Convergence of Human Capital Shares across Cities

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Abstract
In this paper I analyse the impact of human capital on local employment growth for West German regions (1977-2002). I find robust evidence that regions with a large initial share of high-skilled workers have higher *total* employment growth, but lower subsequent growth of *high-skilled* jobs. There has been a convergence of local human capital shares across German cities over time, on average and even within specific industries. These stylised facts sharply contrast available evidence from the US, where researchers have identified a divergence trend. I use a simple theoretical model to interpret the evidence. It suggests that concentration forces, although they exist, are not sufficiently strong relative to dispersion forces to trigger a spatial clustering trend of high-skilled workers in Germany.

Keywords: Human capital, local employment growth, externalities

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1) Introduction

The literature in various fields such as endogenous growth, economic geography, labour or urban economics, emphasises that spatial concentration of economic activity gives rise to localised increasing returns to scale. According to Lucas' (1988) or Marshall's (1890) often cited contributions these scale economies may even be regarded as the fundamental reason for the existence of cities and agglomerations. Various micro-foundations for agglomeration effects have been discussed. It is frequently argued that spatial concentration leads to pooling advantages on factor markets, more vital exchange of ideas and knowledge, higher innovation, linkages due to endogenous market size effects, and more learning.[1]

The (relative) empirical importance of these agglomeration forces is far from clear today (Rosenthal and Strange, 2004). But for almost any of the mechanisms mentioned above it seems plausible that human capital is an important catalyst. If, for example, density generates knowledge spillovers via face-to-face contact and personal interaction, then it will be mainly the spatial concentration of high-skilled workers, rather than spatial concentration of workers in general, that raises local productivity, and that generates agglomeration effects. If local environments with a high concentration of human capital are more productive than locations with a low concentration, e.g. because of knowledge spillovers, these locations will pay a wage premium: Observationally equivalent workers should earn more in human capital abundant areas (as argued e.g. by Rauch 1993).[2] Related evidence is provided by Glaeser and Mare (2001), Yankow (2006), or Wheeler (2006a), who find a "true" urban wage premium that does not reflect ability sorting or compensation for higher living costs. Moeller and Haas (2003) confirm the presence of an agglomeration wage premium in Germany, which is related

[1] For an overview of these and various related issues, the reader might refer to the recent *Handbook* by Henderson and Thisse (2004), in particular to the excellent chapters by Duranton/Puga and Rosenthal/Strange.

[2] In reduced form, this would suggest the presence of a *human capital externality* that is quite commonly used by in endogenous growth theory (Lucas, 1988; Acemoglu, 1996). For a comprehensive overview about human capital externalities, see Moretti (2004b). Recent attempts to identify these externalities empirically have yielded inconclusive results and encountered various difficulties in disentangling them from other effects. Whereas Rauch (1993) and Moretti (2004a) argue that sizeable externalities exist in the US, there is an opposite view by Acemoglu and Angrist (2002) and Ciccone and Peri (2006) that they can not be identified in US data.

to human capital externalities as highly educated people are abundant in cities, and show that the wage premium is larger for high-skilled that for low-skilled workers.

The present paper makes no further attempt to measure, or to quantify this wage premium. It is rather concerned with its *consequences* for the spatial evolution of human capital. If human capital abundant cities pay a wage premium, they should attract individuals. They should particularly attract high-skilled workers, who tend to be geographically more mobile and who tend to earn a larger agglomeration wage premium. This, in turn, may raise local productivity even further. The presumption that "smart cities" grow faster than unskilled ones has, in fact, been confirmed for the US in a variety of papers that find a robust positive correlation between a city's initial employment share of college educated workers and subsequent city employment/population growth (Glaeser et al., 1995; Simon, 1998, 2004; Simon and Nardinelli, 2002). The main reason *why* skilled cities grow faster actually seems to be the positive impact of human capital on local productivity that translates into equilibrium employment gains (Shapiro, 2006; Glaeser and Saiz, 2004).

This "smart city" literature has focussed almost entirely on US cities and metropolitan areas so far.[3] The first aim of this paper is, therefore, to study the relation between local human capital and local employment/population growth for a different country, namely West Germany (1977-2002). As it turns out, some stylised facts carry over to this "European" case. Other stylised facts, however, are decisively different in Germany than in the US. I first report a robust positive impact of the initial employment share of high-skilled workers on subsequent *total* employment growth at the local level. The main cause behind this positive correlation appears to be impact of human capital on local productivity. Both results are consistent with the US, which suggests that European economies are similar in this respect.

The main difference between the two countries concerns the evolution of the spatial distribution of human capital – an issue that has received far less attention than the relation

[3] An exception is Simon and Nardinelli (1996), who look at growth of British cities between 1861 and 1961. Apart from that, I am currently not aware of other studies that deal with this issue for other countries.

between human capital and total employment growth. A few recent papers (Moretti, 2004b; Berry and Glaeser, 2005; Wheeler, 2006b) argue that there is a tendency of increasing inequality in the distribution of human capital across US cities and metropolitan areas. Relatively human capital abundant regions became increasingly skilled over time, i.e. there has been a *divergence* of local human capital in the US.[4] This has been very much different in West Germany. In the empirical part of this paper, I show that there has been a *convergence* of local human capital shares: regional human capital shares have tended to become more equal across German regions.

This stylised fact suggests that centripetal forces (like the agglomeration wage premium) are not sufficiently strong relative to opposing centrifugal forces to trigger a spatial concentration or clustering process for high-skilled workers in Germany. But even though these facts seem to have a "neoclassical flavour", namely a convergence of relative factor endowments across space, they do *not* imply that concentration forces such as localised human capital externalities are absent. Using a simple theoretical model I show that spatial convergence of high-skilled employment shares is consistent with localised increasing returns to human capital, provided that they are not too strong.

The rest of this paper is organised as follows. In section 2 I present a simple theoretical model that helps to interpret the stylised facts. In section 3 I describe the data set and present a descriptive overview. The statistical analysis and the main results are presented in section 4. In section 5 I summarise the empirical facts for West Germany, and I discuss the differences with the related evidence from the US.

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[4] Moretti (2004b) points out: "*Cities that had a relatively high fraction of educated individuals in 1990 experienced larger increases [in the fraction of educated workers] between 1990 and 2000 than cities that had a relatively smaller fraction of educated individuals that year. As a consequence, the distribution of human capital across cities became more unequal during the 1990s. […] But this tendency of increasing inequality in the distribution of human capital across US cities during the 1990s was not a new phenomenon, as it was already in place in the 1980s.*" -
Berry and Glaeser (2005) obtain consistent results. They report that "*U.S. metropolitan areas with more college graduates in 1990 became increasingly skilled over the 1990s. […] A one percent increase in the share of adults with college degrees in the 1990s is associated with a .13 percent increase in the share of the population with college degrees between 1990 and 2000. The correlation between initial share of the population with college degrees and growth in that share was 44 percent in the 1980s and 60 percent in the 1970s.*"

2) Theoretical background

The following simple model illustrates the conflict between human capital externalities as a centripetal force for high-skilled workers, and two opposing centrifugal forces: housing scarcity, and a straightforward neoclassical supply effect according to which returns to human capital are lower in regions where high-skilled workers are abundant.

Consider an economy that consists of $c = 1,...,N$ cities or locations. There are two types of labour. High-skilled workers are assumed to be geographically mobile, whereas low-skilled workers are immobile. This assumption is consistent with empirical evidence about internal labour migration in Germany and elsewhere (see e.g., Hunt 2006). Also there is an exogenous fixed housing stock $\overline{B}_c$ that is owned by absentee landlords.

High- and low-skilled labour is combined to produce a freely tradable, homogeneous final product under perfect competition. For simplicity I assume a simple Cobb-Douglas production function,

$$y_{j,c} = A_c \left(\ell_{j,c}\right)^{\alpha} \left(h_{j,c}\right)^{1-\alpha} \qquad 0 < \alpha < 1 \qquad (1)$$

where $y_{j,c}$ denotes production of firm j located in city c, $\ell_{j,c}$ is the input of low-skilled workers, and $h_{j,c}$ is the input of high-skilled workers in that firm. The price of this good is normalised to unity ($p_Y = 1$). The centripetal force in this model is a localised spillover effect that is introduced in a similar way as in Lucas (1988) or Moretti (2004a) by assuming that total factor productivity in city c, denoted A_c, depends endogenously on aggregate local human capital. In particular, I assume that it depends on the local human capital *intensity*

$$A_c = \varphi_c \left(\frac{H_c}{L_c}\right)^{\gamma} \qquad (2)$$

$\varphi_c > 0$ is some exogenous and city-specific productivity parameter, and $\gamma \geq 0$ measures the strength of the localised externality. Individual firms, whose subscript j will be dropped from

now on, take the productivity level as given.[5] With perfectly competitive labour markets, the wages paid to low-skilled and high-skilled workers by a typical firm are given by

$$w_c^L = \alpha \cdot \varphi_c \cdot \left(H_c / L_c\right)^{1-\alpha+\gamma} \tag{3}$$

$$w_c^H = (1-\alpha) \cdot \varphi_c \cdot \left(H_c / L_c\right)^{\gamma-\alpha} \tag{4}$$

