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ABSTRACT

The Contribution of Transport and Human Capital Infrastructure to Local Private Production: A Partial Adjustment Approach

by Andreas Stephan[*]

This paper uses a partial adjustment approach to measure the contribution of public infrastructure to local private production. In the first step of the empirical analysis we apply a principal component analysis in order to construct 2 new infrastructure indicators from an array of 7 measures of transport and human capital infrastructure. In the second step the output of different sectors is regressed on private factor inputs and on these 2 infrastructure indicators. Our main finding is that expected long-run equilibrium output in an area of local government will be higher, the better it is endowed with both transport and human capital infrastructure. Moreover, transport and human capital infrastructure appear to be complementary, i.e. raising only transport infrastructure will not yield an increase in private production at the local level.

ZUSAMMENFASSUNG

Der Beitrag von Verkehrs- und Humankapitalinfrastruktur zur lokalen privaten Produktion: Ein „partial adjustment“ Ansatz

Diese Studie verwendet einen „partial adjustment“ Ansatz, um den Beitrag von öffentlicher Infrastruktur zur privaten Produktion auf der lokalen Ebene zu bestimmen. Im ersten Schritt der empirischen Analyse wird eine Hauptkomponentenanalyse durchgeführt, um 2 neue Infrastrukturindikatoren aus 7 Variablen für Verkehrs- und Humankapitalinfrastruktur zu bestimmen. Im zweiten Schritt wird der Output von verschiedenen Sektoren auf die privaten Faktorinputs sowie die 2 gefundenen Infrastrukturindikatoren regressiert. Das wichtigste empirische Ergebnis der Analyse ist, daß der erwartete langfristige Gleichgewichtsoutput in einem Kreis höher ist, je besser die Ausstattung sowohl mit Verkehrs- wie auch mit Humankapitalinfrastruktur ist. Weiterhin finden wir, daß Verkehrs- und Humankapitalinfrastruktur zueinander komplementär sind, d.h. falls nur die Ausstattung mit Verkehrsinfrastruktur verbessert würde, daraus keine Erhöhung der privaten lokalen Produktion resultiert.

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1 Introduction

This study examines the role of publicly provided infrastructure for economic development at the local level of the 327 German counties ('Kreise'). Our paper aims at testing empirically the following two ideas. The first postulates that because the main part (about 60-70 percent) of infrastructure is provided by local governments, the main benefits from infrastructure might emerge at the local rather than at the regionally aggregated level (see also Seitz, 1995). Secondly, empirical studies using infrastructure stock measures in monetary terms implicitly assume that infrastructure stocks are homogenous across regions.

However, this assumption is quite often not particularly plausible. Consider, for instance, two regions of the same geographical size, the same population, economy, etc. Suppose both have accumulated a transport infrastructure stock worth 1 billion Euro. However, should one region be geographically flat while the other is mountainous then the productivity of a 1 billion infrastructure stock might be higher in the flat region than in the mountainous one. Thus, in this case public capital can not be regarded as homogenous and therefore comparable across regions. In contrast to this, if transport infrastructure is measured in terms of accessibility, e.g. travel distance to the nearest motorway from a given region, such a measure is comparable across regions even if regions have different geographic characteristics.

Another contribution of this study to the existing empirical literature on the effects of infrastructure is that we simultaneously consider both transport and human capital infrastructure. The importance of the latter type of infrastructure for economic development is stressed in models of 'new growth theories' (e.g. Barro/Sala-I-Martin, 1995; Lucas, 1988).

Previous studies such as Bröcker (1989) which used similar data, i.e. infrastructure indicators at the local level, have either not been based on a local production function or have omitted important factor inputs in the production function such as private capital (e.g. Biehl, 1986). The latter approach is problematic due to a potential omitted variable bias (Greene, 2000: 334).

In our empirical analysis we us an array of 7 infrastructure measures, describing the availability of transport and human capital infrastructure at the local level of the counties. From this set of 7 infrastructure measures, using Principal Component Analysis (PCA), we construct 2 new infrastructure indicators as linear combinations of the original 7 infrastructure measures. These 2 new indicators explain about 64 percent of the variation in infrastructure endowment across the counties. Moreover, specifying a Cobb-Douglas production function within a partial adjustment framework we regress output of different sectors, e.g. *manufacturing*, *services* and *trade & transport*, on private factor inputs and on these 2 infrastructure indicators.

We find that differences in output across counties can be explained by differences in overall endowment with infrastructure. This finding is most pronounced with regard to the *trade & transport* and the *service* sectors. Unexpectedly, we do not find evidence of an effect of infrastructure on production in *manufacturing*. Moreover, for regions well endowed with transport but with poor human capital infrastructure we do not find significant effects of infrastructure on output. Thus, it appears that transport infrastructure alone is not sufficient for higher output in a given county. We interpret this finding as an indication that human capital and transport infrastructure are complementary infrastructure components, at least for the sample studied here.

Finally, tests for spatial independence of residuals in the empirical analysis are performed. It turns out that spatial dependence of residuals is not significant, thus the usual econometric techniques such Ordinary Least Squares (OLS) or Seemingly Unrelated Regression (SUR) are applicable to our estimation problem.

The remainder of this paper is organized as follows. Section 2 describes the partial adjustment model which builds the basis of our approach. Section 3 presents the results of the empirical analysis. Section 4 concludes.

