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From Periphery to Core: Economic Adjustments to High Speed Rail

Abstract: This paper presents evidence that high speed rail systems 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, suggesting that these investments are economically viable. On the other hand, our results confirm theoretical predictions arising from a consolidate body of (New) Economic Geography literature taking a positive, man-made and reproducible shock as a case. We argue that the economic geography framework can help to derive ex-ante expectations on the economic impact of transport projects. The subject case is the German high speed rail track connecting Cologne and Frankfurt, which, provides exogenous variation in access to regions due to the construction of intermediate stations in the towns of Limburg and Montabaur.

Keywords: NEG, transport policy, simulation, market access, accessibility

JEL classification: R12, R28, R38, R48

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VERY PRELIMINARY AND INCOMPLETE MANUSCRIPT

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 raise 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 im-

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¹ In many aspects NEG builds 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 at least dates back to VON THÜNEN (1826).

portance 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). If actually there is a causality running from access to markets to economic wealth, then from the (N)EG framework a direct economic policy dimension emerges. Centrality is not exogenous to economic policy since access to regions essentially depends on transport infrastructure. Hence, given that causality holds, by (public) investment in infrastructure, accessibility as well as economic growth should be promoted.²

The expectation of transport innovations leading to sustainable economic growth effects has since a long time 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 increasing terrorism threats and security costs, high speed rail systems (HSR) are increasingly attracting the attention of transport planners and policy makers. Following the examples of Japan and some European countries like France, Germany and Spain, which started to develop HSR in second half of the 20th century, various countries all over the world plan to develop their own HSR networks. In the US, the Acela Express along the Northeast Corridor is first evidence for the raise in significance of HSR, although these trains only facilitate a maximum speed of 240 km/h (150mph), a velocity that is relatively modest compared to European and Japanese systems and is also only achieved along a very limited fraction of the line. Recently, however, the US president has released a strategic plan for the development of a true inter-city HSR network across the US, including

² Other political dimensions related to NEG include the prospects of temporary subsidies and regulations having a permanent impact on welfare of immobile factors (e.g. Redding, Sturm, & Wolf, 2007).

completely new rail lines that feature velocities of possibly up to 400km/h (250mph) (US Department of Transportation, 2009). The plan already identifies \$8 billion plus \$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 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 economic 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 closer together (N)EG and transport economic research. REDDING & STURM (2008) not only highlight the causal effects of accessibility on economic prosperity, but also show that the spatial distribution of economic activity reacts to a major exogenous shock as predicted by theory. We provide an empirical assessment of whether there is a significant adjustment in spatial economic patterns in case of a relatively limited (positive) shock to accessibility, or whether the respective forces are dominated by path dependency in the existing spatial configuration.³ The prospects of regional economic policy by means of transport infrastructure in general and HSR in particular critically depend on the answer to that question.

One of the empirical challenges in identifying the impact of a new HSR lies from the fact that a new track will usually be endogenous to the economic geography in the sense that the strongest economic agglomerations are connected first as they naturally generate the largest demand. In contrast to road infrastructure, no effects can be expected along a track where no stations are built. Moreover, the marginal impact of a rail line may be small in relative terms within very large agglomerations, and therefore difficult to detect. Given that it is likely that those areas are connected by HSR that do or are expected to

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

perform best in the future, it is difficult to establish the counterfactual of what would have happened in the absence of HSR line and to disentangle its effects from the natural growth path. Ideally, we therefore want to investigate the impact of HSR on peripheral areas, which in all respects are not predestinated. These cases, however, are difficult to find as the connection of such areas would naturally run counter to economic viability.

However, we find such variation in on the case of the new high speed rail track connecting the German cities Frankfurt and Cologne. The line is part of the Trans-European Network and facilitates train velocities of up to 300 km/h. Following inauguration of this 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. The small towns of Montabaur and Limburg, arguably quite peripheral locations in Germany located halfway between both cities, also became connected to the new line. The connection of these towns was the outcome of long and complex negotiations among authorities at the federal, state and municipality level, the rail carrier Deutsche Bundesbahn and various activists groups. The resulting track was finally considered the best compromise in light of cost, speed, environmental and network considerations as well as heavy lobbying pressures of the involved federal states which insisted that an intermediate stations be developed within their boundaries. As a consequence, Cologne and Frankfurt can now be approached by about 40 min train rides from these towns, making their location central with respect to two of the major regional economic agglomerations with a total population of approx. 15 million. This occasion offers the joint advantage of providing variation in access to markets, which at the same time is man-made and reproducible while on the other hand satisfying exogeneity to the economic development of the region under investigation. 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 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, the (N)EG framework potentially can be employed in order to simulate effects of major transport projects as a basis for decision making.

2 Background & Data

2.1 New Economic Geography and Transport Policy

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 during the recent decade. 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 determinant for economic wealth receives increasing attention. 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 U.S. 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 role of regional accessibility for 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

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

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; Ahlfeldt & Wendland, 2009; Bowes & Ihlanfeldt, 2001; Chandra & Thompson, 2000; Gatzlaff & Smith, 1993; Gibbons & Machin, 2005; McMillen & McDonald, 2004; Michaels, 2008). If NEG models yield reliable predictions on the economic impact of changes in (relative) access to regions, then these models naturally represent powerful tools for the evaluation of transport innovations. A theoretically funded ex-ante assessment of economic impact allows authorities to weigh expected economic benefits against the (public) cost for construction and maintenance and therefore better defining priorities.

It is worth noting the potential contribution of such 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, Brakman, Garretsen, & Schramm, 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 like 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 the location fundamentals. However, while (public) investment into the improvement of transport infrastructure also has a temporary character, the resulting increase in accessibility is

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 permanent effect on spatial economic pattern.

permanent and, hence, more likely to have 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 the (N)EG 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 et al., 2007) or war destruction (Brakman et al., 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, thereby facilitating a broader applicability. 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 Cologne–Frankfurt High Speed Rail 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

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

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 is reduced from 2h13 to 59min (Brux, 2002). The construction of the rail track started in December 1995 and was finished until 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 EUR (European Commission, 2005, p. 17).

The broader areas of Rhine-Rhur and Rhine-Main have long been considered the largest German economic agglomerations. The rail lines connecting both centers along both Rhine riverbanks were among the European rail corridors with the heaviest usage in Europe and had represented a traditional bottleneck since the early 1970s, when usage already exceeded capacity. The first plans for constructing a HRS line between Cologne and Frankfurt date back as far as to the early 1960s. Since then, it took more than 30 years until the opening. A reason for the long time period might be the complex evolution process of infrastructure projects in Germany. Several variants at the left-hand and right-hand side of the Rhine river 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 among the major centers, although relatively large cities as Koblenz and the state capitals Wiesbaden (Hesse) and Mainz (Rhineland Palatinate) would not be directly connected to the track. Due to the federal system of the Federal Republic of Germany the states (*Länder*) have a strong influence on infrastructure projects affecting their territory (Sartori, 2008, pp. 3-8). Three federal states were concerned with the mentioned project of the HRS line Cologne-Frankfurt: North Rhine-Westphalia, Rhineland-Palatinate, 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-Palatinate when the plans for the HSR track reached maturity. During a long lobbying process menacing with a blockade of the planning and political decision process the three federal states negotiated three intermediate stops along the HSR line, with one in each of the involved federal states. While Bonn/Siegburg and Limburg represented the shares of North-Rhine Westphalia and Hesse, 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. The stops at these stations, however, have been very controver-

sial in terms of economic viability. The cities of Montabaur and Limburg only exhibit approx. 12,500 and 34,000 habitants. Further, the distance between these two small cities is just about 20 km and the high speed train ICE only needs 9 minutes between both stops which is contrasting the concept of high velocity travelling.

2.3 Data

Data were collected from several sources. We obtain NUTS3 level data from 1992 to 2006 on population, GDP, employment from EUROSTAT for a broad set of 1,335 European regions. Land value data is provided from the In order to increase the precision of our simulation, we analyze impact on accessibility 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. Train times refer to the fastest train connection between the respective cities on December 8, 2008 (Monday) between 12 and 6 p.m. and were taken from official website of the German rail carrier “Deutsche Bahn”. Note that for the city of Wiesbaden, which lies at feeder line inaugurated with the new track, we found no connection to any of the cities along the new track that is superior to the use of a car in terms of travel time.

3 Accessibility impact

Before economic adjustments to the new transport geography can be estimated, the effective changes in accessibility due to the availability of the HSR line need 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 at least dates back to HARRIS (1954).

$$MA_{ht} = \sum_g GDP_{gt} \exp(-\alpha \times tt_{hgt}) \quad (1)$$

where MA_{ht} is market access for a given municipality h at time t , tt_{hgt} 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.

Given that regional accessibility is well described by equation (1) the relative accessibility shock x_h following a transport innovation in t can be described by the change in the travel time matrix tt .

$$x_h = \log\left(\sum_g GDP_{gt} \exp(-\alpha \times tt_{hgt+1})\right) - \log\left(\sum_g GDP_{gt} \exp(-\alpha \times tt_{hgt})\right) \quad (2)$$

where $tt_{gh,t+1}$ in stand for the new travel time matrix 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 locations and assume that prior the transport innovation accessibility patterns are perfectly described by a full road time travel matrix connecting municipalities within our study area. The rationale for leaving the rail network unconsidered lies in the adverse average velocity of non-HSR within an environment with a dense highway network. Even an inter-city rail trip between the economic centers Frankfurt and Cologne took considerably longer than a car drive (2.13h vs. 1.55h). Naturally, the gap in average velocities increases when regional rail lines are considered. With the new high speed track, however, there is a highly attractive alternative available in terms of travel time. Assuming that individuals strictly stick 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.⁷

$$tt_{hgt} = tt_{hgt}^{car} \quad (3)$$

$$tt_{hgt+1} = \min(tt_{hgt}^{car}, tt_{hrt}^{car} + tt_{rst+1}^{HSR} + tt_{hst}^{car}) \quad (4)$$

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

⁷ 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 system and the regional economic performance over time, the effects of transport infrastructure that does not change over time are differentiated out.