Assume that the population of low-skilled workers in city c is exogenous and given by $\bar{L}_c$. Let (inverse) low-skilled labour supply be described by the function $w_c^L = \left(L_c^S\right)^{\varepsilon}$, where $\varepsilon > 0$ is the constant supply elasticity. Equilibrium employment of low-skilled workers can then be expressed in terms of high-skilled employment in city c,

$$L_c = \left(\alpha\varphi_c\right)^{1/(1-\alpha+\gamma+\varepsilon)} \cdot \left(H_c\right)^{\psi} \qquad \psi = \frac{1-\alpha+\gamma}{1-\alpha+\gamma+\varepsilon} \in [0,1] \tag{5}$$

The parameter ψ ranges between zero and one, and it increases with the strength of the externality (γ). Eqs. (3) and (5) show that the wage, and the employment level of low-skilled workers both depend positively on the level of human capital employed in city c, even in the absence of any externality (i.e., $\partial w_c^L / \partial H_c > 0$ and $\partial L_c / \partial H_c > 0$ even with $\gamma = 0$). This arises purely because the two types of labour are imperfect substitutes in production, i.e. because of the positive cross-partial derivative of the production function (1). With a positive human capital externality, w_c^L and L_c are both higher the larger is γ. Substituting (5) into (4), I derive the equilibrium wage of high-skilled workers as

$$w_c^H = \left((1-\alpha)\varphi_c\right)^{\frac{(2-\alpha+\gamma+\varepsilon)}{(1-\alpha+\gamma+\varepsilon)}} \cdot \left(H_c\right)^{(1-\psi)(\gamma-\alpha)} \tag{6}$$

The following result is then readily verified:

[5] Note that the particular functional forms are chosen purely for analytical simplicity. The main qualitative results would also arise with a different constant-returns production function (e.g., CES), or with a different specification of the externality. E.g., in Lucas (1988) productivity A_c is assumed to depend on the local human capital *share*. This would considerably complicate the math in my model, however.

Proposition

The equilibrium wage of high-skilled workers in city c, w_c^H, is increasing/decreasing in the local human capital stock, H_c, if γ is larger/smaller than α. The wage w_c^H does not depend on H_c if $\gamma = \alpha$.

If the externality is absent or weak, the model conveys the straightforward neoclassical insight that the wage for high-skilled workers should be lower in human capital abundant areas. This neoclassical supply effect is only offset if the externality is sufficiently strong, namely if $\gamma > \alpha$, so that there are localised increasing returns to human capital.

The proposition also illustrates the main idea behind the organizing framework by Moretti (2004a), who seeks to quantify human capital externalities. Using a similar framework, Moretti shows that even the *average* regional wage, which is a weighted average of w_c^L and w_c^H, can depend positively on the local human capital share if there is no externality. Moretti concludes that, in order to disentangle the externality from the neoclassical supply effect, one has to study the impact of the local human capital share on the wages of high-skilled workers separately. Applying his framework on US individual earnings data while controlling for unobserved ability he finds, in fact, that $\partial w_c^H / \partial H_c > 0$. In terms of the model presented here this suggests that $\gamma > \alpha$ in the US. Note, however, that $\partial w_c^H / \partial H_c > 0$ is sufficient, but not necessary for the existence of an externality. With $0 < \gamma < \alpha$ an externality exists, but it is not sufficiently strong to render localised increasing returns to human capital.

The present paper is not concerned with measuring or quantifying the externality γ for Germany, but rather with the long-run consequences of human capital externalities for the spatial evolution of human capital. To this end, I need to move from equilibrium (nominal) wages to the equilibrium location choice of mobile high-skilled workers.

Suppose individuals have preferences defined over housing and the tradable consumption good, and that preferences can be described by the following quasi-linear utility function

$$U_{i,c} = Y_{i,c} + \mu \cdot \log\left(B_{i,c}\right) \qquad \mu > 0 \tag{7}$$

where $U_{i,c}$ is the utility level of individual i living in city c.[6] The elimination of income effects from housing demand makes sure that all individuals purchase the same lot size $\left(\mu / p_c\right)$, and that indirect utility of a high-skilled worker living in city c can be written as

$$V_c^H = w_c^H - \mu \cdot \log\left(p_c\right) + \mu\left[\log\left(\mu\right) - 1\right] \tag{8}$$

p_c is the housing price in that location. The housing market is assumed to be competitive, i.e. the housing price adjusts so as to equate supply and demand, hence

$$p_c = \mu\left[\bar{L}_c + H_c\right] / \bar{B}_c \tag{9}$$

From eq. (9) and the assumed exogeneity of the housing stock $\bar{B}_c$ and the low-skilled population $\bar{L}_c$, it is easy to see that the housing price in city c is increasing as more high-skilled workers move in ($\partial p_c / \partial H_c > 0$).

Using (6), (8) and (9) indirect utility of a high-skilled worker in city c can be written as

$$V_c^H = \tilde{\varphi}_c \cdot \left(H_c\right)^{(1-\psi)(\gamma-\alpha)} - \mu \cdot \log\left(\bar{L}_c + H_c\right) + \mu \cdot \log\left(\bar{B}_c\right) + \mu\left[\log\left(\mu\right) - 1\right] \tag{10}$$

where $\tilde{\varphi}_c \equiv \left((1-\alpha)\varphi_c\right)^{\frac{(2-\alpha+\gamma+\varepsilon)}{(1-\alpha+\gamma+\varepsilon)}} > 0$. This equation illustrates how the aggregate distribution of human capital across regions affects individual location decisions. First, an increase in H_c may increase or lower the nominal wage w_c^H in city c, depending on whether γ is larger or smaller than α (see above). Second, housing scarcity is a centrifugal force, because an increase of H_c lowers utility of local high-skilled workers via the housing price channel. In other words, utility V_c^H depends *positively* on H_c if and only if the strength of the externality

[6] I have ruled out city-specific consumption amenities that potentially could also depend endogenously on the local level of human capital (see Shapiro, 2006). This simplification is justified, because below I report evidence that is consistent with a production externality of human capital, but not with a consumption externality.

(the centripetal force) is *sufficiently* strong to compensate both centrifugal forces ($\partial V_c^H / \partial H_c > 0 \Leftrightarrow \gamma \gg \alpha$).

In a long-run spatial equilibrium high-skilled workers must be indifferent in which city to locate. That is, for each pair of cities k and m it must be true that (indirect) utility is equalised,

$$V_k^H - V_m^H = \left[w_k^H - w_m^H \right] - \mu \cdot \log\left(p_k / p_m \right) = 0 \qquad \forall k, m \in \{1, ..., N\} \qquad (11)$$

The consequences of this spatial equilibrium concept are most easily illustrated for the case of two identical cities with identical low-skilled population, housing stock and productivity level φ_c. In this case, equal distribution of high-skilled workers across the two cities ($H_1 = H_2 = H$) must be an equilibrium. However, depending on the strength of the human capital externality, this symmetrical equilibrium need not be stable.