2 Partial Adjustment Model

To begin with, let us assume that production Q_{it} in county i at time t can be described as

$$Q_{it} = f(A(t, INFRA_{it}), K_{it}, L_{it}), \qquad i = 1 \ldots N, \qquad t = 1 \ldots T, \tag{1}$$

where Q_{it} denotes output, K_{it} private capital, L_{it} labour input and $A(t, INFRA_{it})$ denotes a technical efficiency parameter depending both on time t and an index of the public infrastructure stock denoted by $INFRA_{it}$. Specifying a Cobb-Douglas functional form for the production function (1) and assuming a Hicks-neutral form for $A(\ldots)$, we get

$$Q_{it} = A(t, INFRA_{it}) L_{it}^{\alpha_L} K_{it}^{\alpha_K}, \tag{2}$$

where α_L and α_K denote the elasticities of output Q with respect to L and K.

Finally, assuming that $A(t, INFRA_{it})$ has the following functional form

$$A(t, INFRA_{it}) = A_0 \exp(\alpha_t t) INFRA_{it}^{\alpha_{INFRA}}, \tag{3}$$

where A_0 is the initial value of $A(\ldots)$ at time t_0, and dividing (2) by L_{it}, we get

$$q_{it} = A_0 \exp(\alpha_t t) INFRA_{it}^{\alpha_{INFRA}} \; k_{it}^{\alpha_K} L_{it}^{\tilde{\alpha}_L}, \tag{4}$$

where small capitals denote variables in terms of the labour input L and $\tilde{\alpha}_L$ is defined as $\tilde{\alpha}_L = \alpha_L + \alpha_K - 1$. Note that $\tilde{\alpha}_L$ will equal zero if returns to scale are constant with respect to inputs L and K. This approach has the advantage that it *a priori* does not put on (2) any restriction with respect to returns to scale.

Our empirical approach is based on a partial adjustment model. Suppose that long-run equilibrium output q_{it}^* in county i is given by (4). Taking logarithms of (4) we obtain

$$\ln q_{it}^* = \alpha_0 + \alpha_{INFRA} INFRA_{it} + \alpha_K \ln k_{it} + \widetilde{\alpha}_L \ln L_{it} + \epsilon_{it}, \tag{5}$$

where $\alpha_0 = \ln A_0$ and ϵ_{it} is an i.i.d. random variable with variance σ_ϵ.

The adjustment process can be described by the following equation (Greene, 2000: 722)

$$\ln q_{it} - \ln q_{it_0} = (1-\lambda)(\ln q^*_{it} - \ln q_{it_0}), \tag{6}$$

where q_{it_0} denotes initial output at time t_0.

Solving (6) for $\ln q_{it}$ and inserting (5) for q^*_{it} we obtain the baseline model for our empirical analysis

$$\begin{aligned}\ln q_{it} = {} & \lambda \ln q_{it_0} + \alpha_0(1-\lambda) + \alpha_{INFRA}(1-\lambda)INFRA_{it} + \alpha_K(1-\lambda)\ln k_{it} \\ & + \widetilde{\alpha}_L(1-\lambda)\ln L_{it} + (1-\lambda)\epsilon_{it}.\end{aligned} \tag{7}$$

This equation can also be estimated without restrictions as

$$\ln q_{it} = \lambda q_{it_0} + \alpha_0' + \alpha_{INFRA}' INFRA_{it} + \alpha_K' \ln k_{it} + \widetilde{\alpha}_L' \ln L_{it} + \epsilon_{it}'. \tag{8}$$

From (8), the short-run elasticities can be obtained from estimates of α_{INFRA}', α_K', and α_L' (from $\widetilde{\alpha}_L' - \alpha_K' + 1$), whereas long-run elasticities can be calculated either from these estimates as $\alpha_{INFRA} = \alpha_{INFRA}'/(1-\lambda)$, $\alpha_K = \alpha_K'/(1-\lambda)$, and $\alpha_L = \alpha_L'/(1-\lambda)$ or can be obtained directly from (7) by using nonlinear methods.

This partial adjustment specification proves to be particularly useful for our analysis. Suppose that there is some unobserved heterogeneity in output q_{it} across counties, for instance due to the particular locations of counties, or due to different manufacturing technologies, etc. If panel data are available, one can control for this unobserved heterogeneity by including fixed or random individual effects. In our case with cross-sectional data, however, we can presume that if this unobserved individual county-specific attribute was already present at time t_0, then it might be reflected in output q_{it_0} as well. Thus, including the lagged dependent variable q_{it_0} as a right-hand side variable allows us to control for such time-invariant unobserved heterogeneity.

3 Empirical Implementation

3.1 Description of the Data

Our sample comprises of the 327 counties ('Kreise') in West Germany. A county itself usually contains several townships ('Gemeinden'). The next higher regional level above counties is the 166 'labour market regions' ('Arbeitsmarktregionen'). Indicators we use in order to describe local public infrastructure endowment are only available at the level of these 'labour market regions'. Thus, on average, a labour market region consists of about 2 counties. We have merged these two data sets with different regional levels. In the final data set the observations for the variables are at the county level. However, on average 2 counties will have the same values for the infrastructure indicators.