In order to calculate the accessibility shock according to specification (2), however, 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 35min of travel time and are reduced to less than 1% after about 230min. The choice of this parameter value is supported by two alternative approaches. First, 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:⁸

$$\log(W_i) = \alpha_0 + \alpha_1 \log\left(\sum_j GDP_j \exp(-\alpha_2 d_{ij})\right) + \varepsilon_i \quad (5)$$

where w_i is nominal wage at NUTS3 region i measured in GDP per capita.⁹ Equation (5) 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, 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 nominal 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 an useful estimate on the spatial scope of demand linkages (α_2). We estimate equation (5) for a broad European market area consisting of 1335 NUTS3 (counties) regions i and j . Estimates are presented in Table A1 in the appendix. We also estimate a spatial error version of equation (5) as LM tests indicate the presence of spatial autocorrelation.¹⁰ As an alternative approach to determining α_2 we estimate a cumulative commuting density function on the basis of individual observations of commuters using heavy rail systems.

$$1 - F(n) = \sum_{m>n} p(n) = \beta_1 \exp(-\beta_2 TIME_n) + \varpi_n \quad (6)$$

⁸ 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).

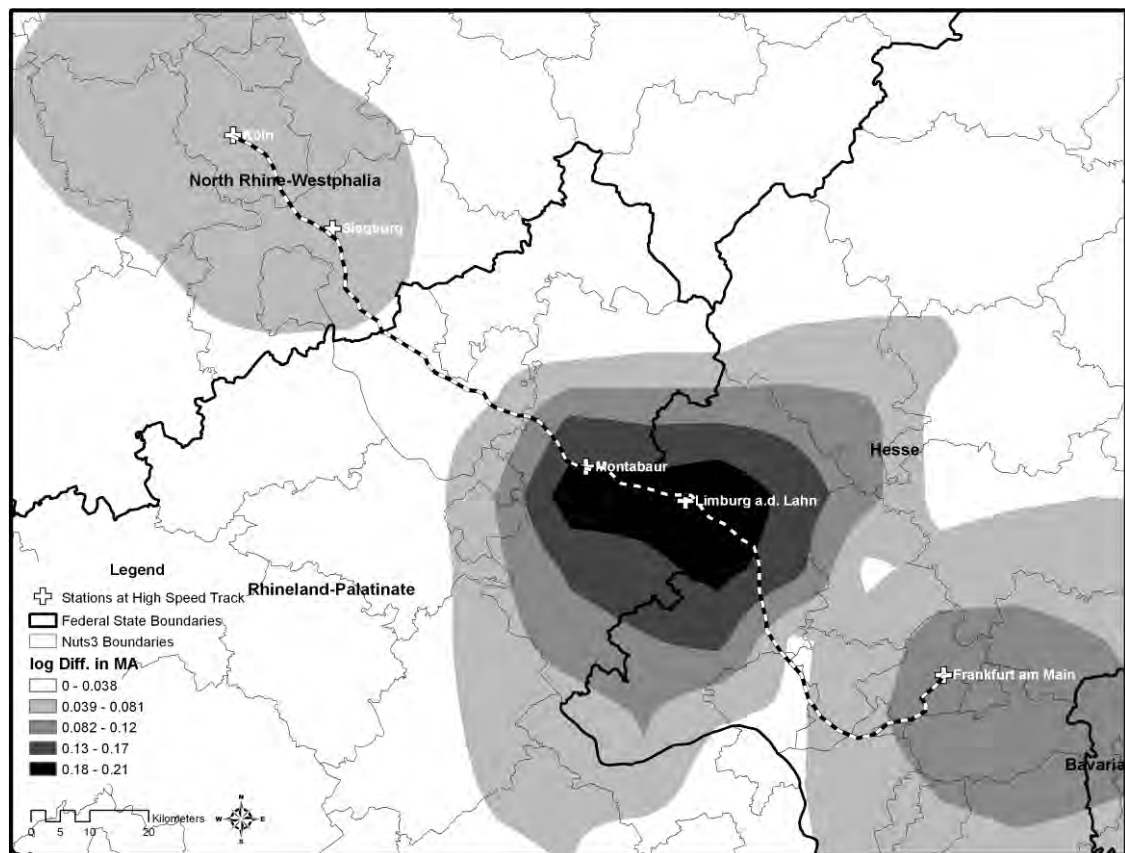
⁹ Internal travel times tt_{ij} are determined using the Keeble, Owens, & Thompson (1982) formula.

¹⁰ A contiguity based weights matrix is used. LM tests reject a spatial lag model in favour of an error-correction model (Anselin & Bera, 1996).

Both approaches yield parameter estimates within the range of 0.02, which is more or less in the 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 (6) is illustrated in Figure 1 using spatial interpolation techniques. Note that 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 Montauban 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 there is an increase in the market potential indicator of about 30%¹¹. Obviously, effects diminish with distance to the stations 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 region 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 transport cost of tradable goods.

¹¹ The percentage effect (*PC*) corresponds to $PC = (\exp(b)-1)*100$ where *b* is the respective log-difference. (e.g. Halvorsen & Palmquist, 1980)

Fig. 1 Accessibility impact

Notes: Own calculation and illustration. Map shows log difference in MA as defined in specification (2), spatially interpolated employing ordinary kriging with spherical semivariogram model. Classification according to the JENKS (1977) algorithm.

4 Empirical Strategy and Estimated Impact

4.1 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 work. We essentially employ a two-part identification strategy.

First, 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, the identification strategy must be able to cope with gradual adjustments due to transaction cost in spatial arbitrage or anticipation effects of investment. These are expected as firms in their location decisions consider the future stream of revenues and, hence, may seek to

take first-mover advantages of moving close to a HSR line as soon as certainty about its inauguration is achieved.

Second, we test whether improved accessibility significantly explains economic growth during the adjustment period identified in the first step. 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, economic density and human capital endowment, among numerous others. Special attention is also played to the initial industry structure as well as turnover rates during the adjustment periods (churning), which increasingly attract scholarly interest.

In order to increase homogeneity within the sample, we restrict the study area to the German federal states of Hesse, Rhineland-Palatinate and North Rhine-Westphalia throughout our empirical analyses. This restriction potentially comes at the expense of underestimating the true treatment if the area as a whole benefited from the transport innovation under investigation. Before analyzing the local impact of the new HSR line we therefore compare the economic performance of our study area to the remaining counties within federal states that belong to former West-Germany, taking the evolution of population, GDP, employment and wage (measured as GDP/capita) as a benchmark (y_{it}).

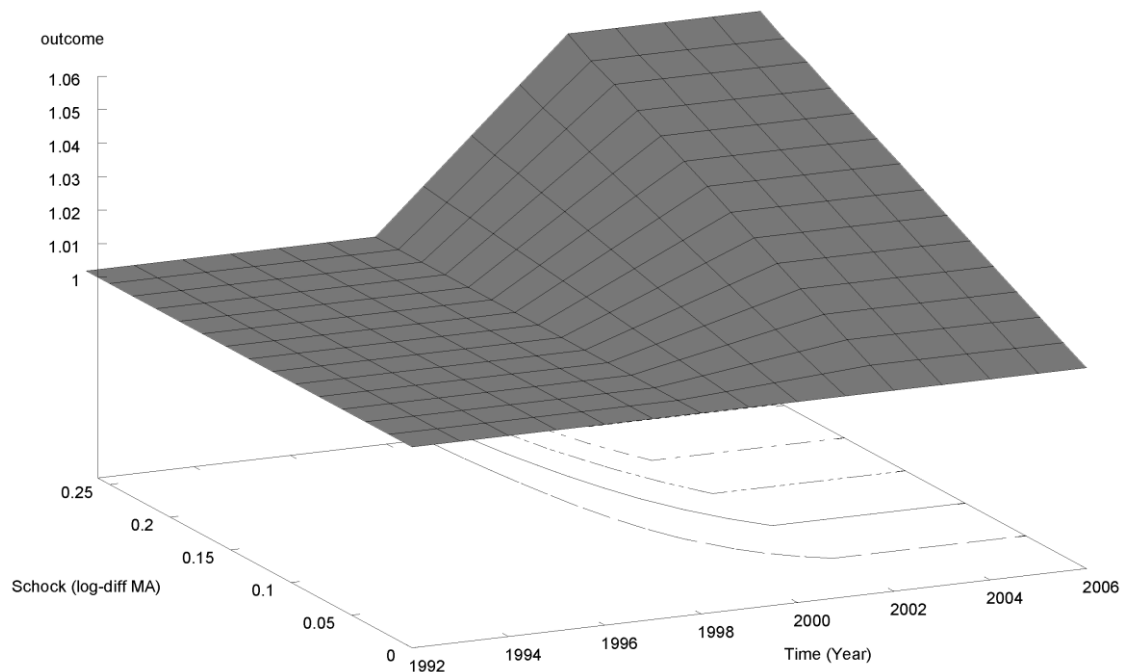
$$\log(y_{it}) = \vartheta_i + \varphi_t + \sum_{1993}^{2006} \tau_u \text{STUDY}_i \times \text{YEAR}_u + \varepsilon \quad (7)$$

Where ϑ_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 mean values for the study area and the rest of West-Germany in year u relative to the base year 1992 and effectively correspond to a series of 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.

4.2 Detecting Discontinuities

Our empirical strategy aims at identifying whether within the areas identified to be potentially affected by the shock there has been an adjustment in economic performance as predicted by theory. 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 is to compare locations that are assumed to be subject to a treatment effect to a control group that is not affected by a shock, but otherwise comparable. This approach works best if the shock can be modeled discretely both with respect to location (treatment vs. control) as well as time (before and after the shock).

Closely related, we are confronted with a two dimensional identification problem. Within our study area some locations i that are affected by a change in market access so that we expect an adjustment in economic response variables after the shock takes place. However, a discrete approach towards the subject intervention is likely to fall short. First, we can hardly rule out the possibility of a gradual adjustment towards and/or after the inauguration time t due to anticipation and spending effects during construction and/or transaction cost in spatial arbitrage. Second, and 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). Figure 2 depicts a potential economic response for locations ordered according to the intensity of the shock they experience. Our preferred indicator in these terms is the log-difference between market access (MA) after and before the shock, which is plotted in two-dimensional space in Figure 1.

Fig. 2 Outcome variable surface


Source: Own illustration.

The Figure shows how during an adjustment period there a transformation to a new spatial equilibrium, where locations systematically benefit the stronger higher their relative increase in market access is. If the change in accessibility is zero, outcome variables presumably are not affected at all. In principle, however, there might be either a) a discontinuity in the outcome variable surface along 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. Even if significant adjustments take place we it is not known a priory when the adjustment process starts and ends.

