotion of economic development by means of temporary public investments. It is therefore worth having a closer look at whether the positive growth effects induced by the HSR line during the identified adjustment period were reversed in the subsequent years, as otherwise our results hold some considerable novelty.

Figure 6 plots normalized growth rates in 2002-2006 against growth rates in 1998-2002, the adjustment period. The degree to which locations were affected by the market access shock is reflected in the size of the markers. The scatter plot supports the notion of a permanent shift in economic activity because a) locations with larger treatments concentrate in the right section with larger growth in the adjustment period, b) no evident concentration of treatment areas is apparent along the vertical axis that reflects growth in the post period, and c) as a result there is no evident negative correlation between growth in both periods, which would be indicative of a reversion process (see dashed trend line).

Fig. 6 Growth rates and change in market access



Notes: Own illustration. GDP growth is measured in log-differences. The size of the dots reflects the change in MA as defined in (19).

DAVIS & WEINSTEIN (2002) develop a formal framework to derive an empirical test on whether a temporary shock is dissipated in the subsequent years or whether the structure of a city system is altered permanently. They show that from a regression of growth rates during a post-shock on growth rates during a shock period it can be inferred how much of the temporary shock is dissipated in one period, given that the error term μ is uncorrelated with shock.

$$\log(y_{it+2}) - \log(y_{it+1}) = (\rho - 1)[\log(y_{it+1}) - \log(y_{it})] + \mu \tag{30}$$

Accordingly, if ρ=1, which implies an estimated coefficient of zero, the shock had a permanent impact on the city system. In contrast, if ρ=0, which implies an estimated coefficient of -1, the shock was fully dissipated after one period. In practice, we are almost certainly confronted with severe measurement error problems since growth rates during the shock period will not only contain information on the shock and, hence, estimates may be biased in either direction, depending on ρ. As a cure the authors propose to instrument the growth rates during the shock period with direct shock measures. In the

2SLS estimated presented in Table 9 we use our market access and discrete treatment measures x_i^a and x_i^b defined in (19) and (20) as instruments for growth rates during the adjustment period (*t*=1998-*t+1*=2002). Our post-shock period spans over the years 2002 (*t+1*) and 2006 (*t+2*).

Table 9 (1-3) presents 2SLS for specification (30), with first stage results reported in Table A5 in the appendix. Robust to the inclusion of various controls and pre-shock growth rates, the estimated coefficients are relatively close to zero and cannot be statistically distinguished from being zero based on conventional significance criteria. Note that we use the predicted values from the first-stage regression of Table A5, column (1) in models (1-3) of Table 9. The results imply a ρ parameter close to 1 and, ergo, that we cannot reject that the shock had persistent effects.

Still, the negative sign of the coefficient estimate suggests that the effects might be dissipated over time, which would perhaps become more relevant if a longer post-shock period was considered. The interpretation of the coefficient, however, implicitly relies on the assumption that pre-trends are random in the sense that they are uncorrelated with the shock. The negative coefficient estimates in Table 8, however, indicate that individual trends exhibit a weak negative correlation with the shock in both the pre- and the post-period.

If we assume that counties follow individual growth paths in the long term, persistency of a shock implies a return to the long-run growth pattern. Following the same inherent logic underlying equation (30), the *change* in growth rates from the period prior to the shock to the shock period should be entirely reversed by a respective *change* in growth rates from the shock period to the post-period. In other words, if we switch from levels to trends, instead of a parameter value ρ=1, λ=0 will imply persistency.

$$[\log(y_{it+2}) - \log(y_{it+1})] - [\log(y_{it+1}) - \log(y_{it})] = (\lambda - 1)([\log(y_{it+1}) - \log(y_{it})] - [\log(y_{it}) - \log(y_{it-1})]) + \mu \tag{31}$$