Table 1 shows a list of variables used in the analysis. Output (Q) in counties is measured as gross value added at *factor costs* in 1988 and has been drawn from a publication of the Statistisches

Table 1 Labels of Variables

Label	Short Description
Transport Infrastructure	
Motorway	accessibility of motorways, 1989
FreightTr	accessessibility of freight transfer railway stations, 1989
Airport	accessibility of regional airports, 1989
ICTrain	accessibility of inter-city express trains, 1988
Human Capital Infrastructure	
VocTrain	vocational training in future-oriented branches, 1988
Coll&Uni	students at colleges & universities, 1988
ScienceP	availability of science parks, 1988
Production Function Variables	
Q	Output measured as gross value added
	at factor costs, different sectors, 1980, 1988
K	private capital stock of manufacturing sector, 1988
L	number of employees, different sectors, 1987

Landesamt Baden-Württemberg (1995). The difference between gross value added at market prices and at factor costs is, that the latter is calculated from the former by subtracting the difference between indirect production taxes and governmental subsidies. The difference is on average only about 1-2 percent. As initial value for Q in t_0 we use the value for gross value added in 1980.

The indicators for public infrastructure endowments of the labour market regions are taken from Gatzweiler/Irmen/Janich (1991). As shown in Table 1, our first 4 indicators describe counties' endowment with transport infrastructure. We employ these indicators in order to describe the accessibility of a county by means of transport. A short description of the 4 indicators is also provided in Table 1.

The variable *Motorway* measures the percentage of employees in a given 'labour market region', whose places of work are located in a county closer than 30 minutes travel by car to the nearest motorway (or similar long-distance road). Variable *FreightTrans* measures the percentage of manufacturing sector firms in a 'labour market region' located in a township closer than 45 minutes travel by lorry to the nearest freight transfer railway station. Variable *Airport* measures the percentage of firms in a given 'labour market region' which are located in a township closer than 45 minutes travel by car to the nearest regional airport. Variable *ICTrain* gives the percentage of people in a labour market region which have access to inter-city express train stations within a travel distance of 30 minutes by car.

Furthermore, the data also contain measures of counties' infrastructure with regard to human capital. Variable $VocTrain$ is a combined indicator which is based both on the availability of vocational training in general and on the number of training opportunities in future-oriented industries such computing, biotechnology, etc. Variable $Coll\&Uni$ is a combined indicator both for the availability of colleges & universities and for the percentage of students at colleges & universities in a given region studying engineering, computing, mathematics or natural sciences. Finally, variable $ScienceP$ is a combined indicator for the availability of science parks and science & technology transfer service centres in a given region. For further details how these indicators are constructed, see Gatzweiler et al. (1991).

Table 2 displays some descriptive statistics of the infrastructure variables. Note that for some of the variables, e.g. $Motorway$, $FreightTr$ or $Airport$, the median is substantially different from the mean, thus the distribution of these variables appears to be skewed.

We estimate the contribution of public infrastructure to local private production also separately for 3 sectors, i.e. *manufacturing*, *trade & transport*, and *services*. Note, that the output measure of *all* sectors also includes the *agriculture*, *forestry & fishing* as well as the *governmental* sector.

Output for the 3 sectors *manufacturing*, *trade & transport*, and *services* is also measured as gross value added at *factor costs* in 1988 prices. In the publication mentioned above, however, only gross value added at *market prices* is reported for the single sectors. Thus, we computed the difference between gross value added at *factor costs* and *market prices* for each sector from the difference given for total gross value added, and allocated this difference according to the share of each sector in total gross value added.

Table 2 Descriptive Statistics of Infrastructure Variables

	Mean	**Std.**	**C.V.**	**Min**	**Max**	**Median**
$Motorway$	90.49	22.767	25.16	0	100	0
$FreightTr$	81.67	27.905	34.17	0	100	4.8
$Airport$	56.55	43.385	76.71	0	100	19.4
$ICTrain$	65.36	27.723	42.42	0	100	75.6
$VocTrain$	105.13	13.275	12.63	73	133	105
$Coll\&Uni$	145.4	123.4	84.86	0	568	168
$ScienceP$	4.60	5.52	119.78	0	20	2

Unfortunately, our measure for labour (L), given as numbers of employees, is only available for the year 1987 and not for 1988. It has been drawn from the joint publication of the Federal States Statistical Offices in Germany titled 'Erwerbstätigenrechnung des Bundes und der Länder, Erwerbstätige in den kreisfreien Städten und Landkreisen in der Bundesrepublik Deutschland 1980, 1987, 1990-1993', Heft 2.

The private capital stock (K) of the *manufacturing* sector in 1988 at the county level has been obtained from Deitmar (1993). We have measures neither for the total capital stock in counties nor for the capital stocks of the *trade & transport* or *service* sectors. However, since *manufacturing* is the main part of the total stock we presume that it is a reasonable approximation for the latter. We also approximate the private capital stock of the *trade & transport* or *service* sectors with the capital stock of manufacturing. This allows us to conclude whether or not output of these sectors are related to the *manufacturing* sector.

3.2 Analysis

The structure of the empirical analysis is as follows. First, we analyse the relationships between the various infrastructure indicators using principal component analysis (PCA). In a second step, we apply the PCA to construct 2 new indicator variables, i.e. we use the first two principal components as new indicators. Finally, in a third step we regress output of several sectors on private factor inputs and on these 2 principal components.

