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Does It Pay to Live
in Big(ger) Cities? The Role
of Agglomeration Benefits,
Local Amenities, and Costs
of Living

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DOES IT PAY TO LIVE IN BIG(GER) CITIES? THE ROLE OF AGGLOMERATION BENEFITS, LOCAL AMENITIES, AND COSTS OF LIVING

By Rudiger Ahrend and Alexander C. Lembcke¹

ABSTRACT

This study approaches the question whether it “pays” to live in big(ger) cities in a three-fold manner: first, it estimates how city size affects worker productivity (agglomeration benefits) in Germany, based on individual-level wage data. Second, it considers whether productivity benefits translate into real gains for workers by taking local price levels into account. Third, it examines the role of amenities in explaining differences in real benefits across cities. The estimated elasticity for agglomeration benefits is around 0.02, implying that comparable workers in Hamburg (3 million residents) are about 6% more productive than in Recklinghausen (150 000). But agglomeration benefits are, on average, offset by higher prices, i.e. city size does not systematically translate into real pecuniary benefits for workers. Amenities, e.g. seaside access, theatres, universities, or “disamenities”, e.g. air pollution, explain – to a large degree – variation in real pecuniary benefits, i.e. real wages are higher in low-amenity cities.

Keywords: agglomeration benefits, agglomeration costs, cost of living, cities, local amenities, Functional Urban Areas, Germany

JEL classifications: R12, R23, J31

1 . OECD Public Governance and Territorial Development Directorate. Corresponding author: alexander.lembcke@oecd.org. The authors would like to acknowledge the excellent support with the data provided by the Research Data Centre (FDZ) of the German Federal Employment Agency (BA) at the Institute for Employment Research (IAB), and to thank Rupert Kawka for providing the regional price data. Patrick Reich provided research assistance for this project. Previous versions benefitted from feedback received at an ERSa workshop at the University of Barcelona and the OECD Applied Economics Work in Progress Seminar, as well as from comments by Luiz de Mello, Ioannis Kaplanis and Emily Farchy. The opinions expressed in this paper are the sole responsibility of the author(s) and do not necessarily reflect those of the OECD or the governments of its member countries.

Introduction

About two thirds of the population in OECD countries live in urban areas and nearly 50% in metropolitan areas with 500 000 or more inhabitants (OECD, 2013). Agglomeration benefits, i.e. the positive impact of city size on productivity, are essential in explaining both the concentration of residents in cities, as well as the (growing) importance of cities (Duranton and Puga, 2014). The existing literature focuses on three main reasons for the existence of agglomeration benefits: reduction of transportation costs (i.e. larger cities increase the size of the local market); information and knowledge spillovers from local interactions; and deeper labour markets, i.e. a large number of more suitably skilled or specialised workers, which allows for better job matches (e.g. Glaeser and Gottlieb, 2009).

But cities offer more than “just” jobs. When taking the decision to relocate to a new place, employment opportunities do matter, but so do local costs and the amenities that the new environment has to offer. These amenities include permanent assets, such as quick access to the coast or a historical city centre, as well as publicly or privately provided services, such as hospitals, universities, theatres or even top-tier sports clubs. But other factors, such as the local fiscal system (Gyourko and Tracy, 1991) or the shape of the city (Harari, 2015) can also play a role. On the cost side this means agglomeration costs (Glaeser and Maré, 2001). These costs can be pecuniary, e.g. higher housing costs and higher costs for goods or services, but also non-pecuniary, e.g. pollution or congestion. Both sides, costs and amenities, are important in understanding the spatial equilibrium of an economy, i.e. the equilibrium in which firms and residents are indifferent between locating in different cities. The Roback-Rosen model² formalises the notion in a general equilibrium framework: for workers, the utility a city provides depends on the local nominal earnings, the cost of living and the amenities in the city.

This study contributes to the literature by revisiting Roback’s (1982) notion of a spatial equilibrium for cities in Germany. It considers both sides of the “agglomeration coin”: First, it quantifies the size of agglomeration benefits in Germany, and second it considers the size of “real” agglomeration benefits, i.e. to what degree higher productivity in larger cities actually translates into higher local purchasing power for those who live and work in these cities once local prices are taken into account. Third, it combines the two sides and examines the role of local amenities in explaining heterogeneity in local purchasing power. Prior studies for Germany have considered real wage differentials, e.g. Roos (2006) considers real earnings convergence between eastern and western German Federal States and finds stronger convergence in real than in nominal earnings. Blien et al. (2009) focus on 327 West German NUTS3 regions and show that much of nominal wage differentials between urban and rural regions can be explained by regional characteristics (including labour force composition), with price-level differences accounting, on average, for the remaining gap.

This study extends the existing literature in several dimensions. First, it uses microdata to distinguish city productivity benefits from higher productivity levels in larger cities due to sorting of more productive individuals into these cities. The methodology that disentangles the two effects follows the literature and consists of a two-step procedure to identify productivity (Combes, Duranton and Gobillon, 2011). In the first step, microdata based individual earnings regressions (“augmented Mincer earnings regressions”) are used to identify city productivity, accounting for potential sorting of more productive individuals into (larger) cities. In the second step, city productivity differentials are regressed on city size to identify agglomeration benefits. The second contribution of this study is that it uses instrumental variable estimation in the second step, instrumenting current city size with historical city size and historical administrative fragmentation, i.e. the number of local administrations within a city’s boundary.

2 . After Roback (1982) who builds on Rosen (1979).

Third, in contrast to prior studies, the analysis focuses on functionally defined cities rather than administrative areas. These functionally defined cities, or “Functional Urban Areas” (FUAs), are designated based on an internationally consistent and coherent methodology developed by the OECD and the EU. They consist of both a dense urban centre and its surrounding, typically less densely populated, commuting zone (OECD, 2012), identified by contiguously built-up urban space and commuting flows.³ The definition captures the economic reality of a city’s residents, which does not end at an administrative border.

Fourth, the study considers not only agglomeration benefits, but also takes the remaining two components of the Roback-Rosen model, costs and amenities, into account. Costs are an estimate of city-level cost of living and are used to scale the estimated productivity differences to assess the “real” benefits that larger cities provide to their residents, i.e. how much of the agglomeration benefits accrue to those who live and work in the cities. Amenities are then added to assess their impact and contribution to variation in real agglomeration benefits.

The first-step estimation is based on the 1998-2007 waves of the Employment Panel of the German Federal Employment Agency (BA) hosted by the Research Data Centre (FDZ) at the Institute for Employment Research (IAB).⁴ The panel data is a 2% sample of all registered employees who are subject to social security contributions. It is matched with the EU-OECD FUA definition to identify residents of the 109 FUAs with 80 thousand to 4.3 million inhabitants.

The estimation confirms the presence of sizeable agglomeration benefits in Germany, i.e. productivity increases with city size. The estimated elasticity for agglomeration benefits is about 0.02, implying that – roughly speaking – a 10% increase in city size increases productivity by 0.2%. The agglomeration benefits arise mainly through increased population density in urban agglomerations. A larger population – for a given surface of an urban area – is associated with higher productivity, whereas spreading a given population over a larger surface is associated with lower productivity. The study also finds that there remains a significant divide between western and eastern Germany: for a given population size, productivity is on average 20% lower in eastern German urban agglomerations.

The share of employees in high-tech and medium-high-tech manufacturing is associated with higher productivity of the urban agglomeration. Beyond the strong direct role in influencing individual productivity, human capital also has an indirect role through human capital externalities. Human capital externalities are evidenced when the productivity of an individual is increased by the general education level in the city in which they live.

Cost of living – on average – increases with city size, roughly at the same rate as agglomeration benefits, offsetting the benefits from productivity increases for those living and working in larger cities. The average, however, masks sizeable variation in real benefits across cities, which – to a large degree – can be explained by the presence and quality of local (dis)amenities. Rough measures of local amenities, such as the presence of a large body of water (sea or lake), a UNESCO world cultural heritage site, theatres, hospitals, universities, or disamenities, such as air pollution, account for up to half of the variation not accounted for by time and agglomeration effects. This implies that city dwellers are willing to pay (or forgo income) in order to live in more attractive cities that feature such amenities (or that spare them disamenities). In contrast, top-tier football clubs are not found to increase cities’ price levels.

The above evidence points to location decisions of those living in big(ger) cities being not only driven by the economic potential of cities, but to a large degree also by the availability of consumption amenities

3. “Cities” in this study is used synonymously with FUAs.

4. This study also uses the German weakly anonymous BA-Employment Panel (version 1998-2007). Data access was provided via remote data access. See Schmucker and Seth (2009) for a detailed description of the data.

(and the absence of disamenities). It also highlights that higher price levels in more productive cities reduce the “real” benefits that workers obtain. For policy makers this means growing cities pose a triple challenge: they need to provide framework conditions for productive employment, but also ensure that local amenities create an attractive city, while retaining affordability so that low- and middle-income households are not excluded.

The paper first presents the empirical methodology used for the estimation of productivity differentials across cities and the analysis of agglomeration benefits. It then describes the data employed in the study and discusses the empirical findings on agglomeration benefits, before proceeding to explain the estimation for private agglomeration benefits and discussing the results. The final section concludes.

Methodology and data

Cities are the natural starting point to analyse the impact of agglomeration on productivity. But the built-up area of a city and the economic activity that is directly linked to a city’s residents and firms is rarely, if ever, contained by a city’s administrative boundaries. To capture the actual economic reality of life in a city, the study relies on a functional definition of cities or “Functional Urban Areas” (FUAs) that combines information on the urban built-up area with commuting flows (OECD, 2012). FUAs are cities with at least 50 000 inhabitants living in a contiguously built-up area with at least 1 500 inhabitants per 1 km².⁵ These built-up areas are matched with the smallest available statistical or administrative unit in a country – municipalities in Germany – to form the urban centre of a FUA.⁶ To complete the FUA definition, the less densely populated commuting zone around the urban centre is identified by considering all municipalities with at least 15% of their population commuting to the urban centre as part of the FUA.

Figure 1 depicts the result for the metropolitan area (a FUA with at least 500 000 inhabitants) of Berlin. The city itself forms the major part of the urban centre, which extends further to the south west. But a large part of the city – both in terms of area and population – is located in one of the 267 municipalities that form the metro area’s commuting zone. Clearly, a study that only considers the city of Berlin misses the important contribution by firms and residents in its surrounding municipalities and the links that exist between them. And it is these links and the interaction they facilitate that give rise to agglomeration benefits.⁷

5 . The methodology uses different thresholds for the United States and Canada (lower population density threshold) and Japan and Korea (larger minimum city size). See OECD (2012) for details.