In this framework, our measure of the shock is hence the change in growth rates from [1995 (*t-1*) – 1998 (*t*)] to [1998 (*t*) – 2002 (*t+1*)], which we again instrument using the accessibility treatments x_i^a and x_i^b. The dependent variable, respectively, is the change in growth rates from [1998 (*t*) – 2002 (*t+1*)] to [2002 (*t+1*) – 2006 (*t+2*)]. Figure 7 illustrates an evident negative correlation between the two changes in trends. Moreover, the bulk of the observations that experienced a large market access shock also received a positive impact on their growth trends when entering and a negative impact when exiting the adjustment period (lower right section). Our 2SLS estimate of equation (31) in Table (4) correspondingly yields a coefficient close to and not statistically distinguishable from -1, but significantly different from zero.[20] This implies an almost perfect return to pre-shock trends and, hence, that the increase in market access had a temporary impact on trends and a permanent impact on the levels of economic activity in our study area.

Although these results should be interpreted with some care as the explanatory power of the model is somewhat limited, our 2SLS estimates provide further support for the notion that the MA treatment effects are limited to the adjustment period and that the respective level shift is not dissipated by a negative (relative) trend during the subsequent years. Regarding the interpretation of these findings with respect to the potential of multiple equilibria in the spatial distribution of economic activity, it is important to bear in mind that the shock being investigated in this analysis has a non-temporary character. Our results, hence, do not support that purely temporary economic policies in general promote economic activity sustainably. Rather, we show that improvements in the transport geography, by permanently shifting accessibility pattern, represent a feasible strategy to induce permanent shifts in the distribution of economic activity through temporary (public) investments. In some sense, our results are supportive of both the location fundamentals as well as increasing returns theories as the mechanisms that drive the shift in economic activity are related to increasing returns and agglomeration economies while the reason for the persistency of the effects is likely to be the permanent change in location quasi-fundamental characteristics.

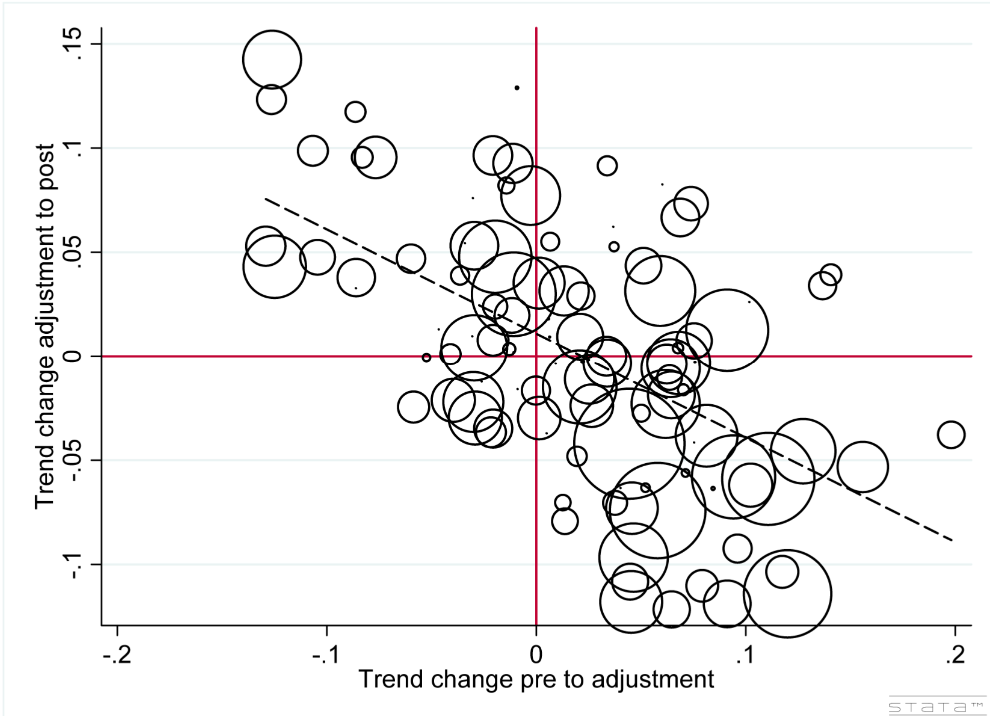
[20] First stage results are in Table A5, column (2).