Table 3 Correlations within Transport Infrastructure Variables

	$Motorway$	$FreightTr$	$Airport$	$ICTrain$
$Motorway$	1.000	0.495	0.308	0.442
$FreightTrans$	0.495	1.000	0.424	0.407
$Airport$	0.308	0.424	1.000	0.407
$ICTrain$	0.442	0.407	0.407	1.000

Table 4 Correlations within Human Capital Infrastructure Variables

	$VocTrain$	$Coll\&Uni$	$ScienceP$
$VocTrain$	1.000	0.417	0.573
$Coll\&Uni$	0.417	1.000	0.572
$ScienceP$	0.573	0.572	1.000

Table 5 Correlations between Transport and Human Capital Infrastructure Variables

	$VocTrain$	$Coll\&Uni$	$ScienceP$
$Motorway$	0.349	0.330	0.294
$FreightTrans$	0.485	0.433	0.409
$Airport$	0.507	0.345	0.549
$ICTrain$	0.462	0.528	0.510

Table 3 displays the correlations between the various indicators for transport infrastructure. It appears that all indicators are positively correlated. The correlation is highest with about 0.5

between the variables $Motorway$ and $Freightransfer$, and lowest with about 0.3 between the variables $Motorway$ and $Airport$.

Table 4 gives the correlations between the indicators for human capital infrastructure. Indicators $VocTrain$, $Coll\&Uni$, and $ScienceP$ are all positively correlated. The correlation is highest with about 0.57 between $VocTrain$ and $ScienceP$.

Table 5 presents the correlations between *transport* and *human capital* indicators. Again, we find that all correlations are positive. We observe the lowest correlations between *transport* and *human capital* indicators for the variable $Motorway$, and the highest for the variable $ICTrain$.

Table 6 Eigenvalues of Principle Components Analysis of Infrastructure Variables

	Eigenvalue	**Difference**	**Proportion**	**Cumulative**
$Infra_1$	3.655	2.799	0.522	0.522
$Infra_2$	0.855	0.134	0.122	0.644
$Infra_3$	0.721	0.176	0.103	0.748
$Infra_4$	0.545	0.067	0.077	0.826
$Infra_5$	0.478	0.064	0.068	0.894
$Infra_6$	0.415	0.087	0.059	0.953
$Infra_7$	0.328	.	0.047	1

Table 7 Eigenvectors of Principle Components Analysis of Infrastructure Variables

	$Infra_1$	$Infra_2$	$Infra_3$	$Infra_4$	$Infra_5$	$Infra_6$	$Infra_7$
$Motorway$	0.322	0.732	0.050	0.303	0.045	0.513	0.036
$FreightTr$	0.376	0.380	0.255	-0.615	0.122	-0.432	-0.263
$Airport$	0.367	-0.297	0.532	0.315	0.538	-0.111	0.304
$ICTrain$	0.390	0.064	-0.411	0.532	-0.189	-0.585	-0.119
$VocTrain$	0.397	-0.193	0.305	-0.114	-0.767	0.109	0.316
$Coll\&Uni$	0.377	-0.121	-0.617	-0.367	0.258	0.156	0.487
$ScienceP$	0.411	-0.419	-0.084	-0.014	0.056	0.400	-0.697

This particular pattern of correlations between the infrastructure indicators lends itself to a Principle Component Analysis (PCA) in order to reduce the complexity of information within the total set of indicators.

The PCA is based on the following decomposition (Greene, 2000: 36)

$$\mathbf{V}'\mathbf{X}'\mathbf{X}\mathbf{V} = \mathbf{\Delta},$$

where $\mathbf{V}'$ is a $(k \times k)$ matrix of the $(\mathbf{v}_1, \ldots, \mathbf{v}_k)$ Eigenvectors of $\mathbf{X}'\mathbf{X}$, where $\mathbf{X}$ is a $(n \times k)$ data matrix (with n observations on k variables) and $\mathbf{\Delta}$ is a $(k \times k)$ diagonal matrix of associated Eigenvalues. The j^{th} $(n \times 1)$ principal component $\mathbf{p}_j$ of the $(n \times k)$ matrix $\mathbf{P} = \mathbf{X}\mathbf{V}$ of principal components is thereby defined as

$$\mathbf{p}_j = \mathbf{X}\mathbf{v}_j, \qquad j = 1, ..., k.$$

Table 6 and Table 7 give the results for the principal components analysis (PCA) of the correlation matrix for all 7 indicators. In Table 6, the Eigenvalues (characteristic roots) of the PCA are presented, and in 7 the associated Eigenvectors (characteristic vectors) are displayed.

It is worth noting, that the first Eigenvector in Table 7, associated with the first Eigenvalue in Table 6, can already explain 52.2 percent of the variation within the infrastructure variables. Moreover, the second Eigenvector can explain 12.2 percent of the total variation. Hence, the first two Eigenvectors together can explain about 64 percent of the total variation within all infrastructure indicators.

The coefficients of the Eigenvectors in Table 7 reflect the contribution of each single indicator to a corresponding principal component. Thus, all indicators contribute with a positive sign to the first component. Consequently, counties with high values on these indicators will also have a high score for the first component.

With respect to the second principal component, the variables $Motorway$ and $FreightTrans$ contribute with a positive sign, whereas the variables $Airport$, $VocTrain$, $CollTrain$ and in particular variable $ScienceP$ contribute with a negative sign. Thus, counties with high values for the variables $Motorway$ and $FreightTrans$ but with relatively low or close to zero values for the variables $Airport$, $VocTrain$, $CollTrain$ and $ScienceP$ will have a high positive score on this second principal component.