We therefore require a flexible identification strategy that can cope with all of these possibilities as well as the continuous nature of the shock. At the same time we need to take into account that any outcome variable surface is not plain either with respect to space or time, which means that locations have idiosyncratic characteristics and that the overall economic environment changes over time. As noted by Dachis, Duranton & Turner (2009), such an outcome variable surface can be described by a Taylor series expansion.

$$y_{it} = y(0,0) + \frac{\partial y}{\partial x} x_i + \frac{\partial y}{\partial t} t + \frac{1}{2} \frac{\partial^2 y}{\partial x^2} x_i^2 + \frac{1}{2} \frac{\partial^2 y}{\partial t^2} t^2 + \frac{\partial^2 y}{\partial x \partial t} x_i t + O(3) \quad (8)$$

The surface we investigate 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 most interested in the latter component that is the adjustment of the spatial economic equilibrium over time to the shock on market access. This is the component, displayed in Figure 2. In order to detect an adjustment, we translate equation (8) into the following regression based identification strategy:

$$\log(y_{it}) = \vartheta_i + \varphi_t + \sum_{1993}^{2006} \gamma_u x_i \times YEAR_u + \varepsilon_{it} \quad (9)$$

As in specification (7) a set of location fixed effects ϑ_i captures the proportion of variation in the wage surface that is solely attributable to location, hence

$$\vartheta_i = \sum_{k=1}^{\infty} \frac{1}{k!} \frac{\partial^k w}{\partial x^k} x_i^k, \quad (10)$$

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

$$\varphi_t = \sum_{k=1}^{\infty} \frac{1}{k!} \frac{\partial^k w}{\partial t^k} t^k. \quad (11)$$

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 locations specific trends that can be evaluated with respect to the change in market access and a random error term. The interactive component of time and the locations specific shock to market access is captured in specification (9) by allowing a 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 (9) 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 tests for a significant change in the treatment effect relative to the base year.

Our preferred treatment measure x_i is modeled in terms of experienced change market access. This yields a pretty strong test on the impact of market access as it not only compares areas subject to treatment to unaffected 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 coefficient estimates during an adjustment period and, constant (significant) coefficients once the new equilibrium is achieved.

While specification (9) controls for time-invariant location characteristics by means of location fixed effects, it still ignores the potential existence of long run location specific trends that are correlated with, but not caused by the change in market access. By introducing an interactive term of treatment measure (x_i) and a yearly trend variable ($TREND_t$) and omitting the 2006 *YEAR*-treatment (x_i) interactive, specification (12) tests for significant yearly deviations from a hypothetical linear relative growth path over the study period for locations that are subject to treatment. In light of positive or negative relative trends within treatment areas, a significant (positive) economic adjustment should still be reflected by a negative deviation from the long run path before effects become effective and/or a positive deviation afterwards, before eventually convergence to long run path is eventually achieved.

$$\log(y_{it}) = \vartheta_i + \varphi_t + \theta x_i \times TREND_t + \sum_{1993}^{2005} \gamma_u x_i \times YEAR_u + \varepsilon_{it} \quad (12)$$

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 und Mullainathan (2004) in all estimations.¹²

¹² The LM test statistic is $LM_5 = \sqrt{NT^2/(T-1)}(\tilde{v}'\tilde{v}_{-1}/\tilde{v}'\tilde{v})$; asymptotically distributed as $N(0,1)$.

As already noted, our preferred treatment is a change in market access measure as any discrete definition of treatment area falls short in accounting for the distinct magnitudes to which locations are exposed to the shock. It is also preferred for a contentious treatment in terms of distance to stations that, even when adjusted for road infrastructure, will not account for complex transport decisions. Clearly, the benefits of access to a HSR connection increases distance to the economic core regions around Frankfurt or Cologne and therefore varies along concentric distance rings around intermediate rail stations. The highest level of geographic detail for which data considered in our analyses are available refers to county level (NUTS3/"Kreise und kreisfreie Städte"). In order to maximize precision we first calculate market access (MA) indicators as defined in (1) for the level of municipalities h before aggregating them to county i level, weighted by population P .

$$MA_{ti} = \sum_h MA_{th} \frac{P_h}{P_i} \quad (13)$$

This method is preferable to the alternative of connecting geographic centroids of counties directly as it accounts for the effective population distribution within counties. Substituting equation (13) into (2) and taking log differences in market access with $(t+1)$ and without (t) the new HSR track being available, our preferred treatment measure (x_i) thus takes following form:

$$x_i^a = \log\left(\sum_h \frac{P_h}{P_i} \sum_g Y_g \exp(-\alpha_2 tt_{hgt+1})\right) - \log\left(\sum_h \frac{P_h}{P_i} \sum_g Y_g \exp(-\alpha_2 tt_{hgt})\right) \quad (14)$$

Note that in order to avoid endogeneity problems we strictly aggregate across 2002 GDP (Y) of municipalities g , weighted by travel time (tt). Similarly we use 2002 population (P) for the aggregation of the municipality (h) to county level (i) in both periods. As a result, x_i represents the required exogenous accessibility treatment. By definition the indicator takes either positive values if areas benefited or a value of zero if an area remains unaffected. Although the market access treatment employed so far is our preferred measure of the accessibility shock, it is also interesting to investigate how the economies responded particularly specifically within the immediate catchment area of the HSR stations Limburg and Montabaur. As discussed, these intermediate stations are the result of policy games and their inauguration therefore provides exogenous variation

narrowest sense. As an alternative treatment variable we define a discrete treatment variable denoting the three counties closest to the respective stations.

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

A third treatment variable is defined, which will be used as an instrument for the market access shock 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 (ttC). Travel time reductions are illustrated in Figure A1 in the appendix. As expected, gains in accessibility are achieved between the intermediate stops along the HSR track and concentrated around the middle stop "Montabaur".

$$x_i^c = \log \sum_h \frac{P_h}{P_i} \min(ttF_{ht+1}, ttK_{ht+1}) - \log \sum_h \frac{P_h}{P_i} \min(ttF_{ht}, ttK_{ht}) \quad (15)$$

Adjustment Processes

Figure (3) illustrates results for a series of specification (0) (left column) and (12) (right column) regressions, showing indices of relative performance as revealed by γ_u coefficients on the background of the respective 90% confidence intervals. The displayed estimates use our preferred continuous treatment measure defined as the log-difference in market access (x_i^a). Results depicted in the first row, which refer to GDP as a response variable, point to a pronounced positive adjustment in GDP levels starting after 1998 and reaching a new plateau 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 heap, also statistically significant, is notable at 1996, the first year of construction (left column). The adjustments from 1998 to 2002 become even more evident if treatment effects are tested against the linear long-term trend (right column). These findings are in line with considerable investment due to anticipation of relative gains in location productivity that were expected to become effective with the inauguration of the new line. While the minor effects in 1996 seem to have been quickly reversed, the major adjustment seems more persistent after 2002.

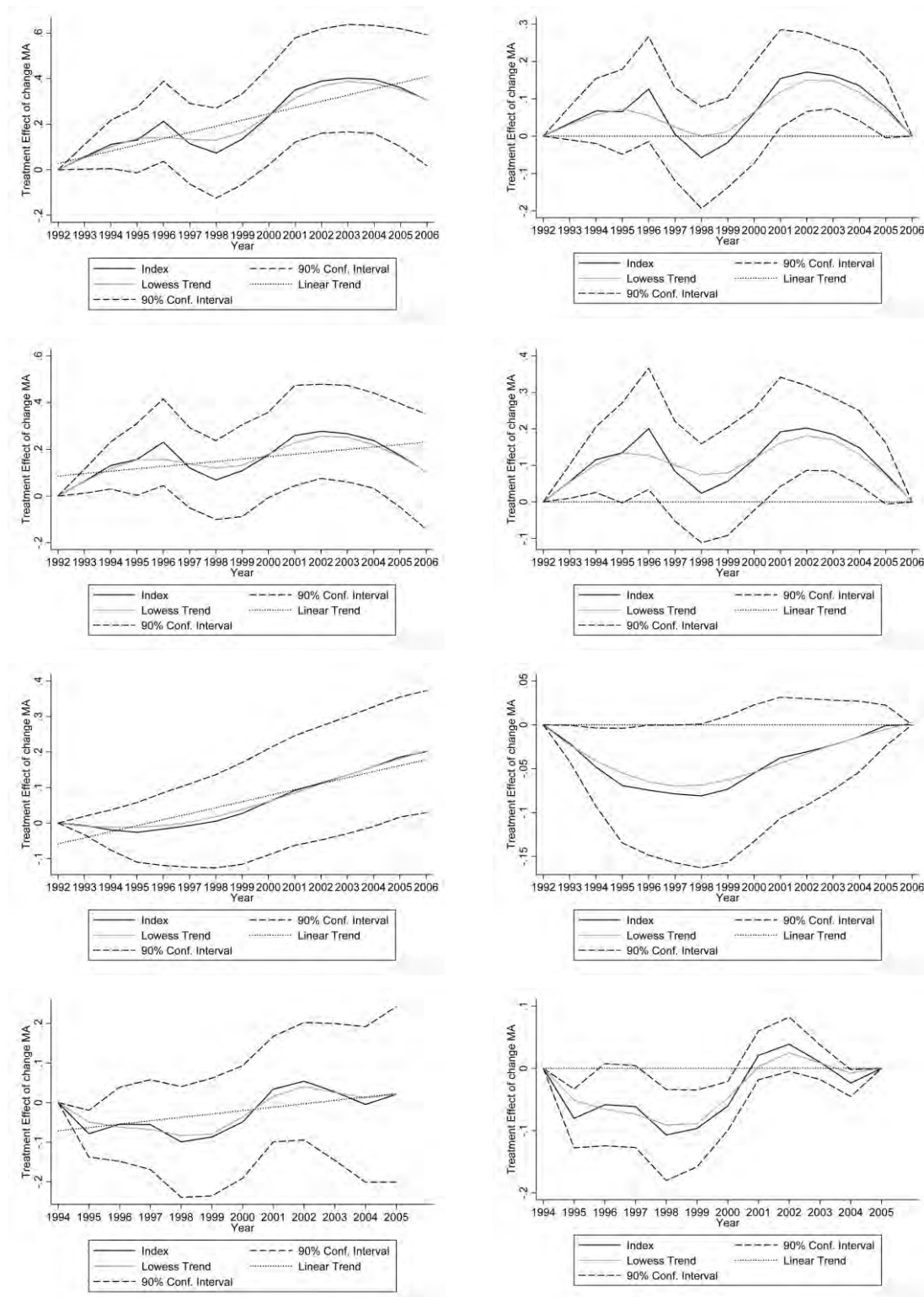
These findings are largely confirmed using GDP per capita as the outcome variable (row 2). The adjustments are somewhat weaker, owed to an increasing attraction of population after 1998 (see row 3). These findings are in line with the prediction that increases in GDP per capita and, hence, nominal wages, initiate worker migration. Note that while in terms of population treatment areas seem to have been at a positive (relative) growth path since 1996, deviations from the linear trend show that the adjustment considerably gained pace after 1998. A pronounced adjustment is also evident in terms of workplace employment (row 4). Both in absolute (left) as well as relative (right) terms, treatment areas perform modestly adverse until 1998, followed by an evident positive shift until 2002. 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) are in support of significant adjustments.