Tab. 9 Persistency – 2SLS results

	(1)	(2)	(3)	(4)
	Growth (2002-2006)	Growth (2002-2006)	Growth (2002-2006)	Difference in Growth (1998-02)-(2002-06)
Log Diff GDP (1998-2002)	-0.274 (0.239)	-0.264 (0.270)	-0.273 (0.270)	
Difference Growth (1995-98)-(1998-02)				-1.119** (0.335)
State Effects		Yes	Yes	
GDP Controls		Yes	Yes	
Geo Controls		Yes	Yes	
Ind Controls		Yes	Yes	
ExChurn		Yes	Yes	
Log Diff GDP (1995-1998)			Yes	
Observations	114	114	114	114
R-squared	0.01	0.26	0.26	0.05

Notes: Endogenous variable is log differences in GDP (2002-2006) in column (1) and difference in log differences in GDP (1998-2002) and (2002-2006). Exogenous variables are instrumented. 1st stage results are displayed in Table A5 in the appendix. GDP controls in log of GDP (2002), log GDP (2002) per capita and log of GDP (2002) per area. Geo controls include log of altitude, log of distance to the nearest navigable river, log of market access (pre), log of distance for Frankfurt and log of distance to Cologne. Industry controls include share of mining at GVA (2002), share of services at GVA (2002) and share of manufacturing at GVA (2002). ExChurn is defined as in equation (29). Robust standard errors are in parenthesis. **/*/+ indicate significance at the 1/5/10%

Fig. 7 Change in growth trends



Notes: Own illustration. GDP growth measured in log differences. Pre period refers to 1995-1998, adjustment period to 1998-2002 and post period to 2002-2006. The size of the dots reflects the experienced change in MA as defined in (19)

7 Conclusion

This study evaluates the economic effects of high speed rail in the realm of recent economic geography research. As a distinctive feature, the Cologne-Frankfurt German high speed rail track, which is analyzed here, provides variation in accessibility along two intermediate stops that can reasonably be assumed as exogenous. This helps to circumvent endogeneity problems, which are among the key-challenges in establishing causal relationships between access to markets and economic development.

Our findings, one the one hand, contribute to the vivid debate on the viability of HSR, e.g. in the US where President Obama recently announced a large-scale investment program. On the other hand, we contribute to the scholarly debate on New Economic Geography, which has reached maturity in theoretical terms, but still is in a comparatively early stage with regard to empirical evidence. Our hypothesis is that by driving economic agents closer together and increasing access to regional markets, HSR should promote economic development. We develop a treatment measure which compares a Harris-type market potential in the situations before and after an HSR has been made available.

A non-parametric identification strategy suggests that the increase in market access led to economic adjustments in several indicator variables such as GDP, GDP/capita, employment at workplace within a four-year adjustment period. We find that counties adjacent to two intermediate Stations Limburg and Montabaur, which were exposed most strongly to the (exogenous) variation accessibility, experienced a 2.7% level shift in GDP, compared to the rest of the study area. This effect can be entirely explained by the market access treatment measure.

The treatment effect is robust to a range of alternative explanations, e.g. convergence growth, economic density, primary geography, industrial composition, including turnover as well as construction and substitution effects, among others. Throughout our analyses we find a market access elasticity that indicates a 0.25% growth in GDP for any 1% increase in market access. Evidently, the reduction in transport costs in the subject case is driven by passenger traffic only and, hence, improved business, customer and employee relations, as the HSR line is not used for freight transport.[21] For highway construction projects, which also facilitate the transport of physical goods in addition, the market access elasticity might be even larger.