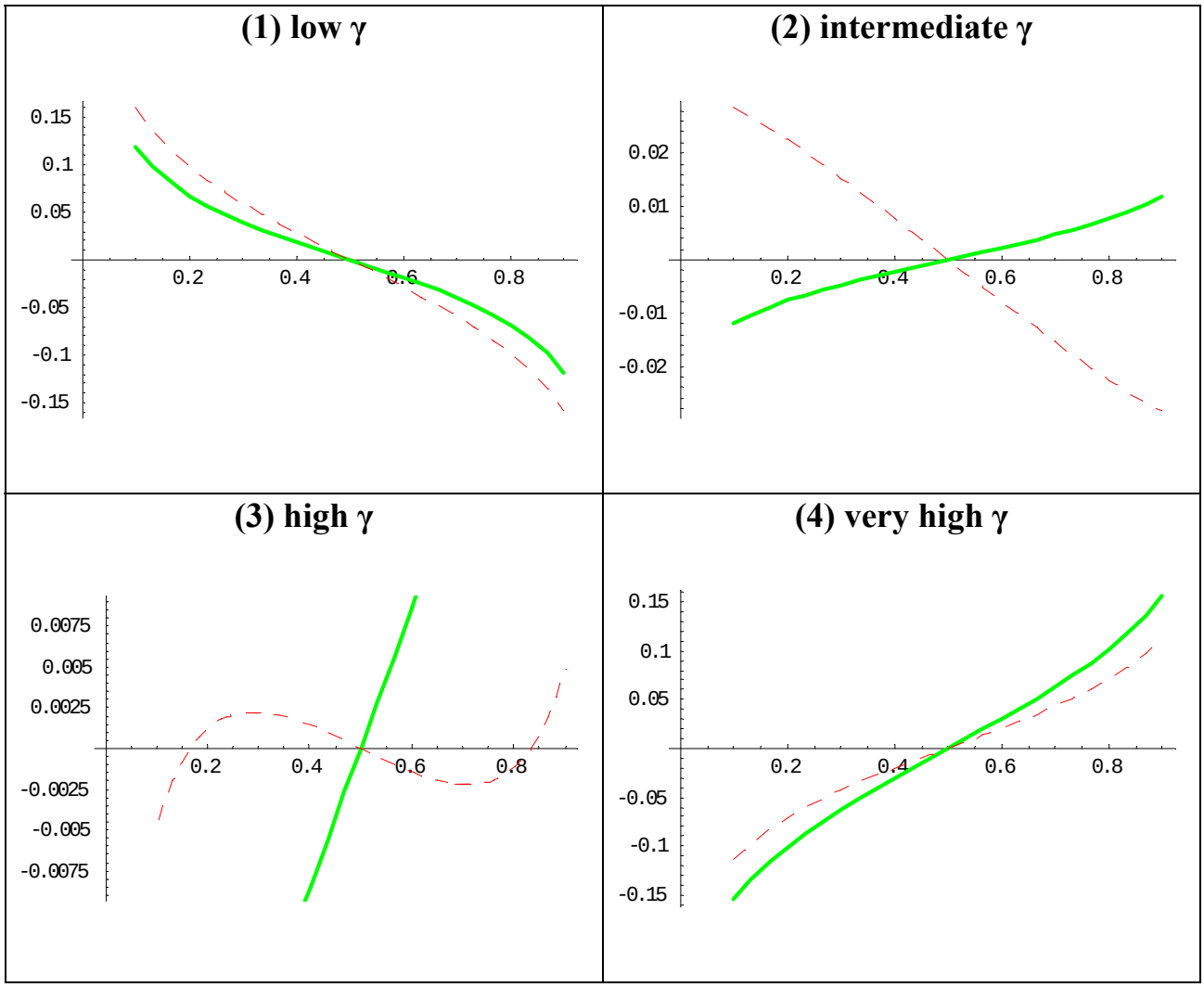
In figure 1 I have plotted the nominal wage differential (the solid line) and the utility differential (the broken line) for high-skilled workers, against the share of high-skilled workers located in region 1. I have used common values for the exogenous parameters in both cities, and I look at four different scenarios for the spillover strength γ.

If the strength of the externality is weak or zero, equal distribution of high-skilled workers is the only equilibrium, which is also stable (panel 1). Hence, starting off from any initial distribution of human capital across space we would expect to see a convergence of local human capital shares to an identical level. Note that the slope of the utility differential is stronger negative, because it entails both centrifugal forces, whereas the nominal wage differential only captures the neoclassical supply effect but not the housing congestion.

In panel (2) the centripetal force is strong enough to render higher nominal wages for high-skilled workers in human capital abundant areas, but not strong enough to render divergence. The localised increasing returns do not compensate the housing congestion force in this case. Increasing γ even further leads to a small parameter range where the model exhibits multiple equilibria, a locally stable equilibrium with equal distribution of high-skilled workers

accompanied by two unstable equilibria with partial agglomeration of high-skilled workers (panel 3). Finally, in panel 4 the centripetal force is so strong that it generates global human capital divergence, i.e. complete concentration of all high-skilled workers.

Figure 1: Spillover strength and spatial equilibrium with two identical cities



To sum up, the small theoretical model predicts that in the absence of a localised a human capital externality we would expect to observe convergence of human capital shares across space by standard neoclassical mechanisms. The reverse, however, is not true. Convergence is consistent with localised increasing returns to human capital ($\gamma > \alpha$, see panel 2). The observation of local human capital *divergence* (panel 4) would be an empirical indicator for a *strong* local concentration force that offsets several opposing centrifugal forces.

Before turning to the empirical part of this paper, I shall put the theoretical framework into a broader perspective. I have presented a static model where agglomeration is driven by geographical mobility of high-skilled workers, and where the agglomeration force is specified in an ad-hoc way. This simple model could be changed or extended in various directions, presumably without affecting its main qualitative insights. Suppose, for example, that all workers are geographically immobile (which would be an extreme representation of the lower mobility of Europeans), but that qualification decisions are endogenous. Without human capital externalities, the relative wage of high-skilled workers, and thus the incentive to become skilled, would be highest in those regions where human capital is initially relatively scarce. Hence, we would expect a convergence of local human capital shares through education choices even in the absence of any labour mobility. Secondly, a dynamic version of the model is conceivable, e.g. by assuming that the technology level φ_c grows at an exogenously given rate. With weak or zero spillovers, migration takes place to equalise relative factor shares, so that regions converge to the balanced growth path. With sufficiently strong externalities, one region would gradually be abandoned by high-skilled workers.[7] Thirdly, the intuition of the model does not hinge crucially on the specific centripetal force that is assumed here. As argued above, several micro-foundations for concentration forces have been discussed in the literature (Duranton and Puga 2004). Similar conclusions as in the present model would follow with a different centripetal force, as long as it is localised and depends endogenously on human capital. Finally, I have modelled high-skilled migration as a transition to a long-run equilibrium where relative factor inputs are equalised across cities. An alternative would be to assume that the economy is in its long-run spatial equilibrium, and that locations experience idiosyncratic random shocks. Again, without sufficiently strong externalities the system would not deliver a spatial clustering of high-skilled workers.

[7] An elaborate multi-region growth model with endogenous technological change, qualification and location choice is also conceivable, but it would certainly be difficult to formalise.

3) Data and descriptive overview

For this study I exploit two data sources. I mainly work with the official employment statistics provided by the Institute of Employment Research (IAB) of the German Federal Employment Agency. This highly reliable official information entails the complete population of full-time employment relationships in West Germany (excluding Berlin) subject to social security, i.e. without civil servants and self-employed individuals. Employment is observed annually from 1977 until 2002 on the spatial scale of 326 NUTS3-districts ("Landkreise" and "kreisfreie Städte"), referring to workplace location. Within each region employment in 28 different industries can be distinguished, encompassing the full range of economic activities. For each local industry not only the total employment level is known, but also average daily labour income per worker, the employment shares of three firm size classes, and – most important for this study – of three qualification groups. One can distinguish individuals without any vocational qualification (low-skilled workers), completed apprenticeship (medium-skilled workers), and completed tertiary education (high-skilled workers).

The second data source is provided by the German Federal Statistical Office (StatBA). It covers the time period 1995-2002 and entails information at the district level about regional GDP, residence population, area size in km^2, and land prices.

Figure 2 plots the development of total full-time employment in West Germany (1977=1.00) and the respective development of full-time employment for high skilled workers only. Whereas the total number of full-time jobs has remained remarkably flat over the observation period (at about 16.2 million), the number of high-skilled jobs has more than doubled to roughly 1.5 million. The average human capital employment share has increased from 3.7% in 1977 to 9.5% in 2002. These aggregate numbers hide strong differences between individual regions. In table 1 (columns 1 and 2) I report the districts with the highest and with the lowest

human capital employment share in 1977 and 2002. In column 3 I report the districts with the highest and the lowest long-run *growth rate* of the local human capital employment share.

Figure 2: Total versus high-skilled employment (1977=1.00)

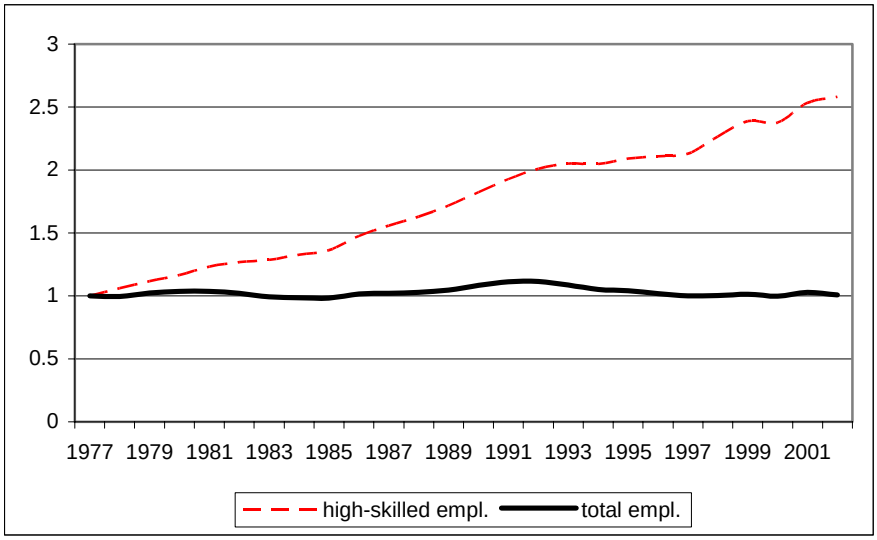


Table 1: Local employment shares of high-skilled workers

	(1)		(2)		(3)	
	Human capital share 1977		**Human capital share 2002**		**Growth of human capital share** (1977-2002)	
Rank	**District**		**District**		**District**	%
1	Erlangen	0.157	Erlangen	0.268	Wolfsburg	271.12
2	Outer-Munich	0.110	Darmstadt	0.232	Ingolstadt	195.55
3	Darmstadt	0.091	Inner-Munich	0.210	Erlangen-Höchstadt	186.03
4	Frankfurt a.M.	0.082	Stuttgart	0.204	Rhein-Neckar Kreis	173.35
5	Inner-Munich	0.081	Outer-Munich	0.193	Aschaffenburg	165.80
…	…	…	…	…	…	…
322	Cochem-Zell	0.009	Schwandorf	0.029	Outer-Munich	56.54
323	Regensburg	0.009	Südwestpfalz	0.028	Erlangen	53.33
324	Neustadt a.d.W.	0.008	Freyung-Grafenau	0.028	Frankenthal (Pfalz)	49.60
325	Wolfsburg	0.007	Straubing-Bogen	0.027	Cuxhaven	47.09
326	Südwestpfalz	0.006	Ansbach	0.025	Herne	14.64