A newly available HSR connection potentially not only impacts on resident location choices through increased economic output and nominal wages, but may also attract residents directly as a result of reduced commuting times. In surveys, HSR commuters were found to account for a considerable proportion at overall traffic at the rail stations in Montabaur and Limburg. If new residents were attracted that commute to the economic centers via the HSR (or existing residents switched to respective jobs), one would expect an increase in the proportion of out-of-town commuters at 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 at the local workforce (workplace) point to a negative long-term trend, hardly exhibiting evidence of a discontinuity. A similar finding holds for land values, showing that the price of the immobile factor land did not systematically increase where accessibility was improved.

Our discrete treatment measure (x_t^b) generally yields similar results. As shown exemplarily for GDP (row 1) and GDP per capita (row 2) in Figure 4, there are a significant positive adjustments between 1998 and 2002. Two results, however, are notable. First, land values within treatment areas follow a positive (instead of negative) trend relative to the control group, although it is still difficult to reject that the evolution is not related to the

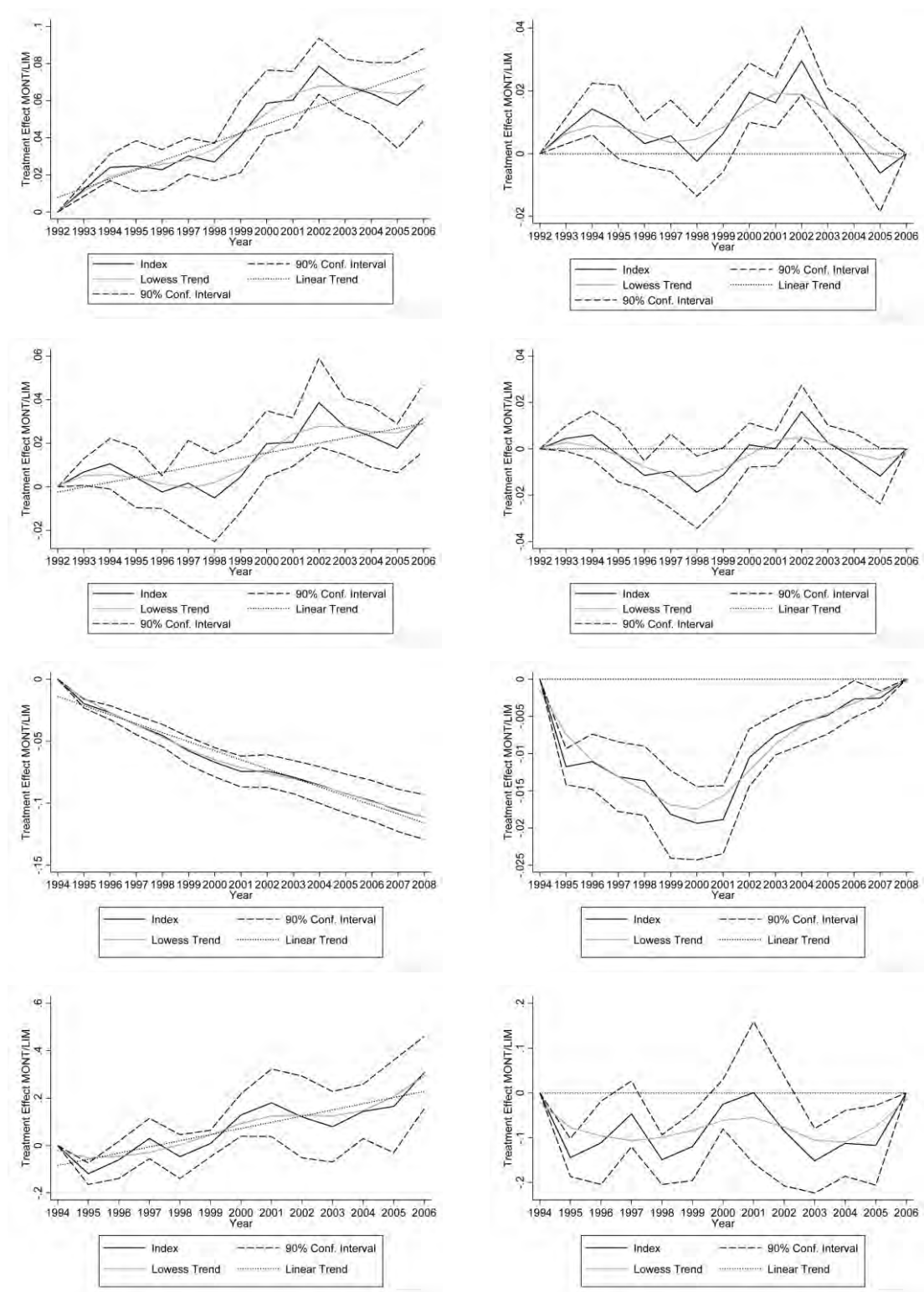
subject rail line. Second, while the share of out-of-town commuters at total workforce (by place of residence) continuously declines over time, there is strong evidence for a decline in the yearly rate of reduction after the HSR line opened in 2002.

Fig. 3 Market Access Treatment



Notes: Figure illustrates time-varying treatment effects according to specification (9) (left column) and (12) (right column). Treatment is log-difference in market access. Outcome variables by row: 1) GDP, 2) GDP/capita, 3) population, 4) employment (workplace).

Fig. 4 Discrete Treatment (catchment area stations Montabaur/Limburg)



Notes: Figure illustrates time-varying treatment effects according to specification (9) (left column) and (12) (right column). Treatment variable is a dummy for counties adjacent to stations Limburg and Montabaur.. Outcome variables by row 1) GDP, 2) GDP/capita, 3) share out commuters at employment (residence), 4) standard land values.

Treatment Effects

Our results presented so far indicate significant (positive) changes in the level of economic activity. In order to explicitly test for a significant level shift in GDP following the opening of the HSR line we employ a hybrid of specification (9) and a more traditional DD or RDD approach. A dummy variable (*POST*) that denotes the period after inauguration beginning in 2002 is therefore interacted with the treatment measure to yields the treatment effect (δ). A set of individual treatment (x_i) *YEAR* interactives for 1999-2001 accounts for the evident 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 to be correlated with our indicator variable in light of unobserved location specific trends, which could bias our treatment estimates.

$$\log(y_{it}) = \vartheta_i + \varphi_t + \sum_i \Omega_i TREN D_{it} + \sum_n \sum_{1999}^{2001} \gamma_{un} x_i \times YEAR_{un} + \sum_n \delta_n x_{in} \times POST_t + \varepsilon_{it} \quad (16)$$

The subscript n denotes treatment measures a and b defined above, which will be introduced separately and jointly into empirical models. The coefficient on our indicator variable basically yields a traditional difference-in-difference estimate as the specification differentiates the response variable across location (treatment/control) and time (pre/post).

$$\log(y_{i,POST=1}) - \log(y_{i,POST=0}) = \delta x_{in} \quad (17)$$

Note that the treatment coefficient can be interpreted as market access elasticity if we use the market access treatment (x_i^a).

$$\delta_a = \frac{\log(y_{i,POST=1}) - \log(y_{i,POST=0})}{\log(MA_{i,POST=1}) - \log(MA_{i,POST=0})} \quad (18)$$

If we employ our discrete treatment measure (x_i^b) 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.¹³

¹³ $PD = (\exp(\delta) - 1) * 100$ (Halvorsen & Palmquist, 1980)

$$\delta_b = (\log(y_{i,POST=1}) - \log(y_{i,POST=0}))^{x_i^b=1} - (\log(y_{i,POST=1}) - \log(y_{i,POST=0}))^{x_i^b=0} \quad (19)$$

Results presented in Table 1 reveal positive and significant treatment estimates 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 of close to 5% is found (2). If linear trends at the county level are accounted for, the estimated market access elasticity slightly falls 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 more sensitive to the individual trend control as the treatment effect is reduced to 2.7% (5). The estimated treatment effects are roughly in line with the level shifts suggested by the non-parametric estimates displayed in the first row (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).¹⁴

In sum, our results provide compelling evidence for an increase in economic activity within areas that gained in access to regional economies following the opening 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 in addition to time-invariant location characteristics as well as common macro-economic shocks, our market access treatment entirely explains the shift in the level of economic activity within those areas that were affected most strongly by the variation in accessibility that reasonably may be assumed as exogenous.

¹⁴ 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 ($x_i^a \times POST$)	0.271* (0.118)		0.212 (0.169)	0.217 (0.143)		0.213 (0.214)
Discrete Treatment ($x_i^b \times POST$)		0.047** (0.010)	0.022 (0.023)		0.027** (0.006)	0.001 (0.028)
Year Effects	Yes	Yes	Yes	Yes	Yes	Yes
County Effects	Yes	Yes	Yes	Yes	Yes	Yes
Anticipation Effects: x_i^a	Yes	-	Yes	Yes	-	Yes
Anticipation Effects: x_i^b	-	Yes	Yes	-	Yes	Yes
Trend Effects	-	-	-	Yes	Yes	Yes
Observations	1725	1725	1725	1725	1725	1725
R-squared (within)	0.84	0.84	0.84	0.94	0.94	0.94

Notes: Endogenous 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.

4.3 Determinants of Growth

Results presented in the subsection above strongly indicate that economic adjustments attributable to the accessibility shock under investigation largely took place between 1998 and 2002, implying that economic agents anticipated the effects of the high speed rail line by the time of inauguration. Focusing on this period, this section investigates whether alternative explanations for the observed economic adjustments can be ruled out. Our baseline specification tests whether the growth in economic activity measured in GDP (y) from 1998 (t) to 2002 ($t+1$) is explained by the respective change in market access conditional on a vector of control variables (Z).

$$\log(y_{it+1}) - \log(y_{it}) = \phi(\log(MA_{it+1}) - \log(MA_{it})) + Z_i\Psi + \xi_j + \varepsilon_i \quad (20)$$

where MA_{it+1} and MA_{it} are defined as in (1) and (13), ϕ provides an elasticity estimate on the impact of market access, and ξ_j are federal state (Bundesländer) fixed effects that account for institutional heterogeneity. 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 (20) effectively corresponds to an extended version of standard empirical growth models. The specification also shares similarities with the approach employed 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 distinguishing between time as well as control and treatment (T) locations.

$$\phi(\log(\text{GDP}_{it+1}) - \log(\text{GDP}_{it})) = (\log(y_{it+1}) - \log(y_{it}))^T - (\log(y_{it+1}) - \log(y_{it}))^C \quad (21)$$

Conditional estimates on the impact of the change in market access according to specification 21 are presented in Table 2. A simple regression of GDP growth on change in MA yields an elasticity coefficient of about 0.3 (1). This is slightly more than suggested the results discussed so far, but brought back into the 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 / capita to control for potential driving forces for convergence growth (and log of GDP per area as measure of economic density and urbanization and related (dis)economies. 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 without the HSR line as indicators of 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 (13). Column (5) extends the set of explanatory variables by the share of mining, services and manufacturing at 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.