Our results indicate that the observed growth effects of the HSR line remained persistent as a) growth is not reversed during the subsequent years and b) there is a return to the local growth trends experienced prior to the shock. We do not, however, interpret this permanent level shift as evidence for multiple equilibria as predicted by New Economic Geography (increasing returns) theories. Instead, we argue that we observe a hybrid effect where economic adjustments are driven by mechanisms emphasized by increasing returns theories, but persistency of effects results from the permanent nature of the accessibility shock and hence a permanent change in location quasi-fundamentals. This is

[21] Statistical economies of scale, which can arise from reduced labor markets mismatch, improved information exchange and incentives for human capital accumulation (HELSLEY & STRANGE, 1991)). This rationale was confirmed by empirical studies investigating productivity and rent differentials between cities and regions (CICCONE & HALL, 1996; RAUCH, 1993).

the distinguishing element compared to previous studies, which investigated purely temporary shocks such as war destruction and found little evidence for permanent shifts in economic activity.[22]

From these findings, a potentially powerful application of NEG models emerges. Empirically calibrated models may serve as a tool for predicting the economic effects of new large-scale infrastructure projects and help authorities to define priorities. More studies would be desirable to confirm the generalizability of the presented results qualitatively and quantitatively.

[22] In their seminal contribution DAVIS & WEINSTEIN (2002) investigate the effects of allied bombing on Japanese cities during WWII. BRAKMAN et al. (2004b) similarly investigate the effects of WWII destruction in Germany.

Appendix

The nominal wage equation

The so-called wage equation (FUJITA, KRUGMAN, & VENABLES, 1999, p. 53) can be derived from structural relationships of general-equilibrium spatial models:[23]

$$w_i = \left[\sum_{j=1}^{J} Y_j\, e^{-\tau(\sigma-1)d_{ij}} T_j^{\sigma-1}\right]^{1/\sigma} \quad \text{(A1)}$$

where w_i is the nominal wage in region *i* and Y_i the income in location *j*, τ is the unit transport cost and d_{ij} the distance between region *i* and *t*. The elasticity of substitution between any pair of varieties is σ and T_j is the CES price index for manufacturing goods available in region *j*. The general mechanism of this equation is that wages at a location are increasing in the income of surrounding regions and decreasing in transport costs to and from these locations. In turn, a higher wage at location *i* increases prices for traded goods at location *j*.

Equation (1) can be translated into a regression equation by taking logarithms:

$$\log(w_i) = \sigma^{-1}\log\left(T_j^{\sigma-1}\right) + \sigma^{-1}\log\left(\sum_{j=1}^{J} Y_j\, e^{-\tau(\sigma-1)d_{ij}}\right) + \varepsilon_i \quad \text{(A2)}$$

The strength of an equation like this is the microeconomic foundation derived from a general-equilibrium model (KRUGMAN, 1992, p. 7). Another valuable feature of this equation is that, in principle, it can be estimated empirically in order to test the validity of the NEG framework. Unfortunately, data for the price index T_j is not readily available at a sufficiently disaggregated geographic level for Europe. Hence, equation (2) cannot be estimated directly. The simplest way to deal with this empirical data problem is to assume that the price index is equal in all regions.[24] Thus, the expression containing the price index T_j is moved into a single constant (α_0) and the elasticity σ^{-1} is transferred into a coefficient (α_1). Furthermore, consistent with Hanson (2005, p. 13), we merge the ex-

[23] For an analytical derivation of the wage equation from HELPMAN's (1998) extension of the KRUGMAN (1991) model see e.g. HANSON (2005, pp. 3-6).