Human capital shares differ by a factor larger than 10 across districts. An established fact from the urban economics literature that can also be observed in Germany is that metropolitan

areas (like Munich, Stuttgart, Frankfurt or Hamburg) exhibit large employment shares of high-skilled workers. Yet, medium sized and strongly specialised cities also tend to be highly skilled. In fact, the "smartest" German city in all years of observation has been Erlangen (with population size at around 100,000), where the headquarters of *Siemens* are located.

Turning to growth of the local human capital share, column 3 shows that even the worst performing city, Herne in the Ruhr area, has experienced a *positive* growth rate of 14.64%. This implies that the high-skilled employment share has increased in *each* West German district between 1977 and 2002. But table 1 also suggests that initial level and long-run growth of local human capital shares are negatively correlated. The district with the highest *growth rate* (Wolfsburg, the headquarter location of *Volkswagen*) belonged to the group of five regions with the lowest *initial level* of the human capital share, and turns out to be ranked 34th in 2002. The opposite is true for Erlangen and Munich. These cities belong to the group with the highest *level*, but also with the lowest *growth rate* of the local human capital share.[8]

The impression of a negative correlation is verified in figure 3. In a univariate OLS regression linking the (log) intial level with the long-run growth rate of human capital shares I estimate a coefficient of –0.237 (std. error 0.023) as indicated by the negatively sloped line. One would, therefore, expect a convergence of local human shares across districts over time. Figure 4 illustrates the coefficient of variation based on the weighted standard deviation. There has been, in fact, a steady decline in cross-district dispersion of local human capital shares that is flattening out to some extent in the post-unification period since the mid-1990s. Together with the general tendency of all cities to become more skilled over time, figures 3 and 4 suggest that high-skilled employment grew over-proportionally in districts with a relatively small initial human capital share. This impression will be verified in the statistical analysis below.

[8] Another interesting observation is that regions with high growth rate of the human capital share are often adjacent to skilled cities. For example, the high-performing district Erlangen-Höchstadt is a neighbour of Erlangen, Aschaffenburg is close to Frankfurt, Ingolstadt is not far from Munich.

Figure 3: Initial level and long-run growth rate of local human capital shares (N=326)

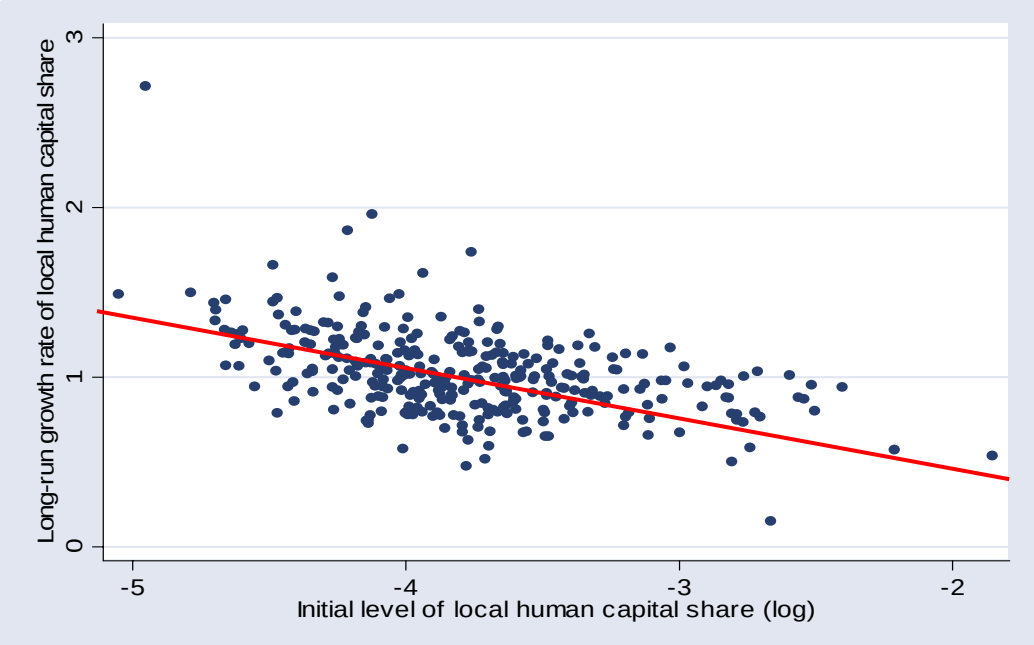
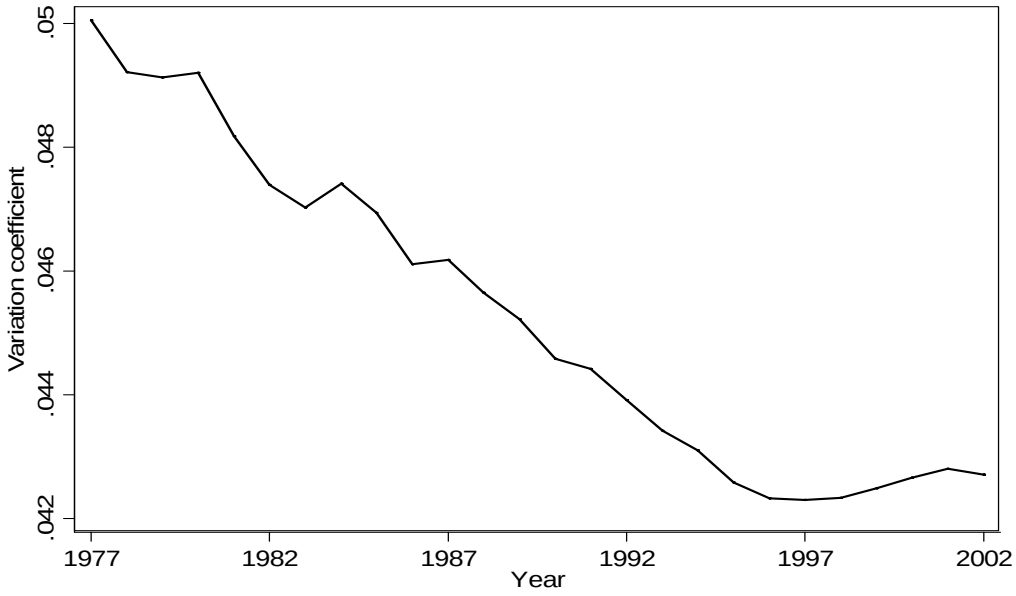


Figure 4: Variation coefficient of local human capital shares (N=326)



Briefly considering the distribution of human capital along industry dimensions, one finds that the range of human capital employment shares goes from below one per cent in hotels & gastronomy and the household-related services to above 30 per cent in the education sector (in 2002). There is also clear evidence of structural change: Primary and traditional

manufacturing sectors disappeared rapidly, whereas service industries (notably business-related services) grew significantly faster than West Germany overall. The correlation between the initial human capital share in 1977 and the industry's long-run growth rate of total employment is 0.493, which suggests that skilled industries grew faster on aggregate. These descriptive figures emphasise the widely recognised claim that sectoral structures must be properly controlled for in urban or regional growth regressions (Simon, 2004), in order to disentangle if there is an independent effect of human capital on city employment growth that does not simply reflect a spurious correlation with the regional specialization pattern.

4) Empirical specification and results

In this section I aim to establish stylised facts about the impact of human capital at the local level more formally. I start off with regressions on total and qualification-specific employment growth rates of entire locations (section 4.1). The finer dis-aggregation of the IAB data along regional *and* industry dimensions is exploited in 4.2., where I analyse the employment growth performance of different industries at the local level. In section 4.3, I utilise the StatBA data to provide results on the impact of human capital on regional productivity, wages, land prices and population.