After all it's noteworthy that the estimated elasticity parameters all lie within a relatively small range that is close to the results obtained in the section above. Estimates obtained from 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), although the number of observations is fairly limited. This is particularly remarkable as, with the exception of 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** (0.093)	0.218** (0.068)	0.296** (0.111)	0.208 (0.127)	0.246+ (0.139)	0.247+ (0.140)
Log Diff GDP (1992-1998)						0.011 (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: 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.

Endogeneity

A common concern when investigating the economic effects of transport infrastructure is that the event of a new infrastructure being built is not entirely exogenous, that is 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 subject variable is correlated with the error term. As discussed, the areas exposed to the largest increase in market access, are those that benefit from the intermediate stations “Montabaur” and “Limburg”. These stations are the result of a long process of political bargaining rather than being related to the local economic conditions. We further argue that for the whole track the timing of the construction can be considered as exogenous. While the connection per se clearly followed existing pattern of economic agglomeration, it is important to note that the track had been discussed since the 1960s. The decision to build the track dates effectively back as far as to 1969. During the 1970s, however, following sever opposition of numerous activist groups and lengthy negotia-

tions among stakeholders the track was even temporarily excluded from the Federal Transport Infrastructure Plan. Negotiations continued during the 1980s, particularly on several potential routes. When the Minister of Transport finally decided that the track would be developed on the east of the Rhine in 1989, this decision was made with little regard to the expected economic prospects of the subject region during the end 1990s, but rather perceived as the outcome of a historic policy game that had finally come to an end. On these grounds there is little reason to believe that the shift in market access was not exogenous to the economic adjustments within the identified adjustment period from 1998-2002. We will provide further evidence that the impact of our market access treatment variable is indeed exclusive the adjustment period in section 4.4.

To further reject endogeneity concerns, however, we introduce instruments for the market access treatment, which satisfy 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 4.2. Log-difference in minimum travel time to the closest economic core following the inauguration of the new track (x_i^c), which is defined and illustrated in equation (15) and Figure A1, and the discrete treatment for counties adjacent to the intermediate stations (x_i^a) are clearly correlated with the shock and only make use of the variation that we assume to be “purely” exogenous. In Table 3, we re-estimate selected Table 2 type specification in a 2SLS approach, instrumenting the market access treatment variable. First stage results are presented in Table A5 in the appendix. Compared to Table 2, column (2) and (5), the results change only slightly, with the magnitude and significance level of the treatment coefficients even increasing. Overall it seems fair to state that endogeneity concerns are very limited in the subject case.

Tab. 3 GDP growth and MA change 2SLS

	(1)	(1)
Log Diff MA	0.319* (0.125)	0.296* (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 (xic) defined in equation (15) and our discrete treatment variable xib. First stage results are presented in Table A5. Robust standard errors are in parenthesis. **/*/+ indicate significance at the 1/5/10% level.

Treatment heterogeneity

In order to test whether different cities were affected distinctly depending on their characteristics, there is heterogeneity in the market access treatment effect, we estimate a set of extend type (20) specifications. We introduce an interactive term of our market access treatment variable and a dummy variable D that denotes counties within the upper 50 percentile of selected interest variables e .

$$\log(y_{it+1}) - \log(y_{it}) = \phi(\log(MA_{it+1}) - \log(MA_{it})) + \varrho(\log(MA_{it+1}) - \log(MA_{it})) \times D_{ie} + Z_i\Psi + \xi_j + \varepsilon_i \quad (22)$$

Parameter ϱ provides an estimate on the difference in the market access elasticity for counties with above median characteristics and the rest. We test for treatment heterogeneity with respect to 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. Results presented in Table 4, however, do not allow rejecting the hypothesis of homogenous a treatment effect. If at all, the fact that the introduction of the services interactive (5) considerably reduces the magnitude and the estimation precision of the market access treatment variable might be indicative for the local industry mix influencing the reception of the accessibility shock. Similarly, no

treatment heterogeneity is revealed if our market access treatment is interacted with continuous variables, with the exception of weak evidence for more urbanized areas (higher population density) showing a somewhat stronger reaction.

Tab. 4 Treatment heterogeneity

	(1)	(2)	(3)	(4)	(5)
Log Diff MA	0.247+ (0.138)	0.243+ (0.141)	0.248+ (0.142)	0.250+ (0.149)	0.185 (0.268)
Log Diff MA x D	0.034 (0.233)	0.047 (0.232)	-0.035 (0.255)	-0.023 (0.268)	0.076 (0.268)
Heterogeneity	Pop	GDP/pop	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

Notably, the identified adjustment period falls into the construction period from 1995-2001. One might therefore be concerned that the revealed economic stimuli might be partially driven by spending effects related to the construction of tracks beds, including bridge and tunnel works. As some of the counties through which the tracks were built naturally belong to the area that benefited from the HSR connectivity, the treatment coefficient could be upward biased if GDP growth was significantly promoted by construction works. A second natural 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 along the old mainline along the western Rhine river bank. A negative substitution effect for counties along the western Rhine river bank, by affecting the control group, could upward 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 experienced increase in accessibility and macroeconomic controls the respective counties over the four year study period, in average, experienced economic growth that was 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. Controlled for this negative treatment the estimated market access elasticity even slightly increases to 0.32, significantly estimated at the 5% level. Estimated substitution effects along the old rail connection are very close to zero and do not pass conventional significance criteria, while 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 with 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* (0.138)	0.246+ (0.139)	0.323* (0.139)
Construction	-0.033* (0.015)		-0.035* (0.018)
Substitution		0.002 (0.016)	-0.008 (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 river bank 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)

Regions and cities economic structure is determined by their local industries and their composition naturally influences growth. In an attempt to control for alternative determinants of GDP growth besides the subject shock to market access, 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, 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 “churning” of industries occurs across cities and develops a theoretical framework which predicts cities that are mobile along the city hierarchy due to endogenous industry relocations to 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.¹⁵ In addition, we shed light on whether the new HSR line itself promoted industrial turnover within our study area.

$$ExcChurn_i = \frac{1}{T} \left(\sum_t \sum_z \frac{|GVA(z,i,t+1) - GVA(z,i,t)|}{GVA(i,t)} \right) - \frac{1}{T} \left(\sum_t \frac{|GVA(i,t+1) - GVA(i,t)|}{GVA(i,t)} \right) \quad (23)$$

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 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 findings for the two component of the excess churning index to existing evidence for France, USA and West-Germany. It is evident that compared to USA and France average turnover occurs at a relatively lower rate in Germany, and within slightly lower than average German rate within our study area, although our estimates a pretty close to those provided by Findeisen & Südekum (2008). Similarly the distribution of the excess churning rates within our study area resembles their findings for West Germany (see Figure A3 in the appendix).

Tab. 6 Churning in France, Germany and USA

	<i>Churn</i>	ΔEmp (ΔGVA)	<i>Churn</i> / ΔEmp (ΔGVA)
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

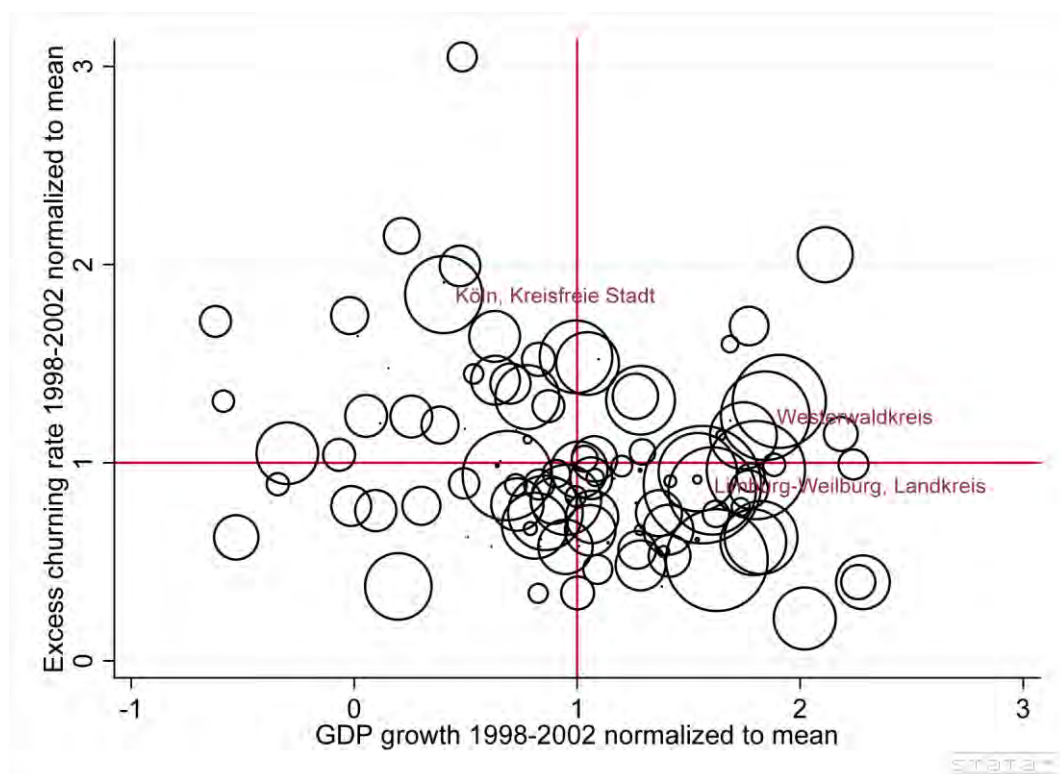
Notes: Values obtained from own calculations (study area), Duranton (2007) (USA, France) and Findeisen & Südekum (2008) (West-Germany).

Figure 5 provides a classification of counties within our study area with respect to the growth and excess churning rates relative to the sample average. The experienced shock to market access is revealed by the size of the markers that stand for individual observations. Notably, there is a concentration of counties that benefit from the transport inno-

¹⁵ We use GVA data obtained from EUROSTAT on the seven industrial sectors construction, manufacturing, mining, trade & retail, banking and public services.

vation under investigation in the right section that indicated above average growth rates. No positive correlation, instead, is evident between increase in market access 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 as defined in (23). The size of the dots reflects the experienced change in MA as defined in (14).