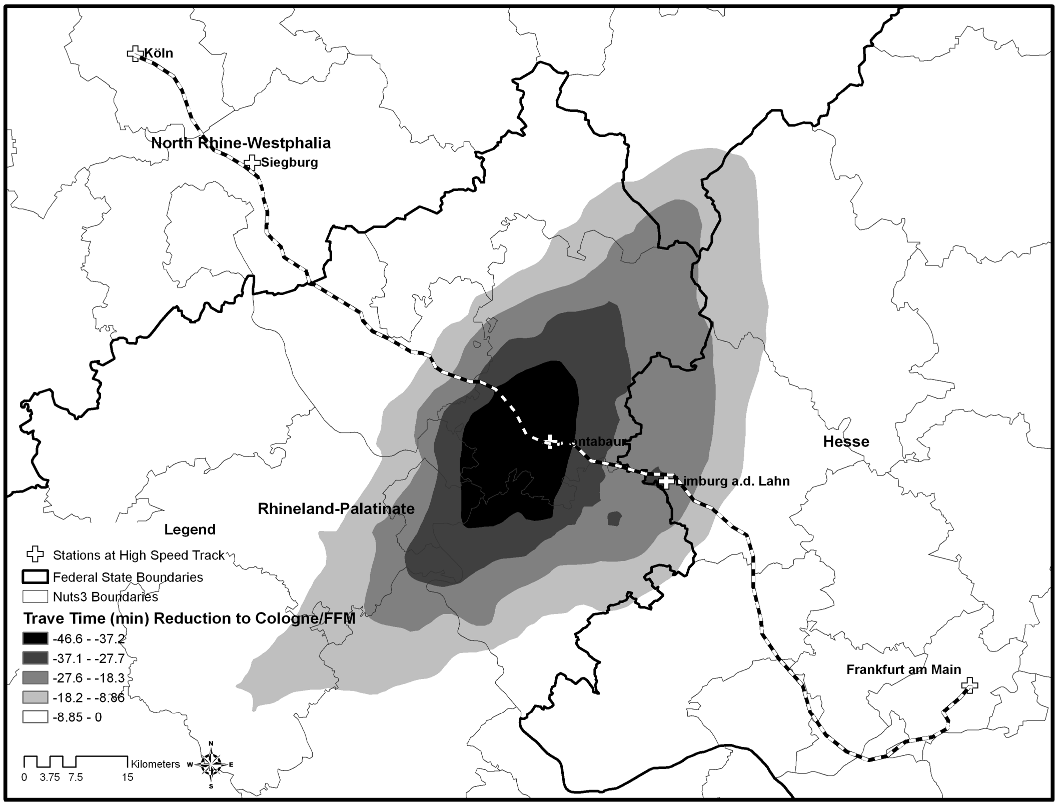
[24] See ROOS (2001). For different approaches to overcoming these shortcomings by means of substituting the price index by other equilibrium conditions see, e.g., HANSON (2005, p. 6) or NIEBUHR (2006, p. 317).

pression $-\tau(\sigma - 1)$ into a single coefficient (α_2) which we refer to as distance decay parameter or spatial weight parameter. Equation (2) can be written in a reduced form:

$$\log(w_i) = \alpha_0 + \alpha_1 \log\left(\sum_{j=1}^{J} Y_j e^{-\alpha_2 d_{ij}}\right) + \varepsilon_i \tag{A3}$$

