The Role of Urban Agglomerations for Economic and Productivity Growth

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Abstract

This article discusses how urban agglomerations – cities – affect economic productivity. It uses an internationally harmonized definition of cities that aims to capture the true extent of an urban agglomeration and is not limited by administrative city boundaries. It shows that labour productivity increases with city size. Among OECD metropolitan areas, agglomerations with more than 500,000 inhabitants, a 1 per cent population increase is associated with a 0.12 per cent increase in average labour productivity. Partly, this is explained by "sorting" as more productive workers tend to live in bigger cities. But bigger cities provide additional "agglomeration economies" to those working in them. Comparable workers are 0.02-0.05 per cent more productive in cities with a 1 per cent larger population. These differences compound to significant differentials, e.g. a similar worker in Madrid (6 million inhabitants) is, on average, nearly 15 per cent more productive than a worker in Toledo (120,000 inhabitants). Furthermore, the paper also shows that cities affect economic performance beyond their boundaries. Since 1995, per capita GDP growth in regions within 90 minutes driving of a large urban agglomeration has been approximately 0.4 percentage points higher than in those with no large urban agglomeration within 300 minutes of driving.

Cities and urban agglomerations are the most productive places in OECD countries. More than 75 per cent of the most productive regions in terms of output (gross domestic product) per worker are urban and more than half are regions with a metropolitan area of 1.5 million or more inhabitants (OECD, 2016a). One of the universal patterns found across countries and regions is that across cities of all sizes, city size is positively correlated with productivity levels. The more people that live in a city, the higher the average level of productivity of its inhabitants. A city of 20,000 inhabitants is likely to have more productive residents than a city of 10,000 inhabit-

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ants, just as a city of 2 million inhabitants is likely to have more productive residents than a city of 1 million inhabitants.

Several mechanisms are responsible for this phenomenon. One explanation lies in the fact that urban populations are equipped with skills and qualifications that make them on average more productive. For example, urban dwellers are on average more highly educated than inhabitants of rural areas. This gap arises on the one hand, because institutions of higher education tend to be located in urban areas, making access for local residents easier and more affordable and also increasing the educated workforce as people who come to study in a city are more likely to stay after they graduate. On the other hand, cities offer more and better job opportunities for highly educated people, thus attracting people with high levels of education and offering better matches between worker skills and the jobs they fill.[2] This might be particularly relevant for highly educated "power" couples as larger cities make it more likely for both partners to find suitable jobs (Costa and Kahn, 2000).

Beyond differences in skills and education, there is another important set of mechanisms that make workers in cities, and especially larger cities, more productive. This set is summarized under the term "agglomeration economies". Agglomeration economies increase the level of productivity in cities independent from individual characteristics of their inhabitants. Several channels through which agglomeration economies occur are frequently mentioned.[3]

One mechanism concerns knowledge and the innovations it spurs. Closer proximity and more face to face contact between workers can lead to a faster spread of new ideas within cities, thus causing firms to adopt new innovative production techniques more quickly. Another mechanism is related to scale and the capacity to share infrastructure or input facilities. Since most infrastructure investments include fixed costs that are to some degree independent from the number of users, larger cities with a higher number of users can use infrastructure more efficiently on average. The same applies to local inputs. A law firm specializing in exports and investment to a specific country requires a large enough local demand. Finally, the greater number of businesses and workers in cities makes it easier for businesses to find workers that closely match the required profiles and workers can work in jobs that better match their skills.

All these mechanisms increase the productivity of workers in cities beyond the level that they would have in less densely populated areas. These ideas are not new, but build on a long history of research, with early discussion of the concept of agglomeration benefits ranging back to the 19th century economist Alfred Marshall and gains from specialization being a key aspect of Adam Smith's work.

The influence of cities on productivity goes beyond their own borders. For example, Camagni, Capello and Caragliu (2015) find that productivity in second tier cities (with less than 1 million inhabitants in the larger urban zone) is positively affected by the presence of other cities. Partridge *et al*. (2009a) estimate positive effects on population growth in US counties that are close to higher tiered urban centres, but also find evidence that the largest urban areas adversely affect growth in mid-sized metropolitan areas in their vicinity. Looking at long run

2 Andersson, Burgess and Lane (2007) find that in denser counties in California and Florida high-skill workers are more likely to be matched with firms that have high average skill levels. Studies for Italy and Portugal find positive but weaker evidence for such "assortative" matching (Andini *et al*, 2013 and Figueiredo, Guimarães and Woodward, 2014).

3 See Duranton and Puga (2004) for a detailed discussion.

trends and using the loss in market access of cities close to the border between East and West Germany after the postwar division, Redding and Sturm (2008) find strong adverse effects on population growth, especially in the early years following the split.