6 . Non-contiguous urban centres can be part of polycentric FUA if the urban centres are linked via commuting flows.

7 . See Duranton and Puga (2004) for a discussion of the three main channels: sharing of inputs, matching of workers and jobs and learning/knowledge spillovers.

Figure 1. The metropolitan area of Berlin

Source: Authors' elaborations based on OECD (2012).

Empirical specification: agglomeration benefits

Agglomeration benefits capture the increase in productivity of firms and workers that arises through increased interaction in larger cities. Empirical studies have approached the estimation from both the firm's and the worker's perspective: trying to estimate the impact on multi-factor productivity based on firm-level data or on labour productivity using worker-level data.⁸ In both cases the challenge is to distinguish between selection and productivity effects. If the denser markets in larger cities are also "tougher" markets, the exit of less productive firms truncates the productivity distribution, resulting in higher average productivity levels (Combes, Duranton and Gobillon, 2011). For workers there is a similar selection effect. Larger cities are associated with higher levels of per capita output partly because they attract more productive residents.

To identify the productivity impact of city size – the agglomeration benefits – the selection effect needs to be taken into account. While some studies have used firm-level data (e.g. Combes et al, 2012), the challenge to adequately account for firm-selection, coupled with the challenge to attribute productivity to different establishments in multi-establishment firms has led most of the literature to focus on estimating productivity based on workers' wages. With competitive labour markets, the remuneration paid to workers reflects the value of their marginal product (Puga, 2010).

8 . See Rosenthal and Strange (2004) and Puga (2010) for reviews and Melo, Graham and Noland (2009) for a meta-analysis of available studies.

A naive estimator for agglomeration benefits is a regression of average earnings within a city on regional characteristics, among them an indicator for city size. Microeconomic theory posits that wages are a sensible measure for productivity. Under the assumption of competitive markets they reflect individuals' marginal productivity. With wages as dependent variable, the size indicators (a combination of indicators for area covered by the FUA and its number of inhabitants) capture the change in productivity associated with larger city size (urbanisation economies or agglomeration benefits).

This estimation strategy, however, leads to biased results as it does not account for sorting of individuals across cities of different sizes. Productivity differences are – to a large degree – explained by individual characteristics (e.g. education, experience, or "skill"). In addition, migration into different urban areas is not random but systematically related to these characteristics. Individuals with higher skills tend to locate in (larger) cities. These two facts imply that the naive estimator is upward biased. Some of the productivity mark-up of large cities is due to a higher fraction of individuals with productivity-enhancing skills. It is therefore necessary to consider skill-adjusted wage differentials, i.e. the residual differences across urban areas, which are left once individual characteristics that determine both an individual's productivity and migration decision are taken into account.

With detailed microdata it is feasible to account for sorting bias using a two-step estimation procedure. The first step estimates earnings differentials across cities, adjusted for individual selection. The second step then estimates the impact of urban characteristics using the first step's differentials as dependent variable (see Combes, Duranton and Gobillon, 2011, for a detailed discussion of this methodology). The city level indicators used in this study aim mainly at capturing agglomeration benefits, but other productivity relevant measures are also considered and include the industrial- and skill structure of the city.

First step: accounting for individual selection into FUAs

Under the assumption of competitive markets, employees' earnings reflect the value of their marginal product. This suggests that these earnings could be used to identify productivity differences across urban agglomerations. The idea is to decompose earnings or wages as a proxy for productivity, breaking them down into three components: first, productivity driven by individuals' skill, knowledge and experience, in short, by their characteristics; second, the impact of their place of residence on their productivity, capturing agglomeration economies and other aspects of the city's economic structure; third, an error term that absorbs any residual variation. In practice, this decomposition consists of estimating an "augmented Mincer earnings regression"⁹, i.e. a regression of (the natural logarithm of) earnings on individual characteristics and fixed effects for the functional urban areas.

$$y_{iat} = \beta X_{iat} + \gamma_{at} d_{iat} + \varepsilon_{iat}$$

With y_{iat} the natural logarithm of total monthly earnings for individual i in city a at time t , X the individual's characteristics, d a set of dummy variables that indicate an individual's current FUA of residence and ε , an error term. The coefficient of the FUA fixed effects (γ) capture the relative earnings (i.e. productivity) difference between a city in a given year compared to the grand (time and city) average earnings, net of (observable) skill differences. The simplest way to think about these estimates is as "productivity differentials". Comparing the estimated coefficients for two cities in the same year gives the relative productivity mark-up a person with the same characteristics has in one compared to the other city. Estimates of, for example, -0.05 and 0.1 mean that a person with the same characteristics earns on average 15% more in the city with coefficient 0.1 than in the city with coefficient -0.05. Under the assumption of

9. Named for Jacob Mincer (1974).

competitive labour markets, the 15% earnings difference is taken as an indication of a 15% productivity differential between the two cities.

A specific feature of the administrative data used in this study (see below for a detailed data description) is that it is top coded at the upper earnings limit for social security contributions. The data used in the first step is therefore right-censored, which results in biased and inconsistent OLS regressions (see e.g. Amemiya, 1984). Under certain assumptions on the underlying data-generating process (see the appendix for details), this drawback can be overcome by using a Tobit model for the estimation.¹⁰

In addition to the above base specification, which accounts for *observable* characteristics, the panel nature of the data can be used to account for some *unobservable* characteristics. This alternative first-step estimation includes individual specific fixed effects (d_i) and accounts for all time-invariant observed and unobserved heterogeneity across employees. Since it is infeasible – both computationally, as well as theoretically – to estimate individual fixed effects in the Tobit Model¹¹, it is impossible to simultaneously account for both censoring and individual unobserved characteristics. Instead OLS can be used to estimate the individual fixed effects model, keeping in mind that the first-step estimates will suffer from censoring bias. Since the number of observations, as well as the number fixed effects is high, the model is estimated with the `felsdvreg` program in Stata (Cornelissen, 2008). Formally, the above “base specification” is augmented by a set of individual fixed effects d_i .

$$y_{iat} = \beta X_{iat} + \gamma_{at} d_{iat} + d_i + \varepsilon_{iat}$$

While censoring will result in biased OLS estimates, the bias should be moderate given that the fraction of censored observations is less than 1.5%. In addition, the estimates should identify a lower bound. If more densely populated areas do indeed result in higher productivity and therefore higher earnings, the estimate for agglomeration benefits will be downward biased, i.e. the first-step estimates for denser cities will be too small (since a higher share of employees will have earnings above the censoring threshold) for densely populated areas, which in turn attenuates the second-step estimate downwards. The model choice is further discussed in the empirical results section below. The fixed effects specification is mainly considered as a robustness check in this study and results are reported in the appendix.

Second step: explaining FUA productivity differentials

The estimated productivity differentials from either first-step specification ($\hat{\gamma}_{at}$) are explained in the second step with indicators for structural determinants of agglomeration benefits (Q), while controlling for common time trends (d_t). Specifically models (for different sets of control variables) of the following form are estimated using OLS.

$$\hat{\gamma}_{at} = \delta Q_{at} + d_t + u_{at}$$

10 . Earnings data in general suffers from an additional censoring or even truncation problem: earnings are only observed for individuals who are working. But the selection of an individual into work depends positively on the wage they can command. James Heckman (1974) famously analysed this selection for the labour supply of married women. The selection effect for other labour market groups is typically not as pronounced as for married women, which limits the bias created by selection into work (i.e. at the extensive margin). Another point to note is that to threaten the validity of the next estimation step, selection at the extensive margin needs to be correlated with city size, e.g. because better child care facilities are available in larger cities, women’s reservation wage is lower and more women choose to work.

11 . Individual fixed effect in the Tobit model result in inconsistent estimates because of the “incidental parameter problem”, i.e. the number of estimated parameters increases without bound when limit conditions are considered (Greene, 2012, 628)

To allow for arbitrary autocorrelation in the error term (across time; within FUA), standard errors are clustered at the city level.

The two step procedure accounts for selection of employees into specific urban areas that is associated with their observed and their time-invariant unobserved (with individual fixed effects) characteristics. A remaining concern is that time-varying shocks to the productivity in a city attract migrants and are therefore correlated with FUA size. In the above model, this implies correlation between the error term u and the regressors of interest. To break this link, a strategy that identifies exogenous variation in the size of a FUA is required. Following the seminal contribution by Ciccone and Hall (1996), historical data has been used to identify variation in contemporaneous controls that is uncorrelated with contemporaneous productivity.

For Germany, detailed population data at the municipality level are available for the year 1910.¹² This introduces two types of instruments: first, the population (or population density) in 1910; and second, the historical administrative fragmentation of the FUA, i.e. the number of municipalities in 1910 within today's FUA boundaries. In contrast to historical fragmentation, the use of historical population is a well-established instrumentation strategy. Historical fragmentation, however, is likely to be as valid as historical population. It is expected to have a negative impact on population growth. Housing prices and the adjustment to productivity shocks depend on housing supply (Glaeser, Gyourko and Saks, 2006), which in turn is affected by geography and regulation (Saiz, 2010). Challenges in the coordination of investment in infrastructure; housing and zoning regulation; and local development strategies are aggravated by the number of stakeholders (Ahrend, Farchy, Kaplanis and Lembcke, 2014), which leads to expected smaller city sizes. On the other hand, contemporaneous shocks to productivity in a region should not be affected by pre-World War I administrative boundaries.

Data

Two main data sources are employed in this study. The EU-OECD definition of Functional Urban Areas (OECD, 2012) and the Employment Panel of the German Federal Employment Agency (BA) hosted by the Research Data Centre (FDZ) at the Institute for Employment Research (IAB).¹³ The FUA definition relies on high-resolution population data in combination with administrative data on commuting patterns. For Germany, the EU-OECD definition identifies 109 FUAs with 80 000 to 4.3 million inhabitants, which are aggregated from the municipality (*Gemeinde*) level.

The focus on municipalities in the EU-OECD FUA definition allows the concept to be linked with national administrative data sources, such as the IAB Employment Panel. The IAB Employment Panel is a panel data set that contains a 2% sample of all registered employees who are subject to social security contributions on the date of reference. The sample covers the years from 1998 to 2007, with data for employees with earnings below the social security contribution threshold becoming part of the sample in 1999. Municipal codes in the data are current as of the date of reference and change across waves.¹⁴ Adjustments are required since the boundaries of municipalities (especially in East Germany) changed

12 . Collected by Uli Schubert: <http://www.gemeindeverzeichnis.de> (accessed September 2013)

13 . See Schmucker and Seth (2009) for a detailed description of the data.