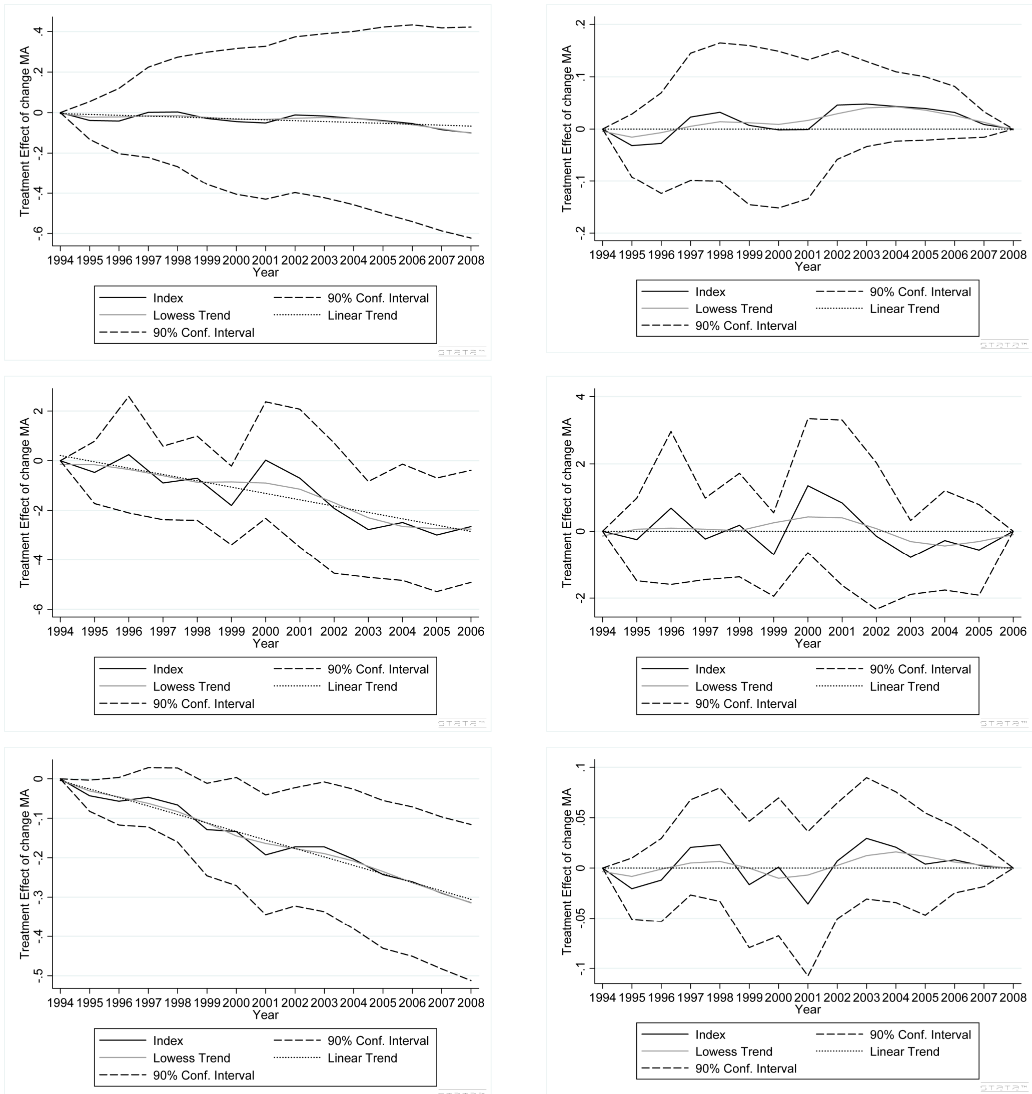
where w_i, T_j, and d_{ij} are defined as in equation (1). α_0, α_1, and α_2 are parameters to be estimated and ε_i is the disturbance term. The reduced form of equation (2) can be called the nominal wage equation because regional price variations are excluded.

Fig A1 Travel time treatment



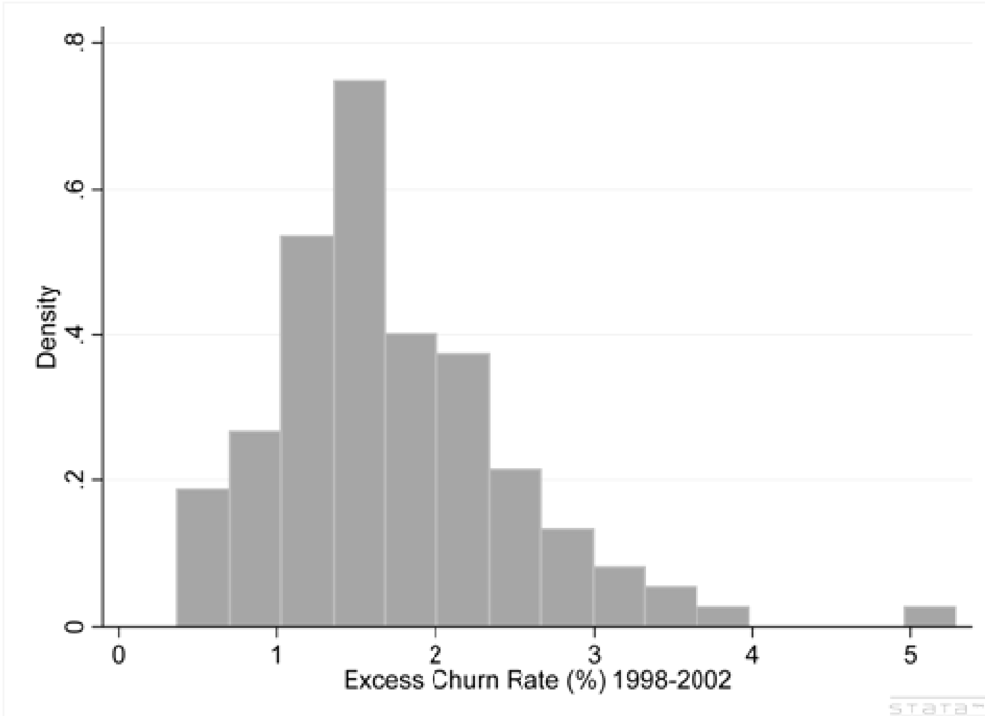
Notes: Own calculation and illustration. Map shows the reduction in travel time in minutes to the closest main centre defined as Frankfurt or Cologne. Travel times are spatially interpolated employing ordinary kriging with a spherical semivariogram model. Classes are defined based on the Jenks (1977) algorithm.