Conditional estimates provided in Table 7 confirm that industrial turnover does not explain the growth effects within the treatment areas. Compared to Table 2 results, the estimated market access elasticity remains virtually unchanged and is still estimated at a satisfying 10% level of significance. 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 for a dominance of “structural change losers”. These cities are in a process of industrial transforma-

tion, but the gains from raising sectors are (still) not large enough to compensate for losses from the declining sectors. Typical cities, accordingly, lie within the traditionally coal & steel dominated Ruhr area in North Rhine-Westphalia (NRW), which belongs to our study area. Note that if the qualitative implications of industrial turnover were different outside NRW, e.g. because 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 would not allow for heterogeneity in the respective treatment effect the variable would not appropriately capture the turnover effect at the locations where market access increased most strongly (these areas lie outside of NRW) so that the estimated market access elasticity would be biased. In order to allow for 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 column (3) results show, 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.

Besides the impact of market access on economic growth, conditional on industrial turnover, an interesting subject is whether a market access shock 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 a 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 change in market access on the excess churning index can be established. The dependency of industrial turnover on city size and industrial composition (see Findeisen & Südekum, 2008) raises concerns that Table 4 (1-3) estimates may suffer from endogeneity problems. 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* with the log of county population and sector shares (mining, services, and manufacturing) at GVA in 1998 and omit industrial controls in column (4). We also omit the log of GDP from GDP controls due to collinearity with log of population, which is used 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 industrial turnover. While the coefficient on the excess churning index is considerably reduced and no longer impacts significantly on growth, the estimated coefficient of our primary interest variable remains virtually unchanged.¹⁶

Tab. 7 Growth and MA conditional on churning

	(1)	(2)	(3)	(4)
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: Endogenous variable is log difference (2002-1998) in GDP in all models. ExChurn is defined in equation (23). 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 river bank 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.

4.4 Persistency

The research strategy employed in this sub-section implicitly builds on the assumption that economic adjustments to the availability of the HSR line took place during the period from 1998 to 2002. This adjustment period is strongly indicated by the non-

¹⁶ First stage results are provided in Table A4, column (4).

parametric treatment estimates provided in section 4.2. In order to affirm this notion on the basis of conditional estimates that consider alternative explanations for economic growth we repeat selected Table (2) type estimates for one period prior (1995-1998) and one period after (2002-2006). Results clearly confirm that the positive impact of our generated MA treatment is limited to the identified adjustment period. Our MA treatment variable 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 for 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 period

	(1)	(2)	(3)	(4)
Log Diff MA	-0.053 (0.086)	-0.139 (0.126)	-0.092 (0.091)	-0.141 (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

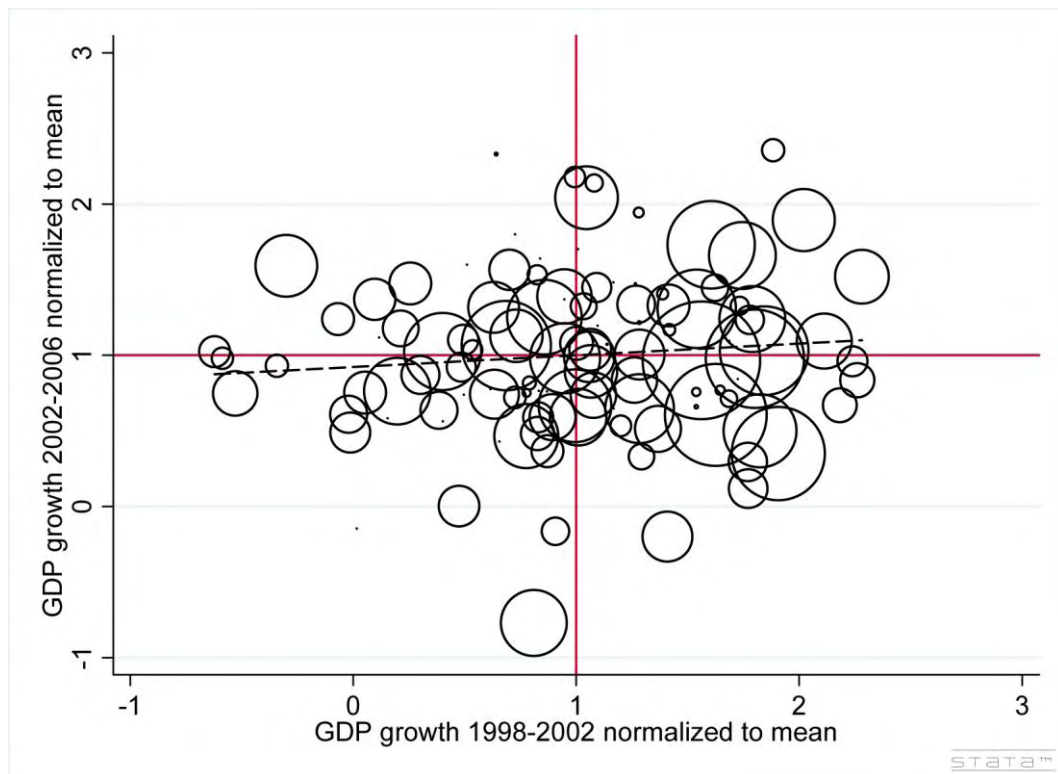
Notes: Endogenous variable is log difference (1995-1998) in GDP in models (1-3) and (2002-2006). GDP controls in columns 1-3/4-6 include log of GDP (1995/2002), log GDP (1995/2002) per capita and log of GDP (1995/2002) per area. Geo controls include log of altitude, log of distance to the nearest navigable 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 (23). 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 considering such large shocks as war devastations during WWII in Japan and Germany, economic activity was found to re-converge relatively

quickly to the prior spatial equilibria (Brakman et al., 2004b; Davis & Weinstein, 2002). These findings were interpreted in support of location fundamental theories that state that the long run distribution of economic activity is determined by primary geography. Regarding newer economic geography theories that emphasize increasing returns as a driving force of spatial concentration (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 of sustainably promoting economic development by means of temporary public investment. It is therefore worth having a closer look on 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 while visualizing the degree to which locations were affected by the market access shock (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 gains in market access 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 for reversion (see dashed trend line).

Fig. 6 Growth rates and change in market access



Notes: Own illustration. GDP growth measured in log differences. The size of the dots reflects the experienced change in MA as defined in (14).

Davis & Weinstein (2002) develop a more formal framework for empirically testing to which degree a temporary shock reflected in growth rates is dissipated in the subsequent years or whether the structure of a city system is altered permanently. Derived from their empirical framework Davis & Weinstein (2002) 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.

$$\log(y_{it+2}) - \log(y_{it+1}) = (\rho - 1)(\log(y_{it+1}) - \log(y_{it})) + \mu \tag{24}$$

If $\rho=1$, which implies an estimated coefficient of zero, then the shock accordingly had a permanent impact on the city system. In contrast, if $\rho=0$, which implies an estimated coefficient of -1, then the shock is fully dissipated after one period. In practice, in such an empirical approach we are almost certainly confronted with severe measurement error problems since growth rates during the shock period will contain not only 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 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 24, 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 also use the predicted values from the first stage regression of model (1) in models (2) and (3). The results imply a ρ parameter close to 1 and, hence, that we cannot reject the shock to have remained persistent.

Still, the negative sign of the coefficient estimate suggest 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 idea that pre-trends are random in the sense that they are uncorrelated with the shock. Table 8 results, however, indicate that individual trends might exhibit a weak negative correlation with the shock in both the pre- and the post period as the treatment coefficients exhibit negative values of similar magnitude, although not satisfying conventional significance criteria. Assuming that counties follow individual medium term growth paths, persistency of the shock would imply a return to the long run growth pattern. Following the same inherent logic underlying equation (24), this implies that the *change* in growth rates from the period prior to the shock to the shock period is 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 $\rho=1$, $\rho=0$ implies persistency.

$$\begin{aligned}
 & [\log(y_{it+2}) - \log(y_{it+1})] - [\log(y_{it+1}) - \log(y_{it})] = \\
 & (\rho - 1)([\log(y_{it+1}) - \log(y_{it})] - [\log(y_{it}) - \log(y_{it-1})]) + \mu
 \end{aligned} \tag{25}$$

In this framework, our measure of the shock, hence, is the change in growth rates from 1995 ($t-1$) – 1998 (t) to 1998 (t) – 2002 ($t+1$), which we again instrument using the acces-

sibility treatments x_i^a and x_i^b . The endogenous variable respectively is the change in growth rates from 1998 ($t-1$) – 2002 (t) to 2002 (t) – 2006 ($t+1$). Figure 7 illustrates an evident negative correlation between the two trend changes. The bulk of the observations that experienced a large market access shock experienced a positive impact on trends when entering and a negative impact when exiting the adjustment period (lower right section). 2SLS estimates of changes in growth trends (column (4)) yield a coefficient estimate close to and not statistically distinguishable from -1, but significantly different from zero. This implies a complete return to pre-shock trends and, hence, that the increase in market access only impacted on trends temporarily.