Thus, it is likely that distances to cities can determine levels of productivity and economic growth. This effect can be positive, as larger cities provide specialized services and serve as hubs for trade and transport. For less-densely populated rural areas, cities can be an essential part of their economy as they markets for products, concentrate public and private services, e.g. patent offices or marketing agencies and provide greater variety in shopping and cultural amenities. Obviously, the closer a region is located to a city, the easier it is for its businesses to access these functions and the easier for residents and businesses in the region to "borrow" agglomeration economies from the city.[4] Conversely, theoretical discussions also highlight that concentration of activity in metropolitan centres might cast "agglomeration shadows" on smaller cities and surrounding areas as the core benefits from productivity and population growth at the expense of surrounding areas (Fujita, Krugman and Venables, 1999).

This article presents evidence from several OECD research projects on the determinants of productivity and growth in cities and regions. Primarily, it summarizes evidence collected in Ahrend *et al*. (2014) and Ahrend and Schumann (2014). Its contribution is threefold. First, in order to better understand how cities affect countries as a whole, it assesses how closeness to urban centres affects economic growth in all regions. Instead of using geographical distance, the article focuses on road-based travel distance and in particular travel time.[5] These variables are more important in determining the accessibility of a city from a region and are therefore more likely to influence the region's economic performance.

Second, it aims to understand the economic benefits of cities themselves and estimates the magnitude of these "agglomeration economies" for five OECD member countries on two continents. In other words, it estimates the difference in productivity of comparable workers in cities of different sizes.

As a third contribution, the article uses an internationally harmonized - functional - definition of urban areas (FUAs) as the unit of observation rather than an administrative city definition, as does most related literature.[6] This is important, because administrative boundaries of cities are often arbitrary and do not correspond to the economic and social realities that define a city. In contrast, the definition of FUAs

4 Camagni, Capello and Caragliu (2016), for example, find that for Europe, proximity to high-level urban functions in other cities is positively associated with productivity and its growth. The authors rely on house prices as a proxy for the productivity differential between cities arguing that it reflects the net benefits of a city, including the productivity benefits they provide. The concept of borrowed size is often attributed to Alonso (1973), who highlighted that smaller cities can sustain urban functions that would typically require larger cities (and markets) if they are located close enough to larger cities.

5 The focus on road-based travel compared to other modes, e.g. rail-based travel, is due to the fact that in Europe (the focus of this part of the study), 92.5 per cent of kilometres travelled by ground transport are travelled by road-based transport (Eurostat, 2017; data for 2014).

6 Many countries have their own function-based regional delineations. For example, Metropolitan Statistical Areas in the United States aim to combine areas with close economic ties. France and the United Kingdom have definitions of local labour markets based on commuting flows (Zone d'Emploi and Travel to Work Areas respectively) that cover the whole country. The advantage of the FUA definition developed by the European Union and the OECD is that it applies the same methodology for all countries (with threshold values adapted for North American and Asian OECD countries) and allows to divide countries into dense urban centres, the surrounding less densely populated commuting zone and low density areas that lie outside (functional) urban areas.

that is used by the OECD and throughout the article defines cities as urban cores and their surrounding commuting zones. As this definition is largely independent from administrative boundaries, it provides a better description of what a city is.

Across OECD countries productivity increases with city size. For metropolitan areas, i.e. functional urban areas with at least 500,000 inhabitants, every 10 per cent increase in population is associated with 1 per cent higher productivity in terms of gross domestic product (GDP) per worker. This means that the output per worker in Paris, the largest French metro area with 12 million inhabitants, is expected to be more than 18 per cent higher than in the second largest metro area Lyon with nearly 2 million inhabitants.[7]

In line with previous work and theoretical predictions, the results indicate that these positive effects are not limited to the cities and metro areas themselves. Per capita GDP in regions that contain urban agglomerations grew faster over the 1995-2010 period than in those without a major city. The benefit increases with city size, from 0.16 per centage points faster annual growth for regions with an urban agglomeration with 200,000 and 500,000 inhabitants to 0.5 per centage points for regions with large metro areas of 2 million or more inhabitants. These effects are sizeable given that many OECD countries grew by less than 2 per cent per year during the period, with growth in some countries below 1 per cent per year.

The estimates also show positive growth effects for regions that are close to large metro areas. The annual average per capita GDP growth rate in regions that had twice the travel time to the nearest metro area was about 0.2 per centage points lower than in closer regions.

Part of the success of (larger) cities comes from their ability to attract highly educated or more diverse workers.[8] Cities are therefore more productive because they attract more productive workers. But this "selection" of more productive workers into larger city is only part of the story. Another part comes through productivity benefits that are conferred by the cities themselves through agglomeration economies. The estimated impact cities have on the productivity of its residents and those in surrounding regions is substantial. Even after controlling for the non-random selection of the city in which they live, the effect of agglomeration on workers' productivity is estimated at 0.2 per cent to 0.5 per cent for a 10 per cent increase in the population in a city. This means that the same