14 . Changes in municipal boundaries were collected from: <https://www.destatis.de/DE/ZahlenFakten/LaenderRegionen/Regionales/Gemeindeverzeichnis/NamensGrenzAenderung/NamensGrenzAenderung.html> (accessed Sept. 2013)

during the 2000s. Mergers and splits of municipalities that are part of a FUA are accounted for by including the newly formed municipality in the FUA.¹⁵

The data are collected from administrative sources, mainly from employer's annual reports. The quality of these reports tends to be very good, meaning that the data is consistent over time and contains few missing values. One exception is educational attainment. Missing values are frequent for this variable and some workers exhibit implausible changes in their educational attainment over time. For example, a worker is reported to have obtained a vocational degree in one year and to have dropped out of high school without receiving a degree in the next. Since education is an important explanatory variable for both individual wage differentials, as well as for capturing human capital externalities, the variable is corrected using an imputation algorithm developed by Fitzenberger, Osikominu and Völter (2006), which uses the available information to both erase implausible changes and fill in missing values.

The data is panel data, which means that individuals can be tracked across waves (the BA identifies them by their social security number). The data contain information for the individual employee and his or her job. In addition to individual characteristics such as gender, age, nationality, and educational attainment (highest degree obtained: 7 categories), the data includes job characteristics such as earnings (only total monthly earnings, no information on hours worked is provided), occupational standing (apprentice, white or blue collar, master craftsmen, etc.: 7 categories), occupation (3-digit), and industry (3-digit). Critically, the on-site version of the BA Employment Panel identifies the municipality (*Gemeinde*) in which an individual resides, which allows the match with EU-OECD defined FUAs.

Since the sample changes in 1999, only the nine years from 1999 to 2007 are used in the estimation. Data is available for a reference date in each quarter but most changes to a given job occur at a lower rate, e.g. raises or promotions are usually limited to an annual frequency. Therefore, only the third quarter (reference date is the 30th of September) for each year is chosen for this study. Two additional selections are applied to the data. First, the sample is restricted to employees who are between 16 and 64 years old, and second, only the main employment of these employees is considered (i.e. secondary jobs are excluded from the sample). Neither selection imposes a large constraint on the final sample, which consists of about 2.7 million observations for nearly 480 000 individuals who live in the 109 German FUAs.

For the second-step regressions, indicators are constructed from the same sample. These indicators include the share of employees working in different 1-letter industries, with the manufacturing sector disaggregated by skill intensity. This disaggregation follows Eurostat's NACE Rev. 1.1. based classification.¹⁶ In addition, industry structure is captured by the Herfindahl index of employment shares at the 3-digit industry level. It is calculated for each city as the sum of the squared employment shares across all industries.

The area of a FUA is calculated from maps provided by the German Federal Agency for Cartography and Geodesy. Local amenities are captured by a set of variables that cover both environmental and cultural amenities. The set contains a dummy that indicates that the FUA includes a UNESCO World Heritage site (from the World Database on Protected Areas¹⁷); a dummy for access to the coast or the presence of a

15 . This results in a growth of some FUAs far beyond their initial limits. For these select cases, municipalities that were created by a merger and included initially only a small fraction of its area within a FUA are excluded.

16 . http://epp.eurostat.ec.europa.eu/cache/ITY_SDDS/Annexes/htec_esms_an2.pdf (accessed September 2013).

17 . IUCN and UNEP. (2013). The World Database on Protected Areas (WDPA). UNEP-WCMC. Cambridge, UK. www.protectedplanet.net (accessed November 2013).

large¹⁸ lake within the FUA limits; a variable indicating the number of theatre seats (in 1993)¹⁹; a dummy for the presence of a university hospital²⁰, a variable indicating the number of universities²¹, and a variable indicating the number of football clubs that played either in the first or second highest national league (*Erste Bundesliga* or *Zweite Bundesliga*) in the city between 1995 and 1999.²²

Disamenities are taken into account in the form of air pollution, measured by the annual average level of PM10 in a city. Data on air pollution is available for each individual air quality measuring station in Germany from the *Umweltbundesamt*²³. Measurements are taken in residential areas, at industrial sites and in street traffic. To create comparable values across cities, the measurements are standardised for each category and year. This creates (up to) three indicators for each FUA which measure the relative deviation from the average level of pollution across all FUAs in a given year. Since not all FUAs have measuring stations in each category, these three indicators are then aggregated to a single measure of PM10 pollution. Even with aggregation the number of measuring stations is limited and data is only available for a subset of FUAs (increasing over time, up to 100 out of 109 FUAs) and from 2002 onwards.

To estimate real agglomeration benefits, a regional price index provided by the German Federal Office for Building and Regional Planning is used.²⁴ The price index is cross-sectional and calculated at the county (*Kreis*) level. Municipalities are completely contained within a county. To harmonise the county level data with the FUA definition, a weighted average is constructed that uses the share of the FUA's population living in each county as weight.

Table A1 in the appendix provides an overview of the data in this study for the year 2000. The first two columns report means and standard deviations for the whole sample, the last two columns for West German Functional Urban Areas only. While the sample starts 10 years after reunification, there are still persistent and sizeable differences between West and East German FUAs and considering West Germany separately can help in interpreting and understanding the results.

Out of 109 FUAs, 88 are located in West Germany. Productivity and prices are slightly lower in the combined German sample (masking much lower productivity and price levels in the 21 East German FUAs). The average city has slightly less than 500 000 inhabitants and extends about 1.2 square kilometres. Employees account for about 30% of total inhabitants. University graduates make up about 10% of the workforce, and 14 to 16% are classified as “low skilled”, i.e. they have no post-secondary education.²⁵ The remaining majority of workers hold a vocational qualification. Manufacturing accounts

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- 18 . Larger than 21 sq.km. Data on lakes comes from the VMap Level 0 extension of the National Imagery and Mapping Agency's (NIMA) Digital Chart of the World.
 - 19 . Source: Theaterstatistik 1992/93, 28. Heft, Deutscher Bühnenverein – Bundesverband Deutscher Theater (German Federal Association of Theatres and Orchestras, <http://buehnenverein.de> (accessed November 2013).
 - 20 . Source: <http://www.deutsches-krankenhaus-verzeichnis.de> (accessed May 2014).
 - 21 . Source: http://www.hs-kompass2.de/kompass/xml/download/hs_liste.txt (accessed February 2014). Only universities that were founded before 1999, or were created after 1999 as a merger of existing institutions are included.
 - 22 . Source: <http://www.kicker.de> (accessed February 2014).
 - 23 . <http://www.umweltbundesamt.de/themen/luft/luftschadstoffe/feinstaub> (accessed December 2013).
 - 24 . Source: BBSR (2009)
 - 25 . These shares are calculated using the imputation algorithm outlined in by Fitzenberger, Osikominu and Völter (2006). No post-secondary education means this category pools all employees that left school without a degree or finished up to 13 years of schooling (*Gymnasium*).

for more than 25% of employment with about equal shares in high/medium-high tech employment and low/medium-low tech.²⁶

Compared to 1910, population in an average FUA nearly doubled and administrative fragmentation has been reduced to about one third of its initial value (see Ahrend, Farchy, Kaplanis and Lembcke, 2014 for current fragmentation). 17 cities are either located on the coast or have (part of) a large lake inside their boundaries; 20 contain an UNESCO World Heritage Site. In 1993, 82 of the 109 German cities possessed at least one theatre. The average number of available seats among those 82 cities was about 1,800 seats, which equates to 1 300 seats if the cities without a theatre are counted as having zero seats. A university is present in 84 cities, with 2.4 universities per city on average. However, only 31 of the FUAs contain a university hospital. The average number of first and second tier football clubs is 0.36 and similarly concentrated (only 30 cities have at least one).

Empirical results

Estimation results: first step estimation

The first-step estimation results are reported in Table A2 in the appendix. In addition to the reported coefficients, 981 dummies for the 109x9 FUA and year combinations are included in each regression. The first column shows the results for the main specification, a Tobit model including controls for gender, education, age (as a proxy for experience), worker type and 272 (excluding the base category) 3-digit occupational dummies.

The results are in line with typical findings in the literature: earnings increase with age (at a decreasing rate) and education, workers who are better skilled earn more and women on average earn less. Employees with vocational training earn more than employees who did not pursue any training after finishing secondary education. The mark-up is 6% for workers who finished up to 10 years of schooling before receiving vocational training and 11% for those who had 12 or 13 years of schooling before their apprenticeship. University graduates earn, on average, 21%-25% more than employees who stopped formal training after leaving school.

Skilled blue collar workers earn, on average, 8% more than unskilled workers. The mark-up for master craftsman over unskilled workers is about 29% and slightly higher than the mark-up for white collar workers (25%).²⁷ Earnings increase with age (i.e. with experience) with (slowly) decreasing returns. Women (on average) exhibit 22% lower earnings than men.

As outlined above, the panel nature of the available data allows the estimation of fixed effect models in the first step. This can reduce the bias in the estimation from unobserved skill differences. The price for the increased robustness is that estimation with fixed effects relies on “movers”, individuals who relocate from one city to another. On the one hand, the population of movers might, however, not be representative for total population. Migration is costly and employees need to be compensated to make a “move”, which should be reflected in their post-move earnings, i.e. the estimated earnings benefits are too high. On the other hand, if agglomeration benefits accrue over time (e.g. through learning) the earnings of recent movers will underestimate the productivity benefits of large cities. The following discussion therefore

26 . The industry shares do not add up to 100%. The reason is that cells with less than 20 employees are suppressed (and the share of employees in that industry is set to 0).

27 . Part time-workers earn less than unskilled blue collar workers, even if they work more than 18 hours per week. This is unsurprising given that total earnings and not hourly wages are considered in this study.

considers predicted FUA wage differentials from both the Tobit specification and the OLS fixed-effects model (see Box 1) to estimate agglomeration benefits.