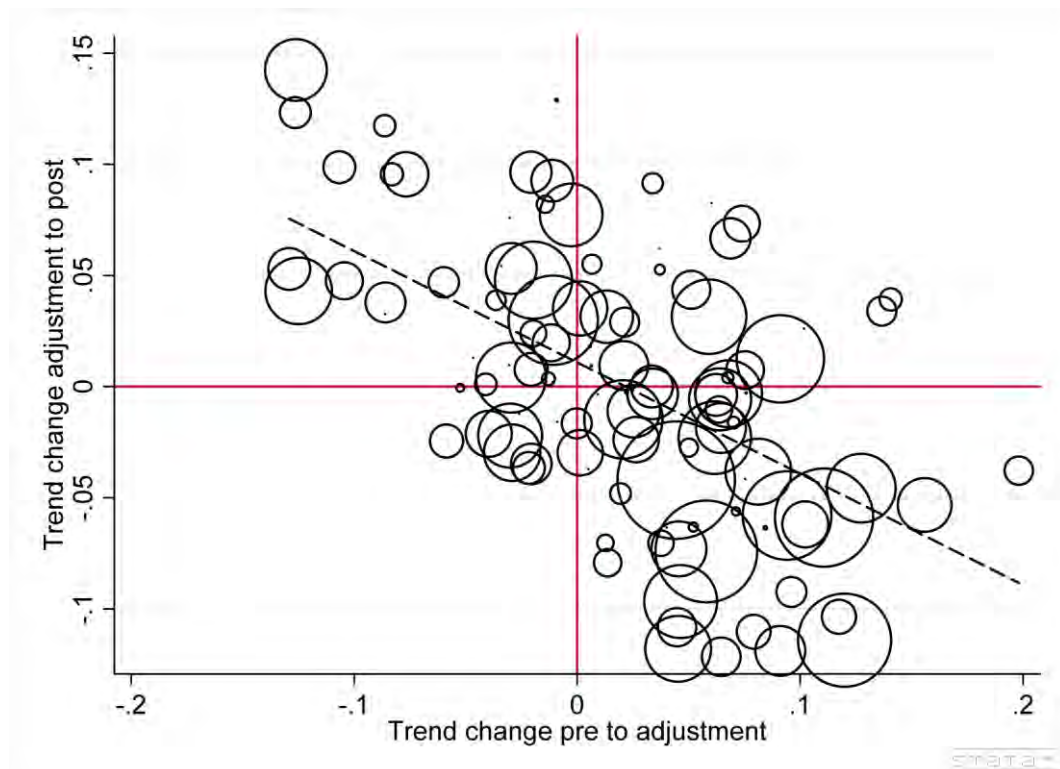
Although these results should be interpreted with some care as the explanatory power of the model is fairly limited, our 2SLS estimates provide further support for the notion that the MA treatment effects we investigate are limited to the adjustment period and that the respective level shift is not dissipated 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, however, important to bear in mind that while its impact on growth rates was temporary, the shock itself clearly was not. Our results, hence, cannot support that purely temporary economic policies in general promote economic activity sustainably. Rather, we show that improvements in the transport geography, if fundamental, by permanently shifting accessibility pattern represent a feasible strategy to induce permanent shifts the distribution of economic activity through temporary (public) investment. 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 persistency of the shock is likely to be the permanent change in location quasi-fundamentals.

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 (1995-98)			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 (23). 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 (14)

4.5 Estimated Tax Revenues

In light of construction costs that are typically large for HSR projects, a natural question to ask is not only whether the economic adjustments were significant in statistical terms, but also whether their magnitude justifies the commitment of public funds. A simple way to address this question is to assess the expected tax revenues and to compare them to the construction costs. If an increase in tax revenues is likely to exceed construction cost, then public funding will be viable from a public budgetary point of view, although this perspective obviously does not account for a range of potential environmental costs. On the basis of the estimated elasticity coefficient from Table 6, column 6 the simulated change in market access and the 1998 county level GDP the yearly increase in aggregated GDP in 1998 prices can be approximated to about € 6 billion, which corresponds to 0.87% of the GDP of the study area. Based on an average tax ratio (*TR*) of 22% (BMF, 2008) and a “naive” discount rate (*DR*) of 5%-10%, which is ought to include future public contributions to maintenance and replacement costs, the GDP increase can be

translated into a present value of tax revenues (*PVT*) of about € 13.3-26.6 billion, which is large compared to the official construction cost of about € 6 billion. Given that the impact on growth rates shows persistency, the assumption of an infinite stream of revenues seems justified. These estimates, however, represent upper bound estimates in the sense that they assume that the estimated impact on GDP to be driven by productivity gains that increase total GDP rather than by treatment areas benefiting at the expense of the control group.

$$PVT = \sum_i \hat{\phi} \times (\log(MA_{it+1}) - \log(MA_{it})) \times GDP_{i1998} \left(\times \frac{TR}{DR} \right) \quad (26)$$

5 Conclusion

This study provides an evaluation of economic effects if high speed rail in the realm of recent economic geography research. A distinctive feature of the Cologne-Frankfurt, Germany high speed rail track that is subject to analysis is that it provides variation in accessibility along two intermediate stops that can reasonably be assumed as exogenous. This helps to alleviate 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 that has emerged in the U.S. at least since President Obama 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 an early stage with regard to empirical evidence. Our hypothesis is that by driving economic agents closer together, the increase in accessibility to regional markets should promote economic development within regions that are subject to treatment. We employ several treatment measures, amongst them our preferred measure that compares a Harris type market potential in the situations where choose a combination of individual transport and HSR for any connection in the study area to the situation where no HSR is 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. Accounting for the adjustment period and individual location specific levels and trends as well as overall economic

shocks we detect a significant discontinuity in the level of economic activity measured in GDP within areas adjoining two intermediate rail stations, which were exposed most strongly to the (exogenous) variation in market access. These areas accordingly experience a 2.7% level shift in GDP relative to the rest of the study area, which can be entirely explained by our market access treatment measure. In a further step we show that growth effects attributable to the shift in market effects are robust to a range of alternative explanations, convergence growth, economic density, primary geography, industrial composition, including turnover as well as construction and substitution effects. Throughout our analyses we find a market access elasticity that indicates a 0.25% growth in GDP for any 1% increase in market access. Finally, our results indicate that the observed growth effects remained persistent as a) growth is not reversed during the subsequent years and b) there is 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. Rather, we observe a hybrid effect where economic adjustments driven by mechanisms emphasized by increasing returns theories, but persistency of effects can be explained by the permanent nature of the accessibility shock, hence, a permanent change in location quasi-fundamentals. This is the distinguishing element compared to previous studies that investigated purely temporary shocks like war destructions where little evidence for permanent shifts in economic activity. could be found.¹⁷

Our results indicate that large-scale infrastructure projects, unlike subsidies and/or tax-reliefs that are purely temporary in nature, possess the potential to promote permanent regional economic development by means of temporary (public) spending. In line with existing evidence, economic adjustments were anticipated by the time of the opening of the new HSR line. Based on the identified GDP effects and the correspondingly expected tax increase, the HSR project is economically viable in the sense that the present value of returns over an infinite horizon is large compared to initial investments, even if high discount rates are assumed. Effectively, investment would not exceed revenues unless the

¹⁷ In their seminal contribution Davis & Weinstein (2002) investigate the effects of allied bombing on Japanese cities during WWII. Brakman et al. Similarly investigate the effects of WWII destruction in Germany.

discount rate exceeded € percent. On the one hand, these figures represent upper-bound estimates in the sense that they assume that growth within treatment areas did not come at the expense of control areas. On the other hand, the reduction in transport cost 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.¹⁸ For highway construction projects, which facilitate the transport of physical goods in addition, the market access elasticity might be even larger.

After all, besides being encouraging with respect to economic effects of HSR and confirming the theoretically predicted role of market access as causal determinant of economic wealth, our findings indicate a potentially powerful application of NEG models. Empirically calibrated models may serve as powerful tool for predicting economic effects of new large-scale infrastructure projects and help authorities to define priorities. As large-scale transport infrastructure projects usually feature among the most expensive public investment projects, a more efficient resource allocation offers the potential for considerable welfare gains. More studies, however, are clearly required to confirm the generalizability of the presented results qualitatively and quantitatively.

¹⁸ Statistical economies of scale, which can arise from reduced labor market 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).

Appendix

The so-called wage equation (Fujita et al., 1999, p. 53) can be derived from structural relationships of general-equilibrium spatial models:¹⁹

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

where w_i is the nominal wage in region i and Y_j the income in location j . τ is the unit transport cost and d_{ij} the distance between region i and j . 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:

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

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 available at a 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.²⁰ 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 expression $-\tau(\sigma - 1)$ into a

¹⁹ 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).

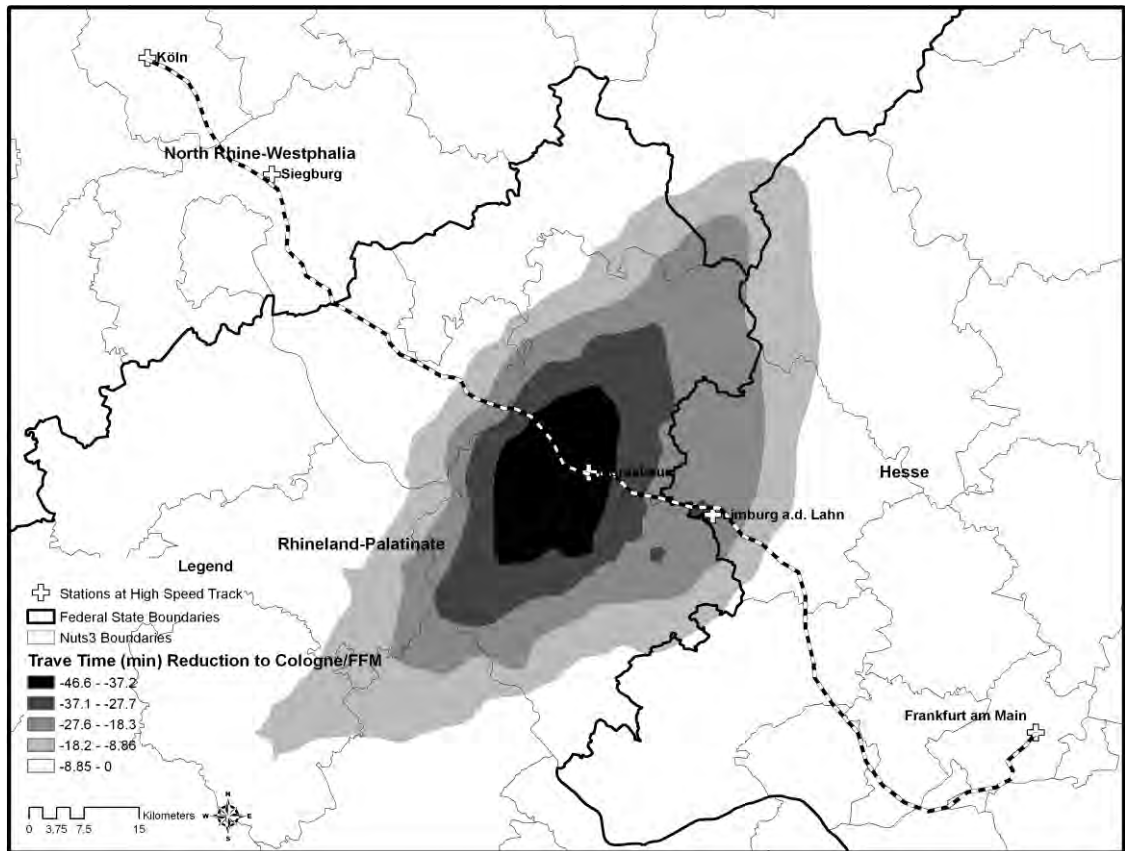
²⁰ See Roos (2001). For different approaches to overcoming these shortcomings by means of substituting the price index by other equilibrium conditions see, e.g., Hanson (2005, p. 6) or Niebuhr (2006, p. 317).