4.1. Regional employment growth

A simple cross-section analysis is a natural starting point. To test the "smart city hypothesis" in the most basic way, I regress long-run growth rates of total employment on local base year characteristics. To address convergence of human capital, I will then exchange the dependent variable with the growth rate of high-skilled (low-skilled) jobs. Growth rates in this benchmark specification are computed for the period 1985-2002, but to address issues of

reverse causality I use all control variables for the year 1977.[9] The central explanatory variable is the initial employment share of high-skilled workers in city c in 1977. As additional controls I use the employment share of medium-skilled workers, employment density (total employment over area size in km^2), and initial local industry composition. One could exploit the variation of employment in 28 different industries, but in order to limit the number of results I will only report estimations where I control for the initial shares of broad sectoral classes.[10] Finally, I include the local firm size structure, because a glance at correlation tables suggests that the employment share in large firms is positively correlated with the high-skilled employment share (ρ=0.550), but *negatively* with employment growth (ρ= –0.502). To avoid omitted variable bias an inclusion thus seems warranted.[11]

Table 3 reports the results of this simple OLS regression with robust standard errors, because the Breusch-Pagan test indicated potential heteroskedasticity problems. The impact of the initial employment share of high-skilled workers on total employment growth is significantly positive in all specifications. The initial share of medium-skilled employees also significantly raises total city employment growth, but the impact is considerably smaller. Comparing the baseline specification (1) with (2), it becomes obvious that an omission of firm sizes leads to a downward bias in the coefficient for human capital intensity (2.0309 versus 2.1667). The reason is that university graduates are over-represented in large firms, but a high local employment share in large firms – per se – reduces growth (-0.3079). Analogously, comparing (1) and (3), an omission of industry composition leads to an upward bias in the estimate for human capital (2.0309 versus 1.8151), because high-skilled labour is positively correlated with booming industries. The impact of human capital remains qualitatively robust,

[9] It seems implausible to argue, e.g., that skilled workers have moved to a particular city in 1977 because they expected growth to be strong from 1985 onwards. We have experimented with different time periods for growth rates. To avoid outlier problems for single years we have also computed growth rates by using three year averages for the base and the end period. The results were very similar to those reported here.

[10] For the definition of the broad groups of industries, refer to the appendix. Qualitative results are robust to small re-definitions of these sectoral classifications or to the inclusion of all industry employment shares.

[11] Another study that emphasises the importance of firm sizes for regional employment growth is Combes et al. (2004), who have no information on qualification structures, however.

however, which suggests that the positive correlation between high-skilled labour and city growth is not spurious.

TABLE 3 HERE

The most comprehensive specification (4) shows a positive and quantitatively large effect of the initial human capital share on total employment growth. An increase of the employment share of high-skilled workers by one percentage point raises local employment growth by roughly 2.4 per cent.[12] Glaeser and Saiz (2004), who also use a log-linear specification and regress population growth of US metropolitan areas on the initial population share of inhabitants with (at least) a Bachelor's degree obtain coefficients that are considerably smaller (between 0.2 and 0.5 in regressions without local fixed effects). Apart from several other details, it appears that one important reason for the quantitative difference is the definition of what is a "high-skilled worker". The group of high-skilled workers in our data set consists of university graduates, who have obtained a diploma or a comparable degree, which is actually closer to a Master's than to a Bachelor's. The group of medium-skilled workers has completed the German system of vocational training ("Facharbeiter"). As the post-secondary education for this group usually exceeds three years, this group might also be regarded as skilled workers. When university graduates and medium-skilled workers are lumped together in one skill group I obtain a coefficient of 0.3625** (t-value 2.44) when redoing estimation (4), which is perfectly in line with the findings of Glaeser and Saiz (2004).

In the estimations (5)-(7) the dependent variable is the long-run growth rate of local low-skilled, low- and medium-skilled, and high-skilled employment, respectively. The central finding can be summarised as follows: Whereas the initial share of high-skilled workers in a city significantly raises subsequent growth of low-skilled jobs (and to a lesser extent of medium-skilled jobs), it significantly reduces growth of high-skilled jobs. The estimated

[12] The standard deviation of district growth is around 0.14, and the standard deviation of the high-skilled employment share is around 0.02. Thus, an increase in the high-skilled employment share by one standard deviation raises subsequent employment growth by more than one third of a standard deviation.

coefficient for the impact on low-skilled employment (5.68) is more than twice as large as the coefficient for total employment (2.367), whereas the impact on high-skilled employment growth (-2.6714) is decisively negative.

This cross-section analysis is potentially problematic, because human capital might proxi for unobserved local characteristics that drive employment growth. For example, some districts are located in more pleasant environments than others or offer more attractive productive amenities. These time-invariant city features may constantly increase employment growth. To address this issue, I make use of the longitudinal data structure and turn to panel estimation. A further advantage of panel techniques is the possibility to consider different time structures. The cross-section approach has imposed a very strict timing: A historical human capital share was thought to influence long-run city growth. However, it is conceivable that it is rather the current human capital share that influences short-run city growth. I will therefore consider both, a long-run and a short-run panel analysis, and I will briefly turn to dynamic panel estimation to sort out the relevant time structure.

Long-run panel analysis

For the long-run analysis I split up the observation period into three parts, and compute employment growth rates for 1980-1985, 1988-1993 and 1996-2002. Control variables for the three periods are, respectively, computed for 1977, 1985 and 1993. Using independent variables with time lag again ameliorates concerns of reverse causality. This procedure gives three observations for each local area, and thus a total number of $3 \times 326 = 978$ observations. Based on Hausman's specification test I decide between the fixed and the random effects (GLS) model. For the long-run panel analysis the model with fixed effects (within-estimator) is generally preferred. The same set of control variables as in the cross-section analysis was used, but for brevity I will only report the result for the high-skilled employment share. The

other estimated coefficients (density, medium-skilled employees, large firms, industrial composition) do not change qualitatively. Table 4 shows the results.

Including fixed effects renders insignificance of the relation between the initial human capital share and *total* city employment growth, i.e. the basic "smart city hypothesis" does not survive in this specification. However, the main result from the cross-section analysis prevails in this panel setup: The initial employment share of high-skilled workers is significantly positively related to growth of low-skilled jobs (1.2396). The impact on subsequent growth of high-skilled jobs (-4.8101) remains significantly negative[13]

Table 4: Long-run panel analysis (1980-1985, 1988-1993, 1996-2002) (N=928)

	(1)	(2)	(3)	(4)
	Total empl. growth	**Low-skilled empl. growth**	**Low-+ medium skilled empl. Growth**	**High-skilled empl. growth**
High-skilled employment share	0.2058 (0.53)	**1.2396*** (1.81)	0.0686 (0.18)	**- 4.8101***** (-5.46)
Other controls	log(emp.density), empl.share medium-skilled, empl.share in large firms, empl. share in advanced services, basic services, modern manufact., constant term.			
local area fixed effects	YES	YES	YES	YES
time period fixed effects	YES	YES	YES	YES
FE/RE model	FE	FE	FE	FE
R^2	0.7440	0.8279	0.7526	0.5210

t-value in parentheses. significance levels: ***) 1%, **) 5%, *) 10%. Controls for 1977, 1985, 1993

Results are not driven by the fact that my data set includes small cities and local areas with rural character. Re-doing the estimation for the sub-sample of large German cities (population

[13] Including a fixed effect for every district is the strictest formulation of the fixed-effects model. Glaeser and Saiz (2004) argue that this approach is "asking a great deal from the data", because identification comes solely from the change in the high-skilled employment share within a district but local fixed effects eliminate most of the variation due to the high persistence of human capital levels over time. Still they find a significantly positive effect of the local human capital share on total city growth in the US. It turns out that a different specification (short-run panel analysis) will also yield a significant effect for the case West Germany. This is one reason why we think that the insignificant coefficient in this specification is not too discouraging. Moreover, the effect on total employment growth is a weighted average of the impacts on the single qualification groups. For addressing issues of convergence of human capital shares across locations, which is the main theme of this paper, the impact on total city growth is less informative than the impact on qualification-specific employment growth rates.

size > 250,000) yields a coefficient of –3.7742** (t-value: -2.08) for the impact of the initial human capital share on high-skilled employment growth. Equilibrating forces appear to be weaker among large cities than among West German local areas overall (where the respective effect has been –4.81), but the results remain qualitatively unaffected.

Quantitatively, the inclusion of fixed effects works in the expected direction. In pooled cross-section regressions (not reported) I receive considerably larger positive coefficients in the estimations for total and low-skilled employment growth, and a smaller negative (yet still significant) impact on high-skilled growth. Idiosyncratic city effects positively covary with human capital. Not taking into account that certain locations constantly attract high-skilled workers leads to an understatement of the equilibrating forces for local human capital shares.