On the other hand, counties with high values for the variables $Airport$, $VocTrain$, $CollTrain$ and $ScienceP$ but low values for the variables $Motorway$ and/or $FreightTrans$ will have a high negative score for the second component. We interpret this as an indication that the second component reflects the contrast of counties with either good quality transport infrastructure (except airports) but with a relatively low human capital infrastructure or vice versa.

Figure 1 graphs the first principal component versus the second. The single observations in this graph are the labour market regions. Note, that by construction the principal components are uncorrelated. Labour market regions well endowed with infrastructure will have high values on the first component, thus they are be located on the right-hand side of the graph. Observations with high values on the second components are located in the upper-half of the graph.

Table 8 gives the correlations of the original indicator variables and the principal components with output, measured for the different sectors. All infrastructure variables are significant and positively correlated with these output measures. This pattern also justifies the application of PCA in the regression analysis because due to this collinearity between infrastructure variables it would be difficult to get precise estimates of the contribution of single variables. The first principal component, which we label as $Infra_1$, is significantly correlated with output measures for all sectors, whereas the second principal component, which we label as $Infra_2$, is not.

Figure 1 Plot of Principal Components for Labour Market Regions

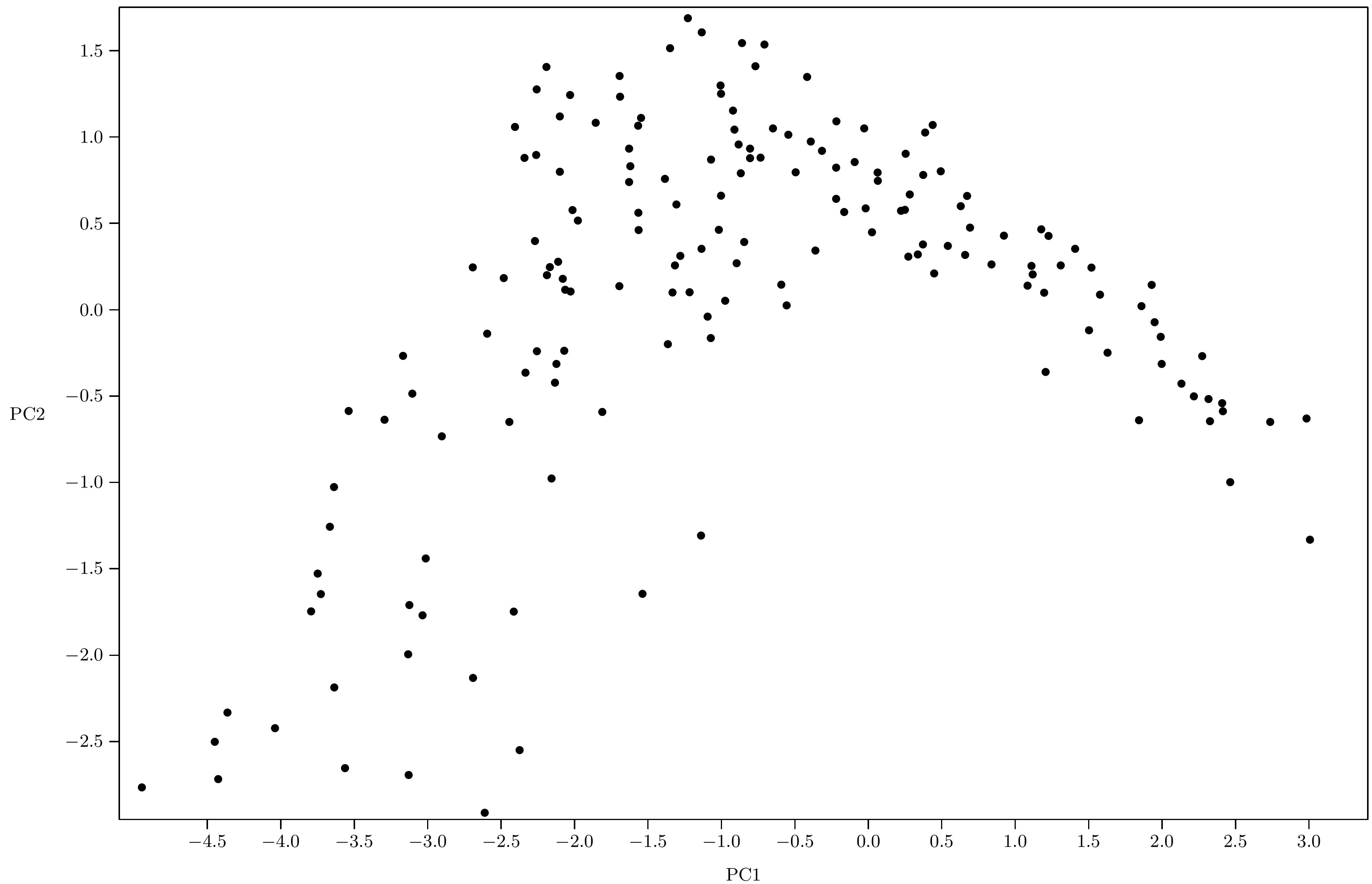


Table 8 Correlations of Infrastructure Variables and Principal Components with Output