Box 1. Model choice

The choice of the best model specification is not obvious in the given situation. While a Tobit model allows taking into account that wage data are right censored (i.e. wages above the German social security threshold are set to the level of the threshold in the database), it is not feasible to estimate individual fixed effects in a Tobit model. An OLS model does allow for individual fixed effects but does not account for the right-censored observations in the dataset. To evaluate the potential bias from censoring, the second column of Table A2 shows the results from an OLS estimation that replicates the Tobit model. The results are virtually identical. Only 1.3% of the sample is affected by right-censoring and the impact of these observations on the overall estimates seems negligible. Since the main variables of interest are the FUA differences in productivity, Figure A1 in the appendix plots the estimated agglomeration benefits for the first and last year in the sample (1999 and 2007). The predictions from the two models are nearly perfectly correlated, only Berlin deviating marginally from the 45 degree line. This result increases confidence in the estimates that rely on OLS to allow for individual fixed effects.

These first-step estimation results are reported in the final column of Table A2 in the appendix. Adding fixed effects significantly reduces the returns to education. This is in line with an “ability” bias, i.e. with unobserved individual specific skill that is positively correlated with both earnings and educational attainment. Note that the reduced coefficients can also arise from other sources. The estimated parameters are identified only by individuals who exhibit changes in this variable over time. In the case of education this is a select group and some of the observed changes might actually be due to misreporting, in other words due to measurement error. Biases arising from (classical) measurement error are (usually)¹ aggravated by the inclusion of fixed effects, this leads to attenuated coefficients, i.e. coefficients that are closer to 0.

The wage differential between different types of workers is similarly attenuated. The difference between an unskilled blue collar worker and a master craftsmen or white collar worker is now about 11%, about double the difference between unskilled and skilled blue collar workers (5%). It is critical to note that the estimated FUA differentials are estimated from “movers”: Employees that relocate from one FUA to another while being part of the sample. If agglomeration benefits accrue instantaneously, i.e. in the year of the move, they are fully captured in this model. However, if benefits from urban agglomerations are generated over time (e.g. from knowledge spillovers or learning) the effect estimated on a sample of “movers” will only capture part of the productivity benefit (see Glaeser and Maré (2001) and de la Roca and Puga (2012) for evidence on learning in cities).

1. The direction depends on the serial correlation in the underlying true level of education (Griliches and Hausman, 1986).

Source: Griliches, Z. and J.A. Hausman (1986) “Errors in variables in panel data”, Journal of Econometrics, Vol. 31(1), pp. 93 – 118.

Estimation results: agglomeration benefits

Before turning to the full estimation, it is useful to consider the basic descriptive evidence. Figure 1 shows that productivity is increasing with city size. But it also shows that even in 2007, more than 15 years after reunification, productivity differentials between East and West Germany are still present. The black line in the graph depicts the linear fit between the estimated productivity differentials and city size ignoring an East-West divide; the grey lines depict the linear fit for West and East German FUAs separately. Split by regions, the slopes are remarkably similar (and less steep than in the combined sample). To address this evident structural difference between the two regions, this study follows two strategies: first a dummy variable for East German FUAs is included in the regressions to account for the apparent level difference; second, the sample is constrained to only West German FUAs.²⁸

28. A separate analysis for East Germany is impossible given the small number of East German FUAs.

Figure 2. Productivity and FUA size in 2007

Note: Vertical axis shows estimated city x year fixed effects in a $\ln(\text{earnings})$ regression with additional controls in a Tobit model that accounts for censoring (Column 2 of Table A2 in the appendix). The vertical axis shows the corresponding estimated city size based on the number of employees in 2007 and the employment rate in 2000 (depicted on a $\ln$ -scale). See the data description for data sources.

Table 1 reports the estimated agglomeration benefits for two indicators of city size: in specification (A) the natural logarithm of employment; in specification (B) the natural logarithms of employment density and area. The table reports results from the Tobit first-step estimation (Columns 1-4) and the baseline estimate that does not account for this individual selection (the “naive” estimate, Columns 5-8).²⁹ Both specifications control for time fixed effects that capture aggregate trends, such as inflation, and a dummy for East German FUAs (excluded in the West German subsample).

Table 1. Second step: FUA productivity and agglomeration benefits

	Germany		West Germany		Germany		West Germany	
	(A)	(B)	(A)	(B)	(A)	(B)	(A)	(B)
$\ln(\text{employment})$	0.019*** (0.005)		0.017*** (0.004)		0.032*** (0.005)		0.032*** (0.007)	
$\ln(\text{emp.density})$		0.029*** (0.005)		0.030*** (0.005)		0.054*** (0.006)		0.059*** (0.007)
$\ln(\text{area})$		0.015*** (0.004)		0.013*** (0.004)		0.023*** (0.005)		0.023*** (0.006)
East dummy	-0.210***	-0.201***			-0.187***	-0.167***		

29. The results based on productivity differentials that are estimated including individual fixed effects in the first step are reported in columns (A) and (B) in Table A3 in the appendix and are only marginally different.

Table 1. Second step: FUA productivity and agglomeration benefits (continued)

	(0.009)	(0.010)			(0.010)	(0.012)		
R-squared	0.875	0.885	0.459	0.536	0.743	0.789	0.338	0.502
FUAs	109	109	88	88	109	109	88	88
Obs.	981	981	792	792	981	981	792	792
First-step controls	ind. ch.	ind. ch.	ind. ch.	ind. ch.	none	none	none	none

Note: Dependent variable consists of estimated city x year productivity differentials. The first-step Tobit regressions include no further controls ("none") or a set of individual level characteristics ("ind. ch.") in a regression with $\ln(\text{earnings})$ as dependent variable (see Table A2 in the appendix). The panel covers 1999-2007. Standard errors are clustered at the city level and reported below the coefficients in parentheses. **/** indicates statistical significance at the 10%/5%/1% level. See the data description for data sources.

As was evident in Figure 1, larger cities are more productive. In both the sample that combines West and East Germany, as well as in the West German subsample, the estimated benefits of agglomeration are statistically highly significant. The specifications that account for individual characteristics in the first-step regressions indicate a benefit of 1.9% and 1.7% respectively, implying that a doubling in a FUAs (employed) workforce is associated with an almost 2% higher productivity.³⁰ The results also confirm the necessity to control for individual characteristics in the first-step regressions to obtain meaningful city productivity differentials. When individual characteristics (e.g. education levels) are ignored in the first-step estimation, the estimated coefficient increases to an unduly large 3.2%.

The focus on employment by itself neglects the fact that cities have quite distinct urban forms. Specification (B) takes this into account. It combines employment density (the ratio of employees and area covered by a FUA) and land area to capture agglomeration benefits. This combination leads to three interesting marginal effects. First, the coefficient on $\ln(\text{employment density})$ measures the impact of an increase in population for a FUA with a fixed area, i.e. for a densification in the existing city. The coefficient on $\ln(\text{area})$ shows the association of productivity with an increase in the area covered by a FUA, given that this increase does not reduce employment density. Finally, subtracting the coefficient on employment density from the area coefficient shows the effect of an increase in the area of the FUA that is not accompanied by an increase in employment.

When holding the area of a FUA constant, the estimated agglomeration benefits are higher than in the prior specifications. The declining pattern across the different first-step specifications remains. Doubling the city population in a given area is on average associated with a 3.0% increase in productivity (Columns 2 and 4). If the increase in employment is accompanied by an expansion of the FUA limits (such that employment density remains constant), the estimated elasticity is smaller (1.3-1.5%) and becomes negative if the FUA expansion results in a less dense urban form.

Productivity in a FUA is determined by more than just its size. If these additional factors are not only correlated with productivity, but also with the size of a city, e.g. because larger cities specialise in specific services, the estimated agglomeration benefit will be biased. If the additional factors are observable, they can be included in the regression thereby avoiding bias. However, agglomeration benefits can also be interpreted in a wider sense that includes indirect agglomeration benefits. In such an interpretation, the

30 . Note that with both the left and the right hand side variable in natural logarithms, the estimated coefficients are elasticities. For small changes the above interpretation is correct, a doubling in city population however is not a small change and the approximation error in this interpretation is fairly severe. To simplify the discussion the interpretation will focus on the presented elasticities, rather than the exact marginal effect. The exact percent change can be calculated by taking the exponential of the product of the reported coefficients with the natural logarithm of 2 and deducting 1, i.e. $\exp(\hat{\delta}_{emp.dens} * \ln(2)) - 1$.

potential of cities to attract more specialised or specific (e.g. high-tech) industries, and thereby enhance their productivity, would be seen as integral part of agglomeration benefits. In such an interpretation, adding the above-mentioned control variables into the regression may turn out to be inappropriate.

To examine how certain control variables affect agglomeration benefits, Table 2 introduces the city's skill mix and industrial composition for both the full sample and the West German subsample using the preferred first-step specification.³¹ It should be noted that these are alternative specifications and necessarily superior to the first four columns of Table 1.

The specifications shown in Table 2 control for the following variables beyond those already present in specification (B) in Table 1:

- the share of university graduates and the share of employees with no post-secondary education - (C) and (F)
- a Herfindahl index for industrial diversity - (D) and (F)
- the share of employees in 1-letter industries (construction as base category) with manufacturing separated into high-tech, medium to high-tech, medium to low-tech and low-tech manufacturing - (E) and (F)

Table 2. FUA productivity and agglomeration benefits with additional controls

	Germany (1999-2007)				West Germany (1999-2007)			
	(C)	(D)	(E)	(F)	(C)	(D)	(E)	(F)
ln(emp.density)	0.026*** (0.006)	0.035*** (0.005)	0.019* (0.010)	0.018 (0.012)	0.027*** (0.004)	0.037*** (0.004)	0.024*** (0.006)	0.018*** (0.006)
ln(area)	0.013** (0.005)	0.017*** (0.004)	0.009 (0.008)	0.008 (0.008)	0.010*** (0.004)	0.014*** (0.003)	0.005 (0.004)	0.002 (0.004)
Share of workers with university degree	0.109 (0.084)			0.166 (0.105)	0.141 (0.090)			0.295*** (0.075)
Industrial diversity (Herfindahl ind.)		1.133*** (0.241)		0.498** (0.202)		1.112*** (0.216)		0.292* (0.167)
A-C: Agriculture, fishing and mining			-0.118 (0.196)	-0.107 (0.214)			-0.032 (0.191)	0.136 (0.193)
E: Electricity, gas and water supply			-0.003 (0.332)	-0.023 (0.320)			-0.669** (0.274)	-0.697*** (0.208)
D: Manufacturing (high tech.)			0.185* (0.104)	0.145 (0.094)			0.294*** (0.108)	0.210** (0.084)
D: Manufacturing (med. high tech.)			0.256*** (0.086)	0.174* (0.096)			0.366*** (0.098)	0.314*** (0.107)
D: Manufacturing (med. low tech.)			-0.023 (0.081)	0.014 (0.082)			-0.037 (0.097)	0.026 (0.093)
D: Manufacturing (low tech.)			-0.276** (0.126)	-0.240** (0.120)			-0.031 (0.122)	-0.003 (0.110)

31 . Table A8 in the appendix report the estimates based on the individual fixed effects first-step estimation.