single coefficient (α_2) which we refer to as distance decay parameter or spatial weight parameter in the remainder of the article. Equation (2) can be written in a reduced form:

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

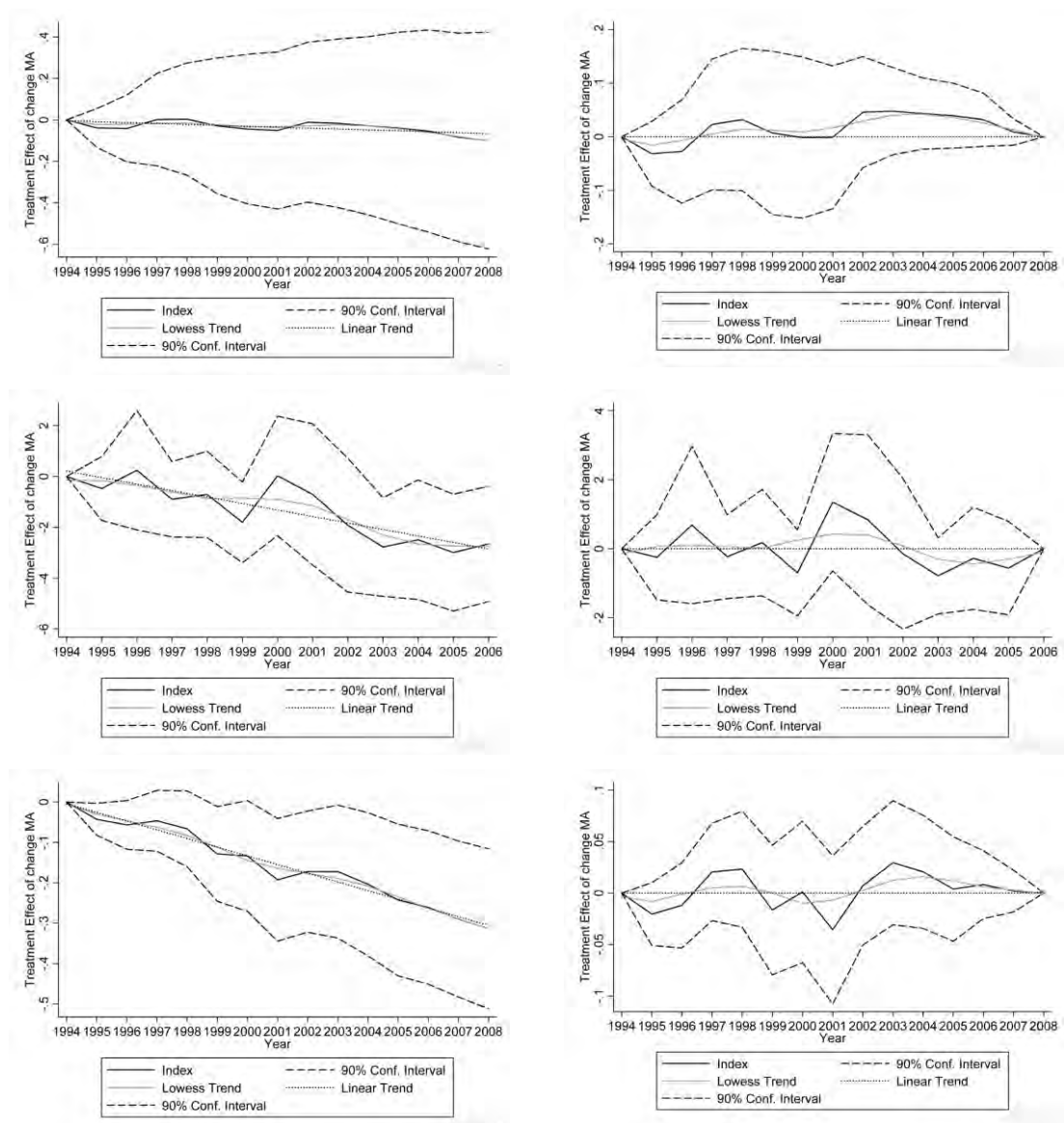
where w_i , Y_j , and d_{ij} are defined as in equation (1). α_0 , α_1 , and α_2 are parameters to be estimated and ε_i is the disturbance term. The reduced form of equation (2) can be called the nominal wage equation because regional price variations are excluded.

Fig A1 Travel time treatment



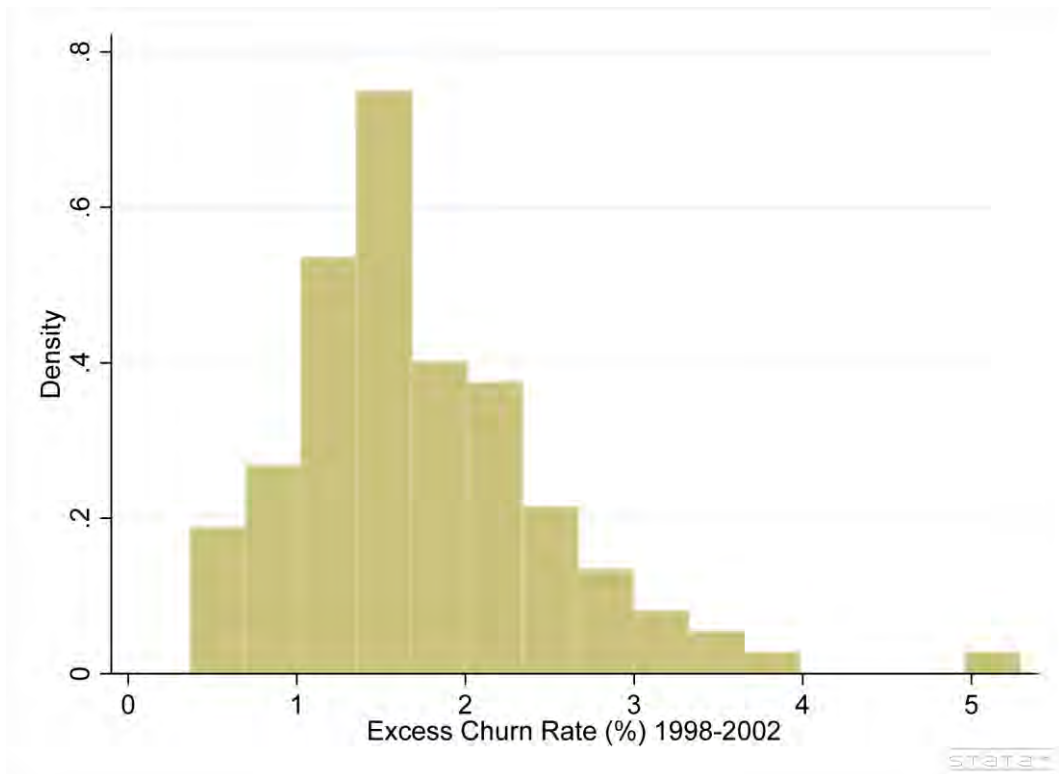
Notes: Own calculation and illustration. Map shows the reduction in travel time in minutes to the closes main centre defined as Frankfurt or Cologne, spatially interpolated employing ordinary kriging with spherical semivariogram model. Classification according to the Jenks (1977) algorithm.

Fig. A2 Market Access Treatment



Notes: Figure illustrates time-varying treatment effects according to specification (9) (left column) and (12) (right column). Treatment is log-difference in market access. Outcome variables by row: 1) share out commuters employment (residence), 2) share in commuters at 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 (23).

Tab A1 Nominal wage equation

	(1) (NLS)	(5) (SAR)
α_0	2.975*** (0.213)	5.603*** (0.294)
α_1	0.285*** (0.008)	0.193*** (0.013)
α_2	0.023*** (0.002)	
λ		0.908***
Obs.	1,335	1,335
(Pseudo) R ²	0.475	0.820

Notes: Endogenous 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
<i>STUDY x YEAR</i> ₁₉₉₃	-0.000 (0.005)	-0.008 (0.009)	-0.008 (0.010)	
<i>STUDY x YEAR</i> ₁₉₉₄	-0.001 (0.005)	-0.014* (0.008)	-0.016 (0.010)	
<i>STUDY x YEAR</i> ₁₉₉₅	-0.002 (0.005)	-0.007 (0.008)	-0.010 (0.010)	
<i>STUDY x YEAR</i> ₁₉₉₆	-0.003 (0.004)	-0.012 (0.008)	-0.015* (0.009)	-0.000 (0.004)
<i>STUDY x YEAR</i> ₁₉₉₇	-0.004 (0.004)	-0.009 (0.007)	-0.013 (0.009)	0.000 (0.004)
<i>STUDY x YEAR</i> ₁₉₉₈	-0.005 (0.004)	-0.019*** (0.007)	-0.024*** (0.009)	-0.001 (0.003)
<i>STUDY x YEAR</i> ₁₉₉₉	-0.007 (0.004)	-0.026*** (0.007)	-0.033*** (0.009)	-0.001 (0.003)
<i>STUDY x YEAR</i> ₂₀₀₀	-0.009** (0.004)	-0.032*** (0.008)	-0.041*** (0.009)	-0.002 (0.003)
<i>STUDY x YEAR</i> ₂₀₀₁	-0.012*** (0.004)	-0.042*** (0.008)	-0.054*** (0.009)	-0.003 (0.003)
<i>STUDY x YEAR</i> ₂₀₀₂	-0.015*** (0.005)	-0.033*** (0.008)	-0.048*** (0.009)	-0.005 (0.004)
<i>STUDY x YEAR</i> ₂₀₀₃	-0.017*** (0.005)	-0.027*** (0.008)	-0.044*** (0.010)	-0.009** (0.004)
<i>STUDY x YEAR</i> ₂₀₀₄	-0.019*** (0.005)	-0.026*** (0.008)	-0.044*** (0.010)	-0.012** (0.005)
<i>STUDY x YEAR</i> ₂₀₀₅	-0.020*** (0.005)	-0.028*** (0.009)	-0.048*** (0.010)	-0.017*** (0.005)
<i>STUDY x YEAR</i> ₂₀₀₆	-0.022*** (0.005)	-0.031*** (0.009)	-0.053*** (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: Endogenous 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 (x_i^a)	0.072** (0.018)	0.079** (0.020)
Log Diff Travel Time (x_i^a)	-0132** (0.031)	-0.076*** (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: Endogenous variable is log difference in MA as defined in equation (14) in all models. Log Diff in Travel time is defined as in equation (14), 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 9. 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 Population	-0.184+	-0.187+	-0.330**	-0.411**	-0.406**
	(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: Endogenous variable is ExcChurn as defined in equation (23). 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 A5 Persistency – 1st stage 2SLS results

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

Notes: Endogenous 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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