	Correlations of Output[1] q_i			
	All sectors	Manufacturing	Trade & Transp.	Services
with original infrastructure variables				
$Highway$	0.241***	0.105**	0.197***	0.160***
$FreightTr$	0.308***	0.183***	0.218***	0.140**
$Airport$	0.368***	0.162***	0.196***	0.210***
$ICTrain$	0.459***	0.328***	0.210***	0.155***
$VocTrain$	0.452***	0.184***	0.322***	0.330***
$Coll\&Uni$	0.322***	0.228***	0.186***	0.142***
$ScienceP$	0.459***	0.249***	0.328***	0.255***
with Principal Components				
$Infra_1$	0.521***	0.288***	0.330***	0.278***
$Infra_2$	-0.114**	-0.052	-0.043	-0.076

1) measured as gross value added.

significant * at 10 %, ** at 5 %, *** at 1 %.

Table 9 displays the results of the regression analysis. The estimations have been carried out using LIMDEP 7.0. Equation (8) has been estimated both in the unrestricted and the restricted form, where the long-run parameters are directly estimated. The unrestricted specification has been estimated with linear OLS. The restricted specification has been estimated both with nonlinear Ordinary Least Squares (OLS) and with nonlinear Seemingly Unrelated Regression (SUR). The correlations of the residuals across equations are shown in Table 10. Some of these correlations, e.g., between equations *total* and *manufacturing*, and *total* and *services* are positive and quite significant. Thus, we expect a gain in efficiency from using SUR compared to OLS.

We have added both Länder dummy variables and a dummy variable indicating whether or not a county is a self-administrated city to all equations. White's (1980) heteroscedasticity test has been applied to all regressions. Homoscedasticity of residuals is rejected except for the *service sector* and partly for the *all sectors* equation. Thus, White's (1980) heteroscedasticity robust standard errors have been used for calculating the t values for the OLS estimations. The reported condition numbers with values greater than 20 may indicate a potential problem of multicollinearity for the estimations (Judge/Griffiths/Hill/Lee/Lütkepohl, 1985: 902).

The fit as indicated by R^2 is remarkably good for all equations. Several key findings emerge from Table 9. First of all, $Infra_1$ is significant for *all,* the *service* and *trade & transport* sectors, but surprisingly not for the *manufacturing* sector. In contrast to this, $Infra_2$ is not significant for private production with regard to all sectors. Second, the estimates of the adjustment parameter

Table 9 Regression Results for Different Sectors

	OLS[1)3)]		**nonlinear OLS**[1)3)]		**nonlinear SUR**[1)]	
Dependent Variable: Output q_i						
			All Sectors			
Dummy var.[2)]	*Länder******		*Länder******		*Länder******	
DCity	0.023	(1.69)	0.062	(1.945)	0.013	(0.26)
Intercept	1.413	(6.69)	3.807	(22.62)	4.102	(14.21)
$\ln q_{it_0}$	0.629	(10.63)	0.629	(10.63)	0.782	(28.98)
$\ln k_i$	0.047	(3.91)	0.120	(3.84)	0.184	(4.44)
$\ln L_i$	0.045	(4.80)	0.123	(4.63)	0.150	(3.67)
$Infra_1$	0.009	(3.47)	0.024	(3.05)	0.029	(2.42)
$Infra_2$	-0.005	(-0.96)	-0.013	(-0.97)	-0.013	(-0.56)
R^2	0.759		0.759		0.750	
White χ^2 (76)[2]	91.5		91.5		94.0**	
			Manufacturing Sector			
Dummy var.[2)]	*Länder******		*Länder******		*Länder******	
DCity	0.041	(2.01)	0.093	(2.27)	0.080	(1.44)
Intercept	0.970	(3.92)	2.191	(6.58)	2.183	(6.27)
$\ln q_{it_0}$	0.557	(8.75)	0.557	(8.75)	0.695	(23.74)
$\ln k_i$	0.169	(5.65)	0.382	(4.74)	0.376	(6.25)
$\ln L_i$	0.072	(4.66)	0.163	(4.51)	0.261	(5.64)
$Infra_1$	-0.009	(-1.92)	-0.020	(-1.71)	-0.041	(-2.79)
$Infra_2$	0.041	(0.32)	0.006	(0.32)	0.010	(0.38)
R^2	0.705		0.709		0.699	
White χ^2 (76)[2]	136.8***		136.8***		124.1***	
			Trade & Transport Sector			
Dummy var.[2)]	*Länder******		*Länder******		*Länder******	
DCity	0.011	(0.54)	0.024	(0.56)	0.016	(0.35)
Intercept	1.948	(5.45)	4.210	(19.28)	4.224	(15.74)
$\ln q_{it_0}$	0.537	(5.56)	0.537	(5.56)	0.601	(14.95)
$\ln k_i$	-0.023	(-1.83)	-0.050	(-1.74)	-0.032	(-0.90)
$\ln L_i$	0.041	(3.08)	0.088	(2.83)	0.070	(2.11)
$Infra1$	0.021	(3.56)	0.045	(2.95)	0.057	(4.27)
$Infra2$	-0.007	(-0.95)	-0.016	(-0.97)	-0.017	(-0.87)
R^2	0.534		0.534		0.530	
White χ^2 (76)[2]	146.2***		146.2***		145.8***	
			Service Sector			
Dummy var.[2)]	*Länder******		*Länder******		*Länder******	
DCity	-0.080	(-4.88)	-0.276	(-3.49)	-0.264	(-3.77)
Intercept	1.679	(6.11)	5.829	(12.13)	5.613	(13.87)
$\ln q_{it_0}$	0.712	(11.37)	0.712	(11.37)	0.724	(21.44)
$\ln k_i$	0.029	(2.48)	0.101	(2.30)	0.175	(3.54)
$\ln L_i$	-0.007	(-0.57)	-0.023	(-0.58)	-0.087	(-1.92)
$Infra_1$	0.018	(4.20)	0.063	(3.96)	0.073	(4.48)
$Infra_2$	0.002	(0.21)	0.006	(0.21)	0.004	(0.15)
R^2	0.603		0.603		0.596	
White χ^2 (76)[2]	57.4		57.4		58.7	
Condition-num.	126.7		52.4		191.4	