Table 2. FUA productivity and agglomeration benefits with additional controls (continued)

G: Wholesale and retail trade			-0.162 (0.135)	-0.113 (0.129)			-0.004 (0.124)	0.034 (0.112)
H: Hotels and restaurants			0.001 (0.193)	-0.020 (0.190)			-0.276 (0.172)	-0.268 (0.165)
I: Transport and communication			0.159 (0.181)	0.243 (0.187)			0.198 (0.198)	0.382** (0.188)
J: Financial Intermediation			0.031 (0.202)	0.039 (0.190)			0.288* (0.150)	0.308** (0.131)
K: Business activities and real estate			0.340** (0.132)	0.259* (0.147)			0.319** (0.126)	0.172 (0.161)
L: Public administration			0.03 (0.214)	-0.024 (0.204)			0.001 (0.199)	-0.032 (0.158)
M-N: Education, health and social work			-0.143 (0.096)	-0.245** (0.101)			-0.089 (0.104)	-0.216* (0.113)
O-Q: Other services			-0.203 (0.174)	-0.212 (0.156)			-0.009 (0.198)	-0.040 (0.161)
East dummy	-0.205*** (0.011)	-0.196*** (0.010)	-0.195*** (0.015)	-0.199*** (0.016)				
R-squared	0.886	0.907	0.934	0.937	0.545	0.647	0.831	0.852
FUAs	109	109	109	109	88	88	88	88
Obs.	981	981	981	981	792	792	792	792

Note: Dependent variable consists of estimated city x year productivity differentials. The first-step Tobit regressions include no further controls ("none") or a set of individual level characteristics ("characteristics") in a regression (ln) earnings as dependent variable (see Table A2 in the appendix). Standard errors are clustered at the city level and reported below the coefficients in parentheses. */**/** indicates statistical significance at the 10%/5%/1% level. See the data description for data sources.

The addition of productivity-relevant indicators reduces the estimated agglomeration benefits moderately. This provides some confirmation that more productive industry and skill combinations are indeed more likely to occur in larger cities. Agglomeration benefits across specifications tend to be around 1.5% to 2.0% for a doubling in FUA size. Estimates for Germany as a whole are slightly lower than estimates for West Germany by itself. Standard errors are smaller when West Germany is considered by itself, even though the sample size is reduced. This indicates not only sizeable heterogeneity between East and West German FUAs, but also implies that estimates for West Germany are likely to be more precise than those for the whole of Germany. Therefore the following will mainly comment on the estimates from the West Germany regressions.

FUAs with higher shares of employees with a university degree are associated with higher productivity; increasing the proportion of workers with a university degree in the city by 10 percentage points (relative to the share of employees without a university degree) is associated with an increase in productivity by close to 3%. This effect is in line with theoretical arguments on positive knowledge spillovers in cities. It should be emphasised that this human capital externality accrues in addition to the (even larger) direct effect of human capital in enhancing individual productivity.

A greater degree of industrial specialisation (i.e. an increase in the Herfindahl index of employment shares at the 3-digit industry level) is associated with higher productivity. Industrial composition shows a positive effect of a large share of employees working in high-tech and medium-high-tech manufacturing in

the city. This effect is particularly large for medium-high-tech manufacturing, which would be in line with Germany's comparative advantage being particularly strong in the medium-high-tech, rather than high-tech manufacturing sector.³² In addition, larger business- and real-estate-related services are associated with higher productivity levels in a FUA, whereas high shares of employees working in the energy and water sector are associated with lower productivity levels (compared to the share of the construction sector as base category).

As discussed above, while adding productivity-relevant indicators might pick up on potential confounding factors and thereby reduce the inaccuracy of the estimated agglomeration benefits, the controls might be part of the underlying process of how agglomeration affects productivity, which means they should be considered an “outcome” of agglomeration rather than a confounding factor. An alternative route to identifying agglomeration benefits is the use of exogenous variation in employment density. Table 3 shows the estimated benefits when contemporaneous employment density is instrumented with historical population density, its square (IV A), and the degree of historical administrative fragmentation (IV B).³³ In this, the area covered by a FUA is taken as exogenous. This methodology avoids the drawback of controlling for potential outcomes of agglomeration. The estimates in Table 3 – by and large – confirm the prior estimates, even though they may have a tendency to be a bit smaller than the initial range of estimates. They imply an increase in productivity of close to 2% both for a doubling in FUA size for German and West German FUAs on their own. The prior result that an increase in FUA size, for a given area, generates productivity is confirmed, as is the result that reducing the density by extending the area covered has a negative effect on productivity.³⁴

32 . See, for example, “German industry: High marks in mid-tech, only middling in high-tech”, DB Note, 2011, http://www.dbresearch.fr/PROD/DBR_INTERNET_EN-PROD/PROD000000000273215/German+industry%3A+High+marks+in+mid-tech,+only+middling+in+high-tech.PDF (accessed July 2014).

33 . First stage estimates for the IV estimation are reported in Table A4. The instruments significantly affect contemporaneous city size and jointly they are “strong” instruments with F-statistics above 150 in all cases.

34 . The IV-estimated elasticities for productivity differentials that include fixed effects (in addition to individual characteristics) in the first step are marginally smaller (given the size of the standard errors) at 0.014 and 0.016 (Table A5 in the appendix).

Table 3. IV estimates of agglomeration benefits

	Germany (1999-2007)		West Germany (1999-2007)	
	(IV A)	(IV B)	(IV A)	(IV B)
ln(emp.density)	0.018*** (0.006)	0.018*** (0.006)	0.019*** (0.005)	0.019*** (0.005)
ln(area)	0.011** (0.005)	0.011** (0.005)	0.007* (0.004)	0.007* (0.004)
East dummy	-0.207*** (0.011)	-0.207*** (0.011)		
R-squared	0.880	0.880	0.513	0.512
FUAs	109	109	88	88
Obs.	981	981	792	792
Instruments	pop./pop. sq. 1910	pop./pop.sq./ mun. 1910	pop./pop. sq. 1910	pop./pop.sq./ mun. 1910

Note: Dependent variable consists of estimated city x year productivity differentials. The first-step Tobit regressions include a set of individual level characteristics ("characteristics") in a regression (ln) earnings as dependent variable (see Table A2 in the appendix). ln(employment density) is instrumented with 1910 population in today's FUA boundaries (and its square) (IV A) and with the number of 1910 municipalities in today's FUA (IV B). The first stage results for the IV estimation are reported in Table A4 in the appendix. Standard errors are clustered at the city level and reported below the coefficients in parentheses. ***/** indicates statistical significance at the 10%/5%/1% level. See the data description for data sources.

Empirical specification: "real" agglomeration benefits

If agglomeration benefits in cities were the whole story, a country's productivity would be maximised by pooling its workforce in a single megacity. The results above indicate that workers in larger cities are more productive, but these agglomeration benefits are only one side of the coin. Agglomeration cost balances the benefits and – in long-term spatial equilibrium – a worker would be expected to be indifferent between all cities (see e.g. Glaeser and Maré, 2001), i.e. without an additional incentive workers do not gain utility from moving to another city. It is however possible – in the short to medium term – for FUAs to be out of equilibrium: adjustments to shocks are not instantaneous, mobility is imperfect and supply of required housing can only adjust slowly.

In addition, each city provides its own baskets of consumption amenities. Employees might be willing to pay a premium, in terms of higher living costs or lower earnings, to have access to these amenities. Figure 2 shows that the cost of living does indeed increase with benefits but it also shows that there is sizeable variation around the benefit-cost locus. In fact, all large metropolitan areas, i.e. the biggest cities that also offer the widest variety in consumption amenities, lie above the fitted line.

Figure 3. FUA productivity differentials and FUA price differentials

Note: Horizontal axis shows estimated and demeaned city x year fixed effects in a $\ln(\text{earnings})$ regression with additional controls (column 2 of Table 7 in the appendix) in a Tobit model that accounts for censoring. The horizontal axis shows the corresponding demeaned $\ln$ city price index. See the data description for data sources.

So far, the empirical strategy considers only agglomeration benefits, captured by higher productivity. But a resident of a city is likely much less interested in their productivity and nominal wage than in their real benefits and their increase in “local purchasing power”, i.e. what they can actually afford in terms of goods, services and housing given the local price level. The importance of accounting for regional price differences is confirmed by recent empirical research (Gibbons, Overman and Resende, 2011; Combes, Duranton and Gobillon, 2012). For the estimation, this means that instead of nominal productivity differences, the dependant variable becomes the relative real earnings benefit of living in a city, or the “real” productivity benefits as they translate into local purchasing power for the worker. The estimated agglomeration benefits are therefore no longer just the increase in productivity, but “private agglomeration benefits”, i.e. the real agglomeration benefits for residents associated with city size. The estimation equation for real agglomeration benefits augments the above second-step equation by deducting the natural logarithm of the relative price index on the left hand side:

$$\hat{\gamma}_{at} - \ln\left(\frac{\text{price}_a}{100}\right) = \delta Q_{at} + d_t + u_{at}$$

Ideally, the price index for local cost of living is collected continuously over time and at the city level. In practice, price data at the sub-national level is scarce (and for many countries simply unavailable). For Germany, the available price index applies to a single cross-section and was calculated by German Federal

Office for Building and Regional Planning based on data from around 2007 (BBSR, 2009). While time-variation is obviously preferable, for the chosen IV strategy a cross-section suffices.³⁵

Estimation Results: “real” agglomeration benefits

This section considers the two remaining key questions in this study: is there empirical evidence for a spatial equilibrium in Germany and what role do local amenities play in explaining heterogeneity in real productivity differences? Table 4 shows that German cities – when abstracting from the recurring east-west divide – are indeed in spatial equilibrium. On average, agglomeration benefits – net of pecuniary agglomeration costs – are non-existent. Positive and significant effects are only present if selection of more productive workers into larger cities is ignored. The IV estimates in the last four columns confirm that this result is robust to endogeneity concerns.³⁶

But this begs the question: what drives the wedge between cities’ productivity and their cost? Table 5 introduces several sets of indicators for local amenities and local disamenities. Four specifications are considered, the first two introduce amenities and disamenities into the above framework, and the remaining two combine these indicators for (dis)amenities with the productivity-affecting indicators that were used in the above specifications for nominal agglomeration benefits.