Short-run panel analysis

For the short-run panel analysis I construct annual employment growth rates, which I regress on time-lagged city characteristics. The estimation equation takes on the form

$$\mathbf{log}\left(\frac{emp_{c,t}}{emp_{c,t-1}}\right) = \alpha + \mu_c + \lambda_t + \beta X_{c,t-2} + \varepsilon_{c,t}$$

where emp_c is either total or qualification-specific employment in city c. λ_t is a time fixed effect and μ_c is a local fixed/random effect, depending on Hausman's specification test. The time-lagged city characteristics $X_{c,t-2}$, among which is the high-skilled employment share, are instrumented with the city features of period (t-3). In table 5 I present the results.

The coefficients in the first column refer to the short-run panel regression for the West German districts (NUTS III) over the entire observation period. They are smaller than the coefficients of the long-run regression in table 4. This seems quite plausible given the persistence of human capital levels over time. Importantly, the qualitative conclusions about the impact of human capital on employment growth remain robust: The local human capital share is positively related to growth of low-skilled jobs (0.1689), but negatively related to

growth of high-skilled jobs (-0.1140). The impact on total employment growth turns significantly positive again in this specification (0.0821). As expected, the effect on total employment is smaller than on low-skilled job growth.

Table 5: Human capital share and qualification specific employment growth - Short run panel analysis

	(1)	(2)	(3)	(4)
	Total empl. growth	**Low-skilled empl. growth**	**Low-+ medium skilled empl. Growth**	**High-skilled empl. growth**
NUTS III, 1977-2002 NOBS = 7824	**0.0821***** (3.46)	**0.1689***** (5.21)	**0.0610**** (2.57)	**-0.1140***** (-2.66)
	RE, R^2=0.4705	RE, R^2=0.3853	RE, R^2=0.4646	RE, R^2=0.4111
NUTS III, 1995-2002 NOBS = 2608	**0.1311***** (4.47)	**0.2302***** (4.96)	**0.1094***** (3.79)	0.0093 (0.15)
	RE, R^2=0.433	RE, R^2=0.4094	RE, R^2=0.4030	RE, R^2=0.6126
NUTS II, 1977-2002 NOBS = 644	**0.1615***** (3.56)	**0.3066***** (4.83)	**0.1226***** (2.72)	**-0.0869*** (-1.66)
	RE, R^2=0.8104	RE, R^2=0.7462	RE, R^2=0.8014	RE, R^2=0.8242
Other controls	log(emp.density), empl.share medium-skilled, empl.share in large firms, empl. share in advanced services, basic services, modern manufact., constant term.			
Local area fixed effects	YES	YES	YES	YES
time period fixed effects	YES	YES	YES	YES

t-value in parentheses. significance levels: ***) 1%, **) 5%, *) 10%.

The results in the second column refer to the post-unification period 1995-2002, which corresponds to the observation period of the secondary data source (StatBA). A similar picture emerges, with one important difference: The impact of the human capital share on high-skilled job growth is now insignificant. This fits well to the descriptive observation from figure 4 that the convergence trend of local human capital shares has come to a halt since the mid-1990s. Cross-district dispersion of human capital has declined mainly before the 1990s. Since then, the spatial configuration of human capital appears to be roughly stable (however, without any apparent signs of divergence of local human capital shares).

I have also checked the robustness of our results with respect to the spatial scale of analysis, because NUTS III districts might be too small to constitute meaningful labour markets. The results in column 3 refer to the short-run panel estimation when I aggregate the data according to the 28 West German NUTS II regions ("*Bezirke*") between which commuting flows are considerably smaller. It turns out that results are similar to the NUTS III-level. The negative coefficient of the human capital share in the high-skilled employment growth regression is weakly significant, indicating that convergence of human capital shares seems to occur also on this scale. The higher R^2 levels can be explained by noting that there is less noise in the NUTS II data, because *Bezirke* are more homogenous spatial units.

Dynamic panel analysis

I finally conduct some dynamic panel estimation à la Arrelano and Bond (1993) to control more properly for endogeneity. I return to the NUTS III level as the unit of observation. As the dependent variable I specify the log human capital share in city c, $hc_{c,t}$, and estimate

$$\mathbf{log}\left(hc_{c,t}\right) = \mu_c + \lambda_t + \sum_{s=1}^{L}\left(\rho_s \cdot \mathbf{log}\left(hc_{c,t-s}\right) + \beta_s \cdot X_{c,t-s}\right) + \varepsilon_{c,t}$$

where $X_{c,t}$ are the usual exogenous controls. Of particular interest are the autoregressive coefficients ρ_s. If local human capital shares exhibit a convergence trend, these coefficients should be well below unity. This would be inconsistent with the idea that local growth of human capital "feeds on itself". A divergence trend would be associated with autoregressive coefficients exceeding unity. This dynamic panel specification allows for a proper instrumentation of the time-lagged dependent variable, and elaborate specification tests.

Table 6, which reports the autoregressive coefficients that refer to a parsimonious specification with time lags L=4, indicates two important results. First, the impact of the lagged dependent variables is decisively below one, hence there is no evidence for a divergent

path of local human capital shares also in this alternative specification. Second, the impact of human capital dies out quickly over time.

Table 6: Dynamic panel analysis (1977-2002)

	ρ_{-1}	ρ_{-2}	ρ_{-3}	ρ_{-4}
$\log(hc_{t-s})$	**0.6193***** (36.47)	**0.0477***** (3.68)	**0.0911***** (7.54)	-0.0107 (-1.08)
	NOBS: 6846 Number of groups: 326 Time fixed effect: YES			
Sargan-test overidentifying restr.	$\chi^2(290) = 308.61$ (P=0.2165)			
No second order autocorrelation	Z = -0.13 (P=0.8967)			

The coefficients of higher-order time lags are far smaller than ρ_{-1}, and there are no significant effects for s>3. It seems to be the current rather than some historical human capital share that influences employment growth performances. All in all, this dynamic panel estimation confirms the insights from the more conventional static analysis.

4.2. Local industries

In this subsection I exploit the finer dis-aggregation of the IAB data set and move the unit of observation from entire regions to single industries at the local level. I analyse if human capital exhibits a different spatial trend in some industries than in the average. Furthermore I can address the question if the impact of human capital on employment growth may have a cross-industry component.

Specifically, I relate the employment growth rate of industry i located in city c to the own-industry share of high-skilled workers *and* to the human capital share of the other industries located in the same city. To this end, I compute the aggregate share of high-skilled workers in city c minus the respective own-industry human capital share,

$$aggregate\ city\ human\ capital_{i,c} = \frac{high-skilled_c}{emp_c} - \frac{high-skilled_{i,c}}{emp_{i,c}}$$

In addition to this variable that refers to the total *stock* of high-skilled workers in other industries, I construct an index for the degree of specialization of surrounding local knowledge in the following way,

$$skill\ specialization_{i,c} = \sum_{s=1, s\neq i}^{S} \left| \frac{high-skilled_{s,c}}{emp_{s,c}} - \frac{high-skilled_s}{emp_s} \right|,$$

i.e. the sum of absolute differences of local minus national human capital intensities across all other industries S. This index is equal to zero if the surrounding local skill structure exactly matches the national average, and it increases with the degree of knowledge idiosyncrasy of the local environment.

The rationale for including these two new control variables is related to the debate on *diversity versus specialization* that has been initiated by Glaeser et al. (1992).[14] These authors have analysed employment growth rates of local industries, and argued that there are significant inter-industry effects. In particular, they find that job growth is positively related to the overall scale and the diversity of the surrounding local economic environment ("Jacobs externalities"). The approach taken in this paper differs from Glaeser et al. (1992) and the subsequent literature, because I do not analyse total employment growth of local industries as a function of diversity and specialization measures, but I will concentrate on growth of high-skilled jobs as a function of initial human capital shares. Thereby I can address the novel question if human capital employed in certain industries tends to cluster in space, or if it rather tends to spread out.

For the estimation, I stick to the long-run panel setup that is described above. I compute qualification-specific employment growth rates for every local industry (i,c) for the three time periods. As local industries are sometimes very small, growth rates exhibit exorbitant jumps

[14] Blien et al. (2006) is a study on West Germany that belongs to this strand of the literature. For a recent survey, see Combes and Overman (2004).

following small absolute employment changes. This erratic noise in the data will yield R^2 levels that are considerably smaller than before. Furthermore, heteroskedasticity problems are exacerbated, so that the use of robust standard errors has to be continued.

I have put local industries together in four sub-samples – modern manufacturing, advanced services, traditional manufacturing, basic services (defined in the appendix). Industry-, city-, and time-period fixed effects are included. I have also experimented with industry×year fixed effects, which yielded similar results for the control variables of interest. Table 7 shows the results for all independent variables that refer to human capital.