Fig. A2 Market Access Treatment



Notes: Figure illustrates time-varying treatment effects according to specification (14) (left column) and (17) (right column). Treatment is log-difference in market access (x^a). Outcome variables by row: 1) share out-commuters at total employment (residence), 2) share of in-commuters at total employment (workplace), 3) standard land values.

Fig A3 Histogram of excess churning rates across counties



Notes: Figure illustrates the distribution of *ExChurn* defined in equation (29).

Tab A1 Decay parameters

	(1) (NLS)	(2) (SAR)	(3) (NLS)
	GDP/capita	GDP/capita	Commuting density
α_0	2.975*** (0.213)	5.603*** (0.294)	
α_1/β_1	0.285*** (0.008)	0.193*** (0.013)	1.665*** (0.021)
α_2/β_2	0.023*** (0.002)		0.021*** (0.001)
λ		0.908***	
Obs.	1,335	1,335	30,590
(Pseudo) R^2	0.475	0.820	0.973

Notes: Dependent variable is log of GDP per capita in all models.. Standard errors are in parenthesis. * denote significance at the 1% level. ** denotes significance at the 5% level. *** denotes significance at the 1% level.

Table A2 Performance of Study Area

	(1)	(2)	(3)	(4)
	GDP	GDP/Capita	POP	EMP
STUDY x $YEAR_{1993}$	-0.000	-0.008	-0.008	
	(0.005)	(0.009)	(0.010)	
STUDY x $YEAR_{1994}$	-0.001	-0.014*	-0.016	
	(0.005)	(0.008)	(0.010)	
STUDY x $YEAR_{1995}$	-0.002	-0.007	-0.010	
	(0.005)	(0.008)	(0.010)	
STUDY x $YEAR_{1996}$	-0.003	-0.012	-0.015*	-0.000
	(0.004)	(0.008)	(0.009)	(0.004)
STUDY x $YEAR_{1997}$	-0.004	-0.009	-0.013	0.000
	(0.004)	(0.007)	(0.009)	(0.004)
STUDY x $YEAR_{1998}$	-0.005	-0.019***	-0.024***	-0.001
	(0.004)	(0.007)	(0.009)	(0.003)
STUDY x $YEAR_{1999}$	-0.007	-0.026***	-0.033***	-0.001
	(0.004)	(0.007)	(0.009)	(0.003)
STUDY x $YEAR_{2000}$	-0.009**	-0.032***	-0.041***	-0.002
	(0.004)	(0.008)	(0.009)	(0.003)
STUDY x $YEAR_{2001}$	-0.012***	-0.042***	-0.054***	-0.003
	(0.004)	(0.008)	(0.009)	(0.003)
STUDY x $YEAR_{2002}$	-0.015***	-0.033***	-0.048***	-0.005
	(0.005)	(0.008)	(0.009)	(0.004)
STUDY x $YEAR_{2003}$	-0.017***	-0.027***	-0.044***	-0.009**
	(0.005)	(0.008)	(0.010)	(0.004)
STUDY x $YEAR_{2004}$	-0.019***	-0.026***	-0.044***	-0.012**
	(0.005)	(0.008)	(0.010)	(0.005)
STUDY x $YEAR_{2005}$	-0.020***	-0.028***	-0.048***	-0.017***
	(0.005)	(0.009)	(0.010)	(0.005)
STUDY x $YEAR_{2006}$	-0.022***	-0.031***	-0.053***	
	(0.005)	(0.009)	(0.011)	
County effects	Yes	Yes	Yes	Yes
Year effects	Yes	Yes	Yes	Yes
Observations	4890	4890	4890	3904
R-squared	1.00	0.98	1.00	1.00