- (L): Considers the residual variation from specification (B), i.e. real productivity benefits net of city size effect, time-effects and the dummy for East Germany. This variation is regressed on local amenity indicators: the FUA is located on the coast or contains a large lake; whether the FUA contains a UNESCO World Heritage Site; the number of seats in the city for theatre, operas, etc. (and the number of seats squared); the presence of a university hospital in the FUA; the number of universities; and the number of football clubs that were in the two highest national leagues in the last 5 years. In addition, the specification includes the share of high and low skilled workers in the city.³⁷
- (M): (L); and the annual average level of PM10 emissions
- (N): Replicates specification (L), but instead of considering residual variation net of only size and time effects, industrial composition is also taken into account.
- (O): (N); and the annual average level of PM10 emissions

35 . The non-IV estimate is consistent as well under the assumption that price differentials are persistent (i.e. they change uniformly with aggregate inflation). The same holds if changes in prices are uncorrelated with the regressors of interests (Q). These assumptions may, however, not hold in the second-step OLS estimation, and price changes could be correlated with city size. If this correlation is positive, i.e. larger cities experience higher cost increases, the estimated coefficient would be a lower bound (the true impact would be underestimated). The chosen IV strategy remedies these problems unless historical city population predicts contemporary price changes, which is rather unlikely.

36 . Table A6 in the appendix reports private agglomeration benefits for the other two first-step estimations. Again the results confirm the importance in accounting for selection in the first step and the addition of individual fixed effects in this first-step regression does not affect the conclusions.

37 . For this estimation to be consistent, the Frisch-Waugh-Lovell theorem shows that the right hand side variables need to be the residual from a regression on the covariates in specification (B) as well. This is accounted for.

Table 4. Real agglomeration benefits

	OLS (1999-2007)				Instrumental Variables (1999-2007)			
	Germany		West Germany		Germany		West Germany	
	(A)	(B)	(A)	(B)	(IV A)	(IV B)	(IV A)	(IV B)
ln(employment)	-0.003 (0.005)		-0.009** (0.004)					
ln(emp.density)		0.001 (0.006)		-0.004 (0.005)	0.001 (0.006)	0.001 (0.006)	-0.004 (0.005)	-0.004 (0.006)
ln(area)		-0.005 (0.006)		-0.011** (0.004)	-0.005 (0.005)	-0.005 (0.006)	-0.011** (0.004)	-0.011** (0.005)
East dummy	-0.158*** (0.009)	-0.155*** (0.010)			-0.155*** (0.010)	-0.155*** (0.010)		
R-squared	0.795	0.797	0.417	0.429	0.797	0.797	0.429	0.429
FUAs	109	109	88	88	109	109	88	88
Observations	981	981	792	792	981	981	792	792
Instruments					pop./pop. sq. 1910	pop./pop. sq./mun. 1910	pop./pop. sq. 1910	pop./pop. sq./mun. 1910

Note: Dependent variables are the difference between city x year productivity differentials and the natural logarithm of a city price index for 2007. The first step Tobit regressions include a set of individual level characteristics ("characteristics") in a regression (ln) earnings as dependent variable (see Table A2 in the appendix). In the final four columns ln(employment density) is instrumented with 1910 population in today's FUA boundaries (and its square) (IV A) and with the number of 1910 municipalities in today's FUA (IV B). The first stage results for the IV estimation are reported in Table A4 in the appendix. Standard errors are clustered at the city level and reported below the coefficients in parentheses. */**/** indicates statistical significance at the 10%/5%/1% level. See the data description for data sources.

Before turning to the results, it is useful to consider the interpretation of the marginal effect of the amenity variables. A negative coefficient indicates that the local cost of living is increasing relative to local productivity, i.e. residents are paying a premium for living in FUAs with access to this amenity. On the other hand, a positive sign is expected for disamenities, since it indicates that residents are compensated, either in terms of higher earnings or lower local cost of living. This is the picture that emerges across the different specifications.

The results reported in Table 5 show that local amenities indeed help to explain the variation in real productivity benefits.³⁸ The statistically significant amenity and disamenity coefficients have the expected signs: negative for amenities and positive for PM10 air pollution. There is some variation in the driving forces of real benefits across specifications. The strongest evidence is found for the impact of theatres (measured by the number of seats), the number of universities, the presence of a UNESCO world cultural heritage site, as well as air pollution. Access to a large body of water is significant if PM10 pollution is excluded. The final two indicators, the presence of a university hospital and the number of first and second tier football clubs do not have a significant impact in any of the specifications.

The addition of amenity variables explains between 45% and 54% of the variation in the gap between a city's productivity and its cost of living that is not explained by time effects, agglomeration indicators, or the structural East-West divide. This share is with 33% to 42% slightly lower when productivity relevant controls are reintroduced.

38. The corresponding estimates that include individual fixed effects in the first step are reported in Table A7 in the appendix.

Table 5. The role of amenities in explaining real productivity differences

	Germany (1999-2007)				West Germany (1999-2007)			
	(L)	(M)	(N)	(O)	(L)	(M)	(N)	(O)
Access to coast or large lake	-0.012* (0.007)	-0.006 (0.007)	-0.014** (0.006)	-0.005 (0.007)	-0.011 (0.008)	-0.003 (0.008)	-0.012* (0.007)	-0.003 (0.008)
UNESCO cultural heritage site	-0.009* (0.005)	-0.009 (0.005)	-0.008* (0.005)	-0.008* (0.005)	-0.012** (0.006)	-0.013** (0.006)	-0.011** (0.005)	-0.013*** (0.005)
Number of theatre seats / 1,000	-0.014*** (0.005)	-0.017*** (0.005)	-0.010** (0.004)	-0.010*** (0.004)	-0.015** (0.007)	-0.019** (0.008)	-0.007 (0.005)	-0.008 (0.005)
Number of theatre seats / 1,000 (sq.)	0.001*** (0.000)	0.001*** (0.000)	0.001*** (0.000)	0.001*** (0.000)	0.001 (0.001)	0.001* (0.001)	0.000 (0.001)	0.000 (0.001)
University hospital in FUA	-0.001 (0.006)	0.000 (0.007)	-0.007 (0.005)	-0.000 (0.006)	-0.004 (0.006)	-0.001 (0.007)	-0.007 (0.005)	0.001 (0.006)
Number of universities	-0.007*** (0.002)	-0.007*** (0.002)	-0.002 (0.001)	-0.002 (0.001)	-0.008*** (0.002)	-0.009*** (0.003)	-0.004** (0.002)	-0.004** (0.002)
Numb. of nat. league football clubs 1995-99	0.001 (0.006)	0.000 (0.006)	-0.002 (0.004)	-0.003 (0.004)	0.002 (0.006)	0.002 (0.007)	0.000 (0.004)	0.000 (0.004)
Avg. annual level of PM10		0.005** (0.002)		0.004** (0.002)		0.003 (0.002)		0.002* (0.001)
Share of workers w/ university degree	-0.315*** (0.087)	-0.254*** (0.085)	-0.379*** (0.077)	-0.323*** (0.083)	-0.322*** (0.088)	-0.267*** (0.084)	-0.345*** (0.073)	-0.264*** (0.066)
R-squared	0.45	0.46	0.39	0.39	0.50	0.54	0.33	0.35
FUAs	109	100	109	100	88	80	88	80
Obs.	981	541	981	541	792	423	792	423
Productivity indicators	Aggl.	Aggl.	All	All	Aggl.	Aggl.	All	All

Note: Dependent variables are the residuals of a regression of the difference between city x year productivity differentials and the natural logarithm of a city price index for 2007 on $\ln(\text{employment density})$, $\ln(\text{area})$, a dummy for East German FUAs (in the full sample) and time dummies ("Aggl."); in addition industry shares and industry diversity are included "All". The first step Tobit regressions include a set of individual level characteristics ("characteristics") in a regression ($\ln$) earnings as dependent variable (see Table A2 in the appendix). Standard errors are clustered at the city level and reported below the coefficients in parentheses. */**/** indicates statistical significance at the 10%/5%/1% level. See the data description for data sources.

An intriguing result is that a larger share of highly educated workers is associated with lower real benefits (as opposed to its positive impact on nominal city productivity). Two arguments might explain this finding: the first is first that highly educated workers have a higher willingness to pay for local amenities; the second that a strong "creative class" constitutes an amenity in itself.

The first step estimation results in Table A2 indicated that university degree holders earn more than employees with lower educational attainment. They might also be more inclined to consume local amenities. When only considering university degree holders, the estimated coefficient is indeed higher (in absolute value) in the West German subsample, but neither the addition of amenity controls reduces the coefficient to zero, nor is this the case for the combined sample. One explanation might be that preferences are not perfectly captured by the included amenities that reflect only part of the spectrum of consumable FUA amenities. It is therefore possible that the result captures higher willingness to pay for FUA amenities by employees with higher education.

The presence of a large share of highly educated workers might have a positive spillover effect on other inhabitants and might be a value in itself. Florida (2002) has argued that agglomeration benefits arise from a strong "creative class". A larger share of highly educated workers can certainly be interpreted in that light.

Conclusion

This study sets out to answer three questions: Firstly, how strong are agglomeration benefits in Germany? Secondly, how much of those benefits remain for those who live and work in cities once cost of living is accounted for, i.e. what are the “private” agglomeration benefits? Thirdly, can local amenities explain the variation in real earnings differences across cities (the difference between $\ln$ city productivity and $\ln$ cost of living)?

For agglomeration benefits, the elasticity of city productivity, and city size, the estimates average around 0.03, and around 0.02 if the agglomeration size is instrumented with historical values or additional productivity relevant controls are included. They are at the lower end but nonetheless in line with the usual range (0.02-0.05) of elasticities in the literature (Combes, Duranton and Gobillon, 2011). The estimated agglomeration benefits account for selection of more productive individuals into bigger cities by using a two-step estimation procedure, controlling for the selection in the first step. Comparisons of the “naive” estimator, which ignores selection, with the two-step estimator show that the former overestimates agglomeration benefits by about 90%.