Table 7: Growth of high-skilled employment – by industry type, panel analysis

dependent variable: high-skilled employment growth rate (i,c)	(1) **Modern manufacturing**	(2) **Advanced services**	(3) **Traditional Manufacturing**	(4) **Basic services**
own-industry empl.sh. high-skilled	**- 3.3759***** (-4.42)	**- 1.5247***** (-2.84)	**- 12.711***** (-3.96)	**- 11.292***** (-4.23)
aggregate city empl.sh. high-skilled	**4.2036**** (2.11)	**3.2117**** (2.55)	0.6184 (0.28)	0.3608 (0.10)
skill specialization	0.1080 (0.50)	**0.4098**** (2.37)	-0.0007 (-0.01)	0.5078 (1.49)
Other control variables	$\log(\text{emp.density}_c)$, empl.share in large $\text{firms}_{i,c}$, fixed effects, constant term.			
Fixed effects	Time period, Industry, Local area			
FE/RE model	FE	FE	FE	FE
NOBS	3912	4890	9511	3912
R^2	0.0132	0.0168	0.0195	0.0270

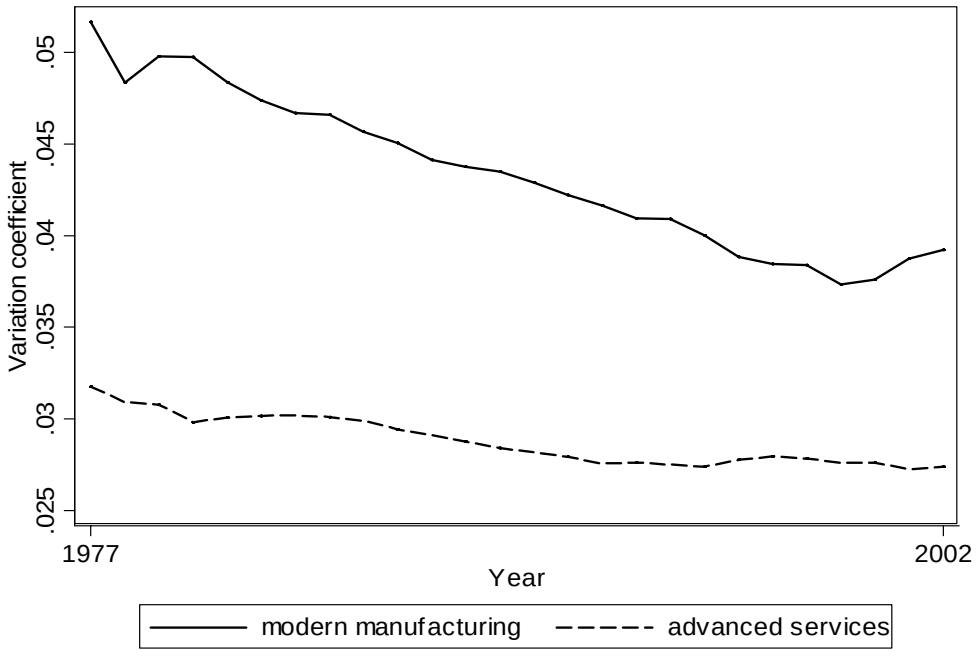
t-value in parentheses. significance levels: ***) 1%, **) 5%, *) 10%.
Growth periods: 1980-1985, 1988-1993, 1996-2002. Control variables, respectively, for 1977, 1985, 1993.

For all four groups I find that the initial own-industry human capital share remains significantly negatively related to subsequent high-skilled employment growth. However, the strength of equilibrating forces differs profoundly across industry groups. Convergence tendencies appear to be particularly strong in traditional manufacturing (-12.711), and in basic service industries (-11.292). They are considerably weaker in modern manufacturing

(-3.3759), and in advanced service industries (-1.5247). This seems plausible, because one would expect that spatial concentration forces for human capital are more important in these two cases. Moreover, for advanced services and modern manufacturing I find a significant impact of the surrounding local human capital. In both cases I obtain a significantly positive coefficient for the aggregate local human capital share (4.2036 and 3.2117, respectively). In addition, growth of advanced service industries is spurred by the degree of specialisation of this surrounding local human capital (0.4098).

These results suggest that high-skilled job growth in modern manufacturing and in advanced service industries flourishes in skilled cities where surrounding human capital in other sectors is abundant. But nevertheless, there are no apparent signs for a spatial divergence or clustering trend of high-skilled workers within these two branches, because the initial level and the subsequent growth of own-industry human capital remain negatively related. This result matches descriptive evidence illustrated in figure 5, which shows the variation coefficient of human capital shares across German regions in these two broad industries.

Figure 5: Variation coefficient of local human capital shares, by industry group (N=326)



The *level* of spatial dispersion is higher in modern manufacturing than in the advanced services, as services tend to be less concentrated geographically. Concerning the development over time, there is a secular decline of dispersion in both cases. Hence the spatial trend of high-skilled employment in these two modern sectors resembles the development of employment in general: Human capital shares have tended to become more equal across districts over time.

4.3. Other city characteristics

Shapiro (2006) argues that there are two principal reasons why skilled cities may exhibit faster employment or population growth than unskilled ones. The first theory is that educated cities generate positive consumption externalities, or higher quality of life (e.g., via better designed local institutions), and thereby attract more individuals subsequently. The alternative theory postulates that human capital raises local productivity.

Building on a dynamic version of the *spatial equilibrium concept* by Roback (1982), Shapiro (2006) shows that land price and wage regressions can be used to discriminate between these two theories. Consumption amenities capitalise in local land prices, whereas local wages would be unaffected. If productivity is the main channel, wages should react stronger to human capital than land or housing prices. The details of these arguments can be found in Shapiro (2006) or in Glaeser and Saiz (2004). Both papers agree that, even though amenities also play some role, productivity appears to be the main reason for higher growth of skilled cities in the US. The theoretical model presented in section 2 also attributes the main role to production externalities and neglects consumption amenities.

In this subsection I study the impact of human capital on average wages, land prices and labour productivity for West German districts. I do not use individual earnings data in this

study, hence I can not disentangle disparities in the private returns to human capital.[15] I rely on the short-run panel setup described above, where the observation period now only runs from 1995 to 2002 due to lower availability of the StatBA data. More precisely, I use an estimation equation of the following form

$$\mathbf{log}\left(y_{c,t}\right) = \alpha + \mu_c + \lambda_t + \beta_1 \cdot \mathbf{log}\left(hc_{c,t-1}\right) + \beta_2 X_{c,t-1} + \varepsilon_{c,t} \ ,$$

where the dependent variable $y_{c,t}$ is either the average city wage, land price, GDP per capita of the residence population, or average labour productivity (GDP/total employment). The time-lagged human capital share $hc_{c,t-1}$, as well as the other exogenous city features ($X_{c,t-1}$) are instrumented with values from period $t-2$. I prefer this specification over a cross-section growth regression of the form $\mathbf{log}\left(y_{c,2002}/y_{c,1995}\right) = \alpha + \beta_1 \cdot \mathbf{log}\left(hc_{c,1995}\right) + \beta_2 X_{c,1995} + \varepsilon_c$, which is sometimes used in similar contexts, because this would not efficiently use all available information. Recall that due to the panel setup with fixed/random district and time effects, I identify the impact of a *change* in the local human capital share on the *change* in the respective dependent variable.

Table 8 provides the results, which can be summarised as follows: The local human capital share in city c is significantly positively related to average labour productivity, wages and GDP per capita, but unrelated to land prices. The elasticity of productivity (0.0859) exceeds the wage elasticity (0.0524), which might represent imperfections in labour markets. The impact of the high-skilled employment share on GDP per capita of the local residence population has the lowest size (0.0303). This changes considerably if I restrict the estimation to large cities, in which case the impact on GDP p.c. is larger than on productivity and wages. This can be explained by the phenomenon of daily commuting. For example, many people

[15] Related works have often utilised Mincerian wage regressions and studied returns to education across regions. Shapiro (2006) has adopted a similar approach, and then studied the impact of the local human capital share on the regional fixed effects that were computed from the individual earnings regression. In this paper we can not construct such a "neutralised" regional wage measure, but we use raw average city wage/productivity as the dependent variable.

who work in the city of Hamburg live in surrounding districts, i.e. Hamburg's GDP per capita is above its GNP per capita, or the GDP per job. The opposite (net outward commuting) is observed for many small cities, hence a positive impact of human capital on GDP per capita should be stronger among large than among small cities.

Table 8: Human capital and local wages, land prices and productivity, panel analysis

	(1)	(2)	(3)	(4)
	Average wages	**Average labour productivity**	**GDP per capita**	**Land price**
Log(high-skilled employment share$_{t-1}$)	**0.0524***** (17.76)	**0.0859***** (7.42)	**0.0303**** (2.16)	0.0851 (0.90)
Log(population density$_{t-1}$)	**0.0186***** (8.43)	0.0048 (0.76)	**0.0911***** (7.13)	**1.2927***** (2.76)
Other controls	empl.share medium-skilled, empl.share in large firms, empl. share in advanced services, basic services, modern manufact., constant term.			
local area fixed effects	YES	YES	YES	YES
time period fixed effects	YES	YES	YES	YES
FE/RE model	RE	RE	RE	FE
R^2	0.8047	0.4550	0.0584	0.3100

Local land prices in Germany are determined mainly by population density (with an elasticity larger than one), but they are unaffected by the skill composition of the local workforce. In estimations without local fixed effects I generally obtain a significantly positive impact of the human capital share on land prices, but this does not seem to be a robust result. Once I control for time-invariant features that undoubtedly play an important role on local land markets, however, the positive impact of the human capital share vanishes.