Number of observations: 327 for each equation

1) Asymp. t-values are given in parentheses.

2) significant *at 10 %, **at 5 %, ***at 1 %.

3) White's (1980) heteroscedasticity robust t-values.

Table 10 Cross Equation Correlations from OLS Table 9

	All sectors	Manu-facturing	Trade & Transp.	Ser-vices
All sectors	1.000	0.703	0.339	0.529
Manufacturing	0.703	1.000	-0.075	0.006
Trade & Transport	0.339	-0.075	1.000	0.262
Services	0.529	0.006	0.262	1.000

λ are positive and significant for all equations. Values of λ of about 0.6 to 0.7 imply a rate of convergence of about 5 percent per year.[1] This implies that the halfway ($\lambda = 0.5$) between the actual value and the long-run equilibrium value of output is reached after 14 years from t_0. Third, the Länder dummy variables are significant for all equations. Hence, there are systematic differences in output of industries and branches across the Bundesländer. Fourth, it turns out that our measure for private capital approximated as the private capital stock of the manufacturing sector, is related to *all, manufacturing* and *service* sectors output, but not to output of the *trade & transport* sector. Fifth, it is worth noting that the city dummy variable is positive and significant for *manufacturing*, but negative and significant for the *service* sector. Sixth and finally, the positive and significant coefficients for $\ln L$ show that economies of scale and/or agglomeration economies are important. However, this does not apply for the *service* sector.

Table 11 Tests on normality of residuals from OLS estimations, Table 9

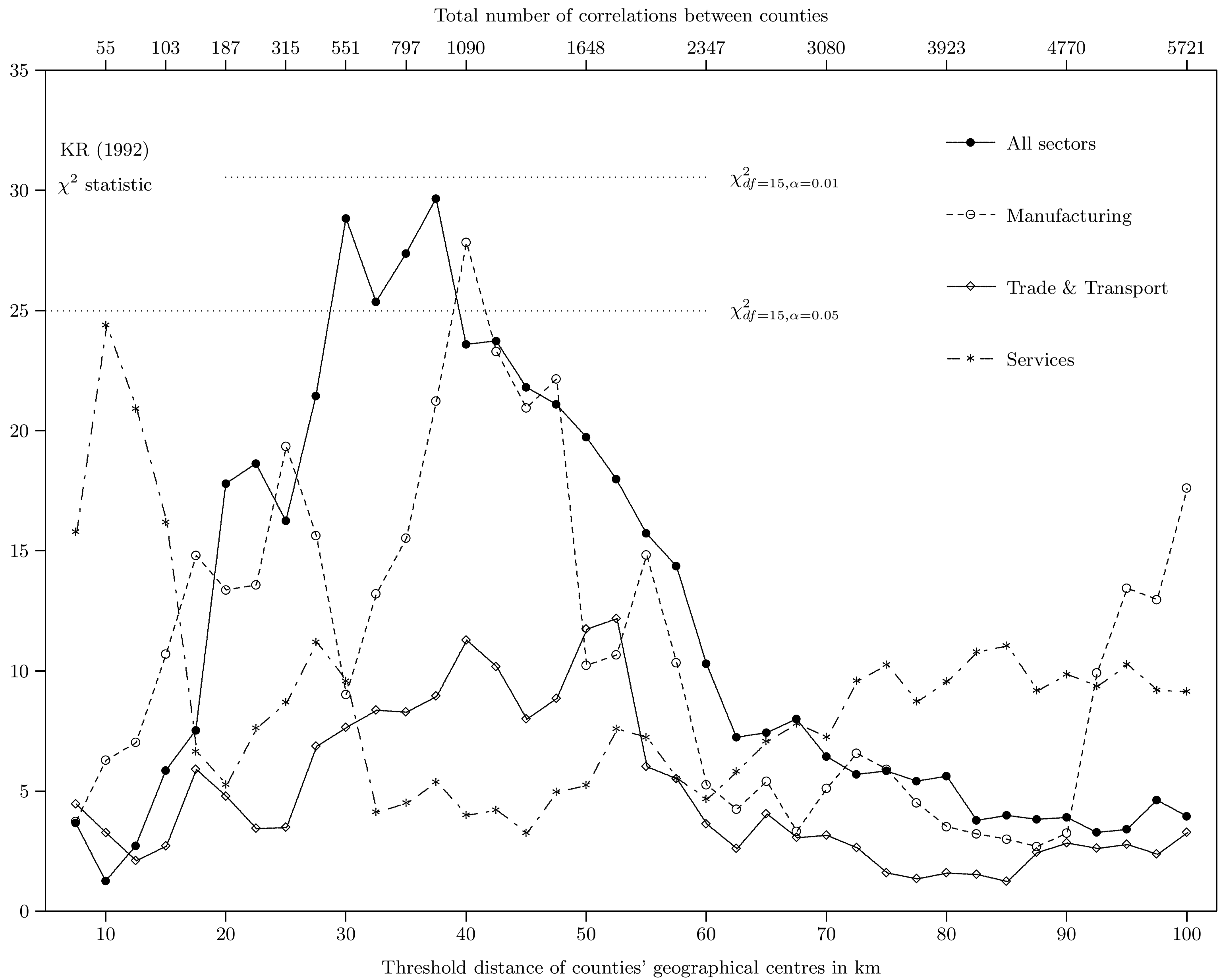
	All sectors	Manu-facturing	Trade & Transp.	Ser-vices
Shapiro-Wilk W	0.982	0.976**	0.935***	0.929***
Jarque-Bera JB	98.1***	86.1***	2172.3***	1014.3***