Agglomeration benefits are just one side of a coin: they are offset by agglomeration costs. The estimates indicate that real agglomeration benefits – the difference between productivity levels and cost of living in cities – do not increase with city size. This means that, on average, there are no “private” agglomeration benefits, i.e. workers are more productive and do earn higher wages in larger cities but they also have to pay the higher cost of living in those cities. But real benefits across cities varies significantly around the average.

This variation can be explained – to a large degree – by the quality of local (dis)amenities. A coarse set of cultural and environmental (dis)amenities can account for up to 50% of the residual variation in real productivity differences across cities. This means that residents are willing to pay a(n implicit) price for living in more attractive cities. Beyond the set of amenities an interesting result emerges: a larger share of university educated workers in a city actually “reduces” real earnings (as opposed to it raising productivity relative to local cost of living). On the one hand, this can indicate a higher willingness-to-pay of more highly educated workers, on the other hand it can be taken as evidence for the amenity value of a “creative class”.

The work in this study highlights the importance of accounting for differences in cost of living when studying agglomeration benefits, or, more generally, when studying the economic role of cities. More work is required in collecting local price information and creating appropriate cost indicators. The results also indicate the need for a better understanding of who benefits from agglomeration benefits (both pecuniary and non-pecuniary, in other words, how are these benefits distributed within society).

APPENDIX

The Tobit (type 1) model

The data used in the first-step estimation is right-censored, which results in biased and inconsistent OLS regressions (see e.g. Amemiya, 1984). Formally, the observed value of earnings y^* is equal to the latent earnings y , up to the censoring threshold $\tilde{y}$, above which it remains constant at $\tilde{y}$.

$$\begin{aligned} y_{iat}^* &= y_{iat} && \text{If } y_{iat} < \tilde{y} \\ y_{iat}^* &= \tilde{y} && \text{If } y_{iat} \geq \tilde{y} \end{aligned}$$

Under the assumptions that the above model describes the latent formation of (log) earnings and the error term ε follows a normal distribution the (type 1) Tobit model can be used to account for censoring and estimate average wage differentials consistently. It does so by estimating the bias introduced by censoring explicitly as part of the model using the functional form implied by the normal errors. The estimator can be implemented by standard maximum likelihood techniques (see Wooldridge, 2002, 519ff).

Additional figures and tables

Figure A1. Comparison of agglomeration benefits estimated by Tobit and OLS in 1999 and 2007

Note: Comparison of the estimated city x year fixed effects in a ln(earnings) regression with additional controls (column 1 and column 2 of Table 7 in the appendix) in a Tobit model that accounts for censoring and an OLS model that does not. See the data description for data sources.

Table A1. Descriptive statistics for 2000

	Germany		West Germany	
	mean	s.d.	mean	s.d.
Productivity differential (residual ln earnings)	5.725	0.097	5.768	0.034
Price index (ln)	4.531	0.045	4.543	0.041
Population (in millions)	0.484	0.639	0.490	0.564
Employment (in millions)	0.149	0.198	0.150	0.178
Area in 1,000 sq.km	1.208	1.136	1.143	1.067
Share of workers with university degree	0.107	0.035	0.101	0.033
Industrial diversity (Herfindahl Index, 3-digit industry level)	0.027	0.013	0.027	0.015
Share of workers in industry:				
A-C: Agriculture, fishing and mining	0.011	0.014	0.009	0.013
D (high): Manufacturing (high tech.)	0.027	0.024	0.032	0.024
D: (med. high): Manufacturing (med. high tech.)	0.097	0.068	0.111	0.068
D: (med. low): Manufacturing (med. low tech.)	0.066	0.042	0.072	0.043
D: (low): Manufacturing (low tech.)	0.063	0.025	0.067	0.025
E: Electricity, gas and water supply	0.006	0.008	0.005	0.007
F: Construction	0.072	0.025	0.062	0.014
G: Wholesale and retail trade	0.155	0.022	0.159	0.022
H: Hotels and restaurants	0.021	0.011	0.022	0.010
I: Transport & communication	0.056	0.015	0.053	0.014
J: Financial intermediation	0.033	0.017	0.037	0.015
K: Business activities & real estate	0.111	0.025	0.109	0.026
L: Public administration	0.068	0.024	0.061	0.020
M-N: Education, health & social work	0.145	0.034	0.140	0.034
O-Q: Other services	0.044	0.015	0.040	0.014
Population in millions in 1910	0.294	0.470	0.248	0.276
Number of municipalities in 1910	159.4	151.7	136.6	133.0
Access to coast or large lake	0.156	0.364	0.114	0.319
UNESCO cultural heritage site	0.183	0.389	0.182	0.388
Number of theatre seats / 1,000	1.333	2.010	1.157	1.415
University hospital in FUA	0.284	0.453	0.273	0.448
Number of universities	2.413	3.074	2.364	2.587
Numb. of nat. league football clubs 1995-99	0.358	0.646	0.352	0.662
Avg. annual level of PM10 (in 2007)	-0.033	1.266	0.016	1.258
FUAs	109 (100)		88 (80)	

Note: Productivity differentials are coefficients of city x year fixed effects in a ln(earnings) regression based on microdata. All data is available for 109 cities except for PM10 data, which is only available for 80 West German and 20 East German FUAs (in addition to the data being only available since 2002 and not in all years for all 100 FUAs). Data sources are listed in the data description.

Table A2. First step estimation results: individual earnings regressions

	(1) Tobit	(2) OLS	(3) FEi
Female	-0.222*** (0.001)	-0.219*** (0.001)	
Education information missing	-0.113*** (0.001)	-0.112*** (0.001)	-0.025*** (0.003)
Upper secondary	-0.004* (0.002)	-0.004** (0.002)	-0.109*** (0.004)
Lower secondary + apprenticeship	0.058*** (0.001)	0.058*** (0.001)	0.022*** (0.002)
Upper secondary + apprenticeship	0.113*** (0.001)	0.112*** (0.001)	0.071*** (0.003)
University of applied sciences	0.208*** (0.002)	0.205*** (0.002)	0.130*** (0.003)
University	0.246*** (0.001)	0.237*** (0.001)	0.203*** (0.003)
Age	0.043*** (0.000)	0.043*** (0.000)	
Age squared	-0.0004*** (0.000)	-0.0004*** (0.000)	-0.0004*** (0.000)
Occ. class: worker	0.633*** (0.006)	0.633*** (0.006)	0.577*** (0.004)
Occ. class: skilled worker	0.715*** (0.006)	0.716*** (0.006)	0.634*** (0.004)
Occ. class: master craftsman	0.920*** (0.006)	0.919*** (0.006)	0.688*** (0.005)
Occ. class: employee	0.882*** (0.006)	0.880*** (0.006)	0.689*** (0.004)
Occ. class: personal service worker	0.137*** (0.014)	0.137*** (0.014)	0.296*** (0.012)
Occ. class: part time < 18h	-0.276*** (0.006)	-0.277*** (0.006)	-0.093*** (0.005)
Occ. class: part time > 18h	0.449*** (0.006)	0.449*** (0.006)	0.495*** (0.004)
Occupation fixed effects	yes	yes	yes
City x year fixed effects	yes	yes	yes
Individual fixed effects	no	no	yes
N	2,707,517	2,707,517	2,707,517
Individuals			479,916
Censored	35,764		

Note: Dependent variable is the natural logarithm of earnings. The first column shows the results from a Tobit model that accounts for censoring (top-coding) of earnings at the upper social security contribution threshold, the second model replicates the estimation using OLS. The final column shows the estimation results including individual fixed effects, estimated using the `felsdreg` command in Stata (Cornelissen, 2008). The controls include educational attainment (with “lower secondary”, i.e. *Real-* or *Hauptschule* as base category), gender and age (as well as its square), occupational classification (with “apprentice” as base category), as well as fixed effects as indicated.

Table A3. FUA productivity and agglomeration benefits with additional controls (individual fixed effects in the first-step estimation)

	Germany (1999-2007)						West Germany (1999-2007)					
	(A)	(B)	(C)	(D)	(E)	(F)	(A)	(B)	(C)	(D)	(E)	(F)
ln(employment)	0.016*** (0.004)						0.016*** (0.005)					
ln(emp.density)		0.024*** (0.005)	0.020*** (0.005)	0.024*** (0.005)	0.026*** (0.008)	0.020** (0.008)		0.025*** (0.006)	0.022*** (0.006)	0.025*** (0.006)	0.032*** (0.009)	0.023** (0.009)
ln(area)		0.013*** (0.004)	0.009** (0.004)	0.012*** (0.004)	0.007 (0.005)	0.005 (0.005)		0.013** (0.005)	0.009* (0.005)	0.012** (0.005)	0.009 (0.006)	0.004 (0.006)
High educ.			0.172* (0.089)			0.371*** (0.109)			0.145 (0.095)			0.399*** (0.105)
Herfindahl				-0.093 (0.167)		-0.199 (0.184)				-0.073 (0.169)		-0.248 (0.190)
A-C: Agriculture, fishing and mining					-0.624** (0.305)	-0.474 (0.308)					-0.769** (0.381)	-0.413 (0.384)
E: Electricity, gas and water supply					-0.048 (0.327)	-0.257 (0.366)					-0.265 (0.382)	-0.464 (0.357)
D: Manufacturing (high tech.)					0.061 (0.177)	-0.091 (0.161)					0.064 (0.201)	-0.052 (0.188)
D:Manufacturing (med. high tech.)					-0.147 (0.134)	-0.144 (0.131)					-0.198 (0.166)	-0.142 (0.157)
D: Manufacturing (med. low tech.)					-0.207 (0.154)	-0.164 (0.137)					-0.305 (0.186)	-0.209 (0.152)
D: Manufacturing (low tech.)					0.218 (0.160)	0.181 (0.160)					0.123 (0.166)	0.144 (0.160)
G: Wholesale and retail trade					-0.593*** (0.224)	-0.566*** (0.210)					-0.484* (0.265)	-0.442* (0.239)
H: Hotels and restaurants					0.183 (0.269)	0.155 (0.260)					0.304 (0.326)	0.338 (0.284)
I: Transport and communication					-0.015 (0.329)	0.118 (0.320)					-0.283 (0.299)	-0.019 (0.297)

Table A3. FUA productivity and agglomeration benefits with additional controls (individual fixed effects in the first-step estimation) (continued)