In sum, our results suggest that the human capital share has a positive impact on productivity at the local level, because the effect of human capital on GDP related measures and on wages is significantly positive. In contrast, I find no evidence that the human capital share is a consumption amenities that capitalises in local land prices.

5. Summing up and interpreting the evidence

I will now summarise the stylised facts for the German economy, and contrast them with previous findings of the related literature. I hope to have conveyed the following facts:

1. The local share of high-skilled workers is positively related to subsequent total city employment growth. I.e., "skilled" German cities grow faster than "unskilled" German cities, overall.
2. The local share of high-skilled workers has a positive effect on subsequent growth of low-skilled jobs that is larger than the effect on total employment growth. In contrast, the local share of high-skilled workers is robustly negatively related to subsequent growth of high-skilled employment. Hence, there has been convergence of human capital shares across regions. Although the human capital share has risen in *all* West German districts over time, growth has been stronger in those regions where human capital was initially relatively scarce.
3. Although the strength of the spatial de-concentration process differs across industries, regional convergence of high-skilled employment shares prevails in all broadly classified industrial branches (such as modern manufacturing or advanced services).
4. The local share of high-skilled workers is robustly positively related to the average wage, average labour productivity and GDP per capita. The skill composition of the workforce is unrelated to local land prices.

There is a substantial literature that has established fact 1 for US cities and metropolitan areas, see e.g. Glaeser et al. (1995), Simon (1998, 2004) Simon and Nardinelli (2002), Glaeser and Saiz (2004) or Shapiro (2006). It seems warranted to conclude that this stylised fact also holds in West Germany. This is already an important observation, because the robustness of the "smart city hypothesis" in countries other than the US has rarely (if at all) been studies so far.

Only very few papers have analysed the spatial evolution of human capital across cities. These papers, namely Moretti (2004b), Berry and Glaeser (2005) and Wheeler (2006b), interestingly find an opposite trend of spatial human capital divergence in the US (cif. footnote 4). Fact 2 shows that the development has been different in West Germany.

Fact 3 makes this observed difference between West Germany and the US even more puzzling. Divergence of human capital shares across German districts cannot even be observed within certain modern industries, where the scope for spatial concentration forces is supposedly stronger than in traditional, basic sectors. To my knowledge, such industry-specific trends in the spatial distribution of human capital have not been studied so far. It would be interesting for future work to provide evidence on this point for the US.

Finally, the facts combined in point 4 are often used to explore the underlying causes of the first fact. I conclude that the human capital share raises productivity at the local level in West Germany, and that productivity (rather than consumption amenities) appears to be the main reason why skilled cities exhibit larger total employment growth. This agrees with the conclusions of Glaeser and Saiz (2004) or Shapiro (2006) on the cause why skilled cities grow faster in the US. A notable difference, however, is that I find no significant impact on local land prices in Germany, whereas such an effect seems to be present in the US.

How can these stylised facts for the German economy be reconciled with the theoretical framework presented in section 2? In an aggregate sense, the observed convergence of high-skilled employment shares suggests that concentration forces for human capital are not sufficiently strong to generate a (possibly self-reinforcing) spatial clustering process of high-skilled workers, not even in particular modern industries. This does *not* imply, however, that agglomeration effects are absent in Germany. The findings by Moeller and Haas (2003) which are based on individual earnings data suggest that an agglomeration wage premium exists in Germany, particularly for high-skilled workers. This may be interpreted as indirect evidence for the existence of localised increasing returns to human capital. The evidence presented here

suggests that this spatial concentration force is not sufficiently strong, since this would then inevitably lead to a spatial divergence trend for human capital – comparable to the one that appears to be going on in the US.

Two natural questions arise: *Why* are the concentration forces too weak in Germany to trigger spatial clustering of high-skilled workers, and *why* has there been convergence of human capital shares across cities in Germany but divergence in the US? The main aim of this paper has been to take the first step: To collect new stylised facts, and to contrast them with existing ones. An in-depth analysis of subsequent issues is left for further research.

However, in the remainder I shall at least make some brief remarks related to the first question. It should be noted that the spatial employment evolution in Germany is not only characterised by a convergence of regional human capital shares, but also by a de-concentration and de-specialisation process of employment in general. According evidence is provided by Suedekum (2006), who has analysed the development of standard indices of geographical concentration of industries and sectoral specialisation of regions over time. On average and with some exceptions, overall employment in industries tends to spread out over time, and regional specialisation patterns tend to become more similar. That evidence stands in some contrast to observations from other countries (for a survey of various studies, see Combes and Overman, 2006), but it is quite consistent with the human capital convergence that has been established in this paper. A more specific observation is that successful districts which gain employment and human capital are often located in the broader vicinity of large metropolitan areas (cif. footnote 8), whereas larger cities often tend to lose jobs. A preliminary analysis of commuting data shows that daily inward commuting flows into large cities are getting smaller over time. These facts are consistent with a process of spatial "employment de-concentration", where (high-skilled) jobs actually move away from core cities. The areas that gain employment are not only directly adjacent sub-urban regions, however, but also more remote districts. Since convergence shows up also on a broader

territorial scale, namely for NUTSII regions between which commuting flows are much smaller, I am confident that the spatial evolution of human capital described in this paper is not only an artefact of the small spatial units. There might be various reasons for why employment de-concentration had occurred. One possibility, which seems quite plausible, is that recent advancements in telecommunication have made it easier for skilled workers to communicate and cooperate without having to be physically close to each other. Consequently, high-skilled jobs may escape from urban congestion and move to less crowded places, which – thanks to the higher population density and lower overall geographical scale of West Germany – are not too far away from the cities, so that personal interaction downtown remains relatively easily possible whenever it is necessary. A more thorough evaluation of this tentative conclusion should be addressed in further research.

Appendix: Definition of broad industry groups

A) Modern manufacturing – utilities & electric industry, synthetic material, machinery, motor vehicles, office supplies, IT & optics.

B) Ad*vanced service industrie*s – finance & insurance, health care, business-related services, education, leisure-related services, social services.

C) *Basic services* – commerce, information & transportation, hotels & gastronomy, household-related services.

D) Traditional manufacturing – chemical industry, non-metallic mineral mining, glass & ceramics, muscal instruments & jewellery, wood-working, paper & printing, leather & apparel, food & tobacco.

E) Other – building & construction, agriculture, mining, public sector.

Advanced services and *modern manufacturing industries* are distinguished by being relatively skill-intensive on average.

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Table 3: Long-run OLS regression (N=326). $\text{Log}(emp_{2002}/emp_{1985})=\alpha + \beta X_{1977} + \varepsilon$

	Total city employment growth				**Low-skilled empl. growth**	**Low-+ medium-empl. growth**	**High-skilled empl. growth**
	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
High-skilled employment share	**2.0309***** (3.10)	**2.1667***** (3.52)	**1.8151**** (2.32)	**2.3696***** (2.95)	**5.6802***** (4.37)	**1.9610***** (2.59)	**- 2.6714**** (-2.04)
Medium-skilled Employment share	**0.4455***** (3.00)	**0.3922**** (2.54)	0.2151 (1.51)	**0.3269**** (2.26)	**0.8896***** (3.64)	**0.3480**** (2.44)	- 0.0274 (-0.12)
log(empl.density)	**- 0.0758***** (- 10.57)	**- 0.0588***** (-6.64)	**- 0.0852***** (-11.42)	**- 0.0604***** (-5.80)	**-0.0412**** (-2.44)	**- 0.0634***** (-6.24)	- 0.0147 (-0.41)
large firms employment share	--	**- 0.3079***** (-3.59)	--	**- 0.4072***** (-3.87)	**-1.0446***** (-5.99)	**- 0.4061***** (-3.95)	**- 0.5937***** (-2.62)
advanced services employment share	--	--	0.1205 (0.66)	- 0.0725 (-0.39)	-0.3859 (-1.40)	- 0.1670 (-0.95)	0.2824 (0.73)
basic services employment share	--	--	**0.6010***** (3.70)	0.2941 (1.60)	**0.8126***** (2.86)	**0.3132*** (1.77)	- 0.3349 (-0.95)
modern manufacturing employment share	--	--	**0.2800***** (4.33)	**0.3057***** (4.81)	**0.2142**** (2.01)	**0.2703***** (4.45)	**0.5075***** (3.82)
Constant term	0.0135 (0.10)	0.0206 (0.15)	0.0093 (0.07)	- 0.0094 (-0.07)	**-0.8447***** (-3.92)	0.0163 (0.13)	**0.9167***** (4.09)
R^2	0.3515	0.3791	0.3953	0.4205	0.3918	0.4701	0.2291

significance levels: ***) 1%, **) 5%, *) 10%.