significant * at 10 %, ** at 5 %, *** at 1 % .

To conclude the empirical analysis, we finally examine whether or not the residuals of the estimations exhibit evidence of spatial dependence. As outlined in Schulze (1998), the first step in the analysis of spatial dependence should consist of a test on the normality of residuals. Table 11 provides the results both of the Shapiro-Wilk and the Jarque-Bera tests for all equations. The Jarque-Bera JB statistic is distributed χ^2 with 2 degrees of freedom, thus the critical value for p=0.01 is 9.21. The null hypothesis of normality is rejected for all equations by the Jarque-Bera test as well as by the Shapiro-Wilk statistic, except for the *all* sectors equation.

[1] The underlying assumption is that $\lambda = \exp(-\beta t)$, where β is the so-called coefficient of convergence (see Barro/Sala-I-Martin 1995: 37).

Figure 2 Dependence of the KR χ^2-statistic on the threshold distance



Hence, in this case the test procedure for spatial dependence suggested by Moran (1950), and extended by Cliff/Ord (1972), appears not to be appropriate. However, as an alternative the KR test proposed by Kelejian/Robinson (1992) is still applicable. In contrast to Moran's I this test neither requires the model to be linear nor the disturbance terms to be normally distributed.

Applying this test it turns out—as it would also be the case with Moran's I—that the outcome of the KR statistic depends on the specification of correlations between regions, i.e. on the specification of the binary spatial weight matrix (see also Cliff/Ord, 1973; Cliff/Ord, 1981).

This point is illustrated in figure 2. It shows the outcome of the KR statistic depending on the specification of threshold Euclidian distance between counties. If the distance between geographical midpoints of regions is larger than the threshold distance, then this corresponds to a zero in the spatial weight matrix. Hence, in this case these 2 counties are not considered in the computation of the KR statistic.

The lower axis in Figure 2 gives the threshold distance in kilometers, the upper axis gives the number correlations between counties which are taken into account in the computation of KR.

The KR statistic is distributed χ^2 and in our case with 15 degrees of freedom. Thus, the critical value at p=0.05 is 24.99 and at p=0.01 is 30.57. These two critical values are plotted as lines in Figure 2.

It emerges that for *all* and the *manufacturing* sectors the KR statistic reaches a maximum when the threshold distance is between 30 and 50 km. At this maximum, the total number of correlations between counties being considered in the calculation of KR ranges between 500 and 1500. This means, that the maximum of the KR statistic is reached when, for each county, between 2-5 correlations with the nearest neighbouring counties are taken into account.

From this explorative analysis, we conclude that spatial dependence is not significant in our case, since for no equation is the maximum of KR larger than the given critical value from the χ^2 distribution for p=0.01, which is 30.57. Hence, the estimation and inference based on the usual econometric techniques e.g. OLS or SUR remain valid.

4 Summary and conclusions

Overall, we find that long-run equilibrium output in a county will be higher, the better it is endowed with infrastructure. Thus, our paper substantiates the findings of other studies e.g. Aschauer (1989), Biehl (1986), Munnell (1992) or Seitz (1993; 1994; 1995) that infrastructure contributes positively to private production. However, our approach is an extension of previous studies in several aspects. The main difference to most studies in this field is that we focus on effects of infrastructure at the local level. This appears to be reasonable since the main part of infrastructure is supplied at the local level, hence one can expect its benefits to be seen particularly at a local level.

Furthermore, in contrast to most previous studies we use indicators for infrastructure instead of public capital stocks measured in monetary terms. This allows us to overcome the unrealistic assumption that infrastructure stocks can be regarded as homogenous and thereby as comparable across regions.

Our main finding is that counties better endowed with both transport and human capital infrastructure have also a higher level of expected long-run total output. However, one surprising result of our study is that we do not find effects of infrastructure endowment on long-run output of the *manufacturing* sector at the local level. Hence, other factors than infrastructural endowment seem to determine the choice of location and production of manufacturing firms. On the other hand, we find that the contribution of infrastructure to local private production is most pronounced for the *service* and the *trade & transport* sectors. Moreover, we find that both transport and human capital infrastructure are important for total output, i.e. these two types of infrastructure appear to be complementary.

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