J: Financial Intermediation					0.143 (0.256)	0.069 (0.239)					0.202 (0.311)	0.222 (0.268)
K: Business activities and real estate					-0.113 (0.182)	-0.289 (0.178)					-0.294 (0.199)	-0.468** (0.203)
L: Public admin.					-0.084 (0.347)	-0.081 (0.314)					-0.295 (0.348)	-0.24 (0.282)
M-N: Education, health and soc. work					-0.535*** (0.159)	-0.656*** (0.139)					-0.637*** (0.186)	-0.726*** (0.167)
O-Q: Other services					-0.317 (0.195)	-0.396** (0.192)					-0.278 (0.224)	-0.325 (0.209)
East dummy	-0.112*** (0.009)	-0.104*** (0.009)	-0.111*** (0.010)	-0.105*** (0.009)	-0.089*** (0.016)	-0.104*** (0.015)						
Intercept	0.183*** (0.048)	0.168*** (0.047)	0.190*** (0.046)	0.174*** (0.048)	0.413*** (0.115)	0.456*** (0.108)	0.188*** (0.059)	0.163*** (0.058)	0.184*** (0.056)	0.168*** (0.059)	0.438*** (0.139)	0.471*** (0.124)
R-squared	0.941	0.944	0.945	0.944	0.959	0.962	0.936	0.940	0.941	0.940	0.963	0.967
FUAs	109	109	109	109	109	109	88	88	88	88	88	88
Obs.	981	981	981	981	981	981	792	792	792	792	792	792

Note: Dependent variable consists of estimated city x year productivity differentials. The first-step regression includes individual fixed effects and a set of individual level characteristics in a regression (ln) earnings as dependent variable (see Table 7 in the appendix). Standard errors are clustered at the city level and reported below the coefficients in parentheses. */**/* indicates statistical significance at the 10%/5%/1% level. See the data description for data sources.

Table A4. IV estimates of agglomeration benefits: first stage for the IV estimation

	Germany (1999-2007)		West Germany (1999-2007)	
	(IV A)	(IV B)	(IV A)	(IV B)
ln(pop.dens.1910)	1.221*** (0.258)	1.321*** (0.251)	1.695*** (0.238)	1.758*** (0.234)
ln(pop.dens.1910) sq.	-0.410* (0.225)	-0.500** (0.217)	-0.814*** (0.200)	-0.872*** (0.198)
ln(area)	-0.057* (0.032)	0.051 (0.055)	-0.074** (0.035)	0.034 (0.059)
ln(fragm. 1910)		-0.100** (0.042)		-0.097** (0.044)
East dummy	-0.654*** (0.063)	-0.605*** (0.067)		
Intercept	-0.159 (0.756)	-0.706 (0.764)	-1.388* (0.776)	-1.843** (0.787)
R-squared	0.902	0.905	0.899	0.903
F-Test on instruments	318.5	227.4	246.8	171.4
FUAs	109	109	88	88
Obs.	981	981	792	792

Note: First stage estimates for the IV estimation with *ln*(employment density) in 1999-2007 as dependent variable. The F-Test reports the F-statistic for a test of the two/three instruments being jointly zero, the p-value in each case is below 0.1% Standard errors are clustered at the city level and reported below the coefficients in parentheses. */** indicates statistical significance at the 10%/5%/1% level. See the data description for data sources.

Table A5. IV estimates of agglomeration benefits

	Germany (1999-2007)		West Germany (1999-2007)	
	(IV A)	(IV B)	(IV A)	(IV B)
ln(emp.density)	0.014*** (0.005)	0.014*** (0.005)	0.016** (0.006)	0.015** (0.006)
ln(area)	0.008* (0.004)	0.008* (0.004)	0.008 (0.005)	0.008 (0.005)
East dummy	-0.110*** (0.009)	-0.110*** (0.009)		
Intercept	0.243*** (0.050)	0.242*** (0.049)	0.242*** (0.061)	0.243*** (0.060)
R-squared	0.942	0.942	0.938	0.938

Table A5. IV estimates of agglomeration benefits (*continued*)

FUAs	109	109	88	88
Obs.	981	981	792	792
Instruments	pop./pop. sq. 1910	pop./pop.sq./ mun. 1910	pop./pop. sq. 1910	pop./pop.sq./ mun. 1910

Note: Dependent variables are city x year productivity differentials. The first-step regression includes individual fixed effects and a set of individual level characteristics in a regression (ln) earnings as dependent variable (see Table A2). ln(employment density) is instrumented with 1910 population in today's FUA boundaries (and its square) (IV A) and with the number of 1910 municipalities in today's FUA (IV B). First stage results for the IV estimation are reported in Table A4. Standard errors are clustered at the city level and reported below the coefficients in parentheses. */**/** indicates statistical significance at the 10%/5%/1% level. See the data description for data sources.

Table A6. Real agglomeration benefits (individual fixed effects in the first-step estimation)

	OLS (1999-2007)								Instrumental Variables (1999-2007)			
	Germany				West Germany				Germany		West Germany	
	(A)	(B)	(A)	(B)	(A)	(B)	(A)	(B)	(IV A)	(IV B)	(IV A)	(IV B)
ln(employment)	0.010**		-0.006		0.006		-0.011**					
	(0.005)		(0.004)		(0.005)		(0.004)					
ln(emp.density)		0.026***		-0.004		0.025***		-0.009*	-0.003	-0.003	-0.007	-0.007
		(0.005)		(0.005)		(0.005)		(0.005)	(0.005)	(0.005)	(0.006)	(0.006)
ln(area)		0.003		-0.007*		-0.001		-0.011**	-0.007*	-0.007*	-0.010**	-0.010**
		(0.004)		(0.004)		(0.005)		(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
East dummy	-0.136***	-0.121***	-0.060***	-0.058***					-0.057***	-0.057***		
	(0.008)	(0.010)	(0.009)	(0.009)					(0.009)	(0.009)		
Intercept	3.052***	3.021***	-4.104***	-4.108***	3.102***	3.051***	-4.052***	-4.056***	-4.118***	-4.116***	-4.073***	-4.070***
	(0.053)	(0.045)	(0.045)	(0.045)	(0.058)	(0.046)	(0.049)	(0.049)	(0.047)	(0.047)	(0.053)	(0.052)
R-squared	0.686	0.732	0.943	0.944	0.309	0.434	0.947	0.947	0.944	0.944	0.947	0.947
FUAs	109	109	109	109	88	88	88	88	109	109	88	88
Observations	981	981	981	981	792	792	792	792	981	981	792	792
First stage contr.	None		Charact. + ind. FE		None		Charact. + ind. FE		Char+FE	Char+FE	Char+FE	Char+FE
Instruments									pop./pop. sq. 1910	pop./pop. sq./mun. 1910	pop./pop. sq. 1910	pop./pop. sq./mun. 1910

Note: Dependent variables are the difference between city x year productivity differentials and the natural logarithm of a city price index for 2007. The first-step regression includes individual fixed effects and a set of individual level characteristics in a regression (ln) earnings as dependent variable (see Table A2). In the final four columns ln(employment density) is instrumented with 1910 population in today's FUA boundaries (and its square) (IV A) and with the number of 1910 municipalities in today's FUA (IV B). First stage results for the IV estimation are reported in Table A4. Standard errors are clustered at the city level and reported below the coefficients in parentheses. */**/** indicates statistical significance at the 10%/5%/1% level. See the data description for data sources.

Table A7. The role of amenities in explaining variation in real agglomeration benefits

	Germany (1999-2007)				West Germany (1999-2007)			
	(L)	(M)	(N)	(O)	(L)	(M)	(N)	(O)
Access to coast or large lake	-0.036*** (0.008)	-0.035*** (0.010)	-0.032*** (0.008)	-0.032*** (0.010)	-0.026*** (0.009)	-0.023** (0.010)	-0.024*** (0.008)	-0.021** (0.010)
UNESCO cultural heritage site	0.004 (0.008)	0.004 (0.009)	0.005 (0.008)	0.005 (0.010)	0.000 (0.009)	0.000 (0.009)	-0.002 (0.008)	-0.003 (0.009)
Number of theatre seats in 1,000s	-0.001 (0.005)	-0.002 (0.005)	0.001 (0.005)	0.002 (0.005)	0.000 (0.005)	-0.002 (0.006)	0.005 (0.007)	0.003 (0.008)
Number of theatre seats in 1,000s (squared)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	0.000 (0.000)	-0.000 (0.001)	-0.000 (0.001)	-0.001 (0.001)	-0.001 (0.001)
University hospital in FUA	-0.011* (0.007)	-0.016** (0.007)	-0.002 (0.008)	-0.008 (0.009)	-0.003 (0.007)	-0.005 (0.008)	0.007 (0.007)	0.005 (0.008)
Number of universities	-0.004** (0.002)	-0.003 (0.002)	-0.003 (0.002)	-0.002 (0.002)	-0.003 (0.002)	-0.002 (0.002)	-0.003 (0.002)	-0.002 (0.002)
Numb. of nat. league football clubs 1995-99	-0.000 (0.004)	-0.001 (0.004)	-0.000 (0.004)	-0.001 (0.004)	0.000 (0.004)	0.000 (0.004)	0.000 (0.004)	-0.001 (0.004)
Avg. annual level of PM10		0.001 (0.002)		0.001 (0.002)		0.002 (0.002)		0.001 (0.002)
Share of workers w/ university degree	-0.326*** (0.097)	-0.253** (0.103)	-0.236** (0.113)	-0.173 (0.127)	-0.464*** (0.094)	-0.407*** (0.102)	-0.316*** (0.102)	-0.244** (0.122)
R-squared	0.348	0.325	0.182	0.180	0.389	0.367	0.191	0.151
FUAs	109	100	109	100	88	80	88	80
Obs.	981	541	981	541	792	423	792	423
First-step controls	Char. + FE	Char. + FE	Char. + FE	Char. + FE	Char. + FE	Char. + FE	Char. + FE	Char. + FE
Productivity indicators	Aggl.	Aggl.	All	All	Aggl.	Aggl.	All	All

Note: Dependent variables are the residuals of a regression of the difference between city x year productivity differentials and the natural logarithm of a city price index for 2007 on $\ln(\text{employment density})$, $\ln(\text{area})$, a dummy for East German FUAs (in the full sample) and time dummies ("Aggl."); in addition industry shares and industry diversity are included "All". The first-step regression includes individual fixed effects and a set of individual level characteristics in a regression ($\ln$) earnings as dependent variable (see Table A2 in the appendix). Standard errors are clustered at the city level and reported below the coefficients in parentheses. */**/** indicates statistical significance at the 10%/5%/1% level. See the data description for data sources.

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