Notes: Dependent variables are log of GDP (1), log of GDP per capita (2), log of population (3) and log of employment (workplace) (4). Table presents τ coefficient estimates according to specification (1). Employment data was only available for 1995-2005 so that 1995 was chosen as a base year. Robust standard errors are in parenthesis. **/*/+ indicate significance at the 1/5/10% level.

Tab A3 GDP growth and MA change 2SLS – 1st Stage results

	(1)	(1)
Discrete	0.072**	0.079**
(x_i^a)	(0.018)	(0.020)
Log Diff Travel Time	-0132**	-0.076***
(x_i^c)	(0.031)	(0.036)
State Effects	Yes	Yes
GDP Controls		Yes
Geo Controls		Yes
Ind Controls		Yes
Observations	114	114
R-squared	0.49	0.86
Kleinbergen-Paap rk LM stat (P-Val)	5.203 (0.074)	5.930 (0.0516)
F-stat (Kleinbergen-Paap rk Wald)	29.803	18.649
Hansen-Sargan stat (P-Val)	0.767 (0.381)	0.243 (0.622)

Notes: Dependent variable is log difference in MA as defined in equation (19) in all models. Log Diff in Travel time is defined as in equation (21), GDP controls include log of GDP (1998), log GDP (1998) per capita and log of GDP (1998) per area. Geo controls include log of altitude, log of distance to the nearest navigable river, log of market access (pre), log of distance for Frankfurt and log of distance to Cologne. Industry controls include share of mining at GVA (1998), share of services at GVA (1998) and share of manufacturing at GVA (1998). Second stage results are in Table €. Robust standard errors are in parenthesis. **/*/+ indicate significance at the 1/5/10% level.

Tab A4 Determinants of churning

	(1)	(2)	(3)	(4)	(5)
Log of	-0.184+	-0.187+	-0.330**	-0.411**	-0.406**
Population	(0.105)	(0.105)	(0.111)	(0.127)	(0.119)
Log Diff MA		0.317	-0.345	-0.912	-3.15
		(1.683)	(1.561)	(2.680)	(2.716)
GDP Controls			Yes	Yes	Yes
Geo Controls				Yes	Yes
Ind Controls					Yes
Observations	114	114	114	114	114
R-squared	0.02	0.02	0.14	0.17	0.28

Notes: Dependent variable is ExcChurn as defined in equation (29).GDP controls include log of GDP (1998) per capita and log of GDP (1998) per area. Geo controls include log of altitude, log of distance to the nearest navigable river, log of market access (pre), log of distance for Frankfurt and log of distance to Cologne. Industry controls include share of mining at GVA (1998), share of services at GVA (1998) and share of manufacturing at GVA (1998). Robust standard errors are in parenthesis. **/*/+ indicate significance at the 1/5/10% level.

Tab A3 Persistency – 1st stage 2SLS results

	(1)	(2)
	Growth(1998-2002)	Difference in Growth
Log Diff MA	0.255+	0.342+
(x^a)	(0.134)	(0.197)
Discrete Treatment	0.021	0.008
(x^b)	(0.019)	(0.031)
Observations	114	114
R-squared	0.05	0.04
Kleinbergen-Paap rk LM stat (P-Val)	6.095	5.515
	(0.048)	(0.064)
F-stat (Kleinbergen-Paap rk Wald)	13.068	4.808
Hansen-Sargan stat	0.089	1.915
(P-Val)	(0.765)	(0.384)

Notes: Dependent variable is log differences in GDP (1998-2002) in column (1) and difference in log differences in GDP (1995-1998) and (1998-2002). Robust standard errors are in parenthesis. **/*/+ indicate significance at the 1/5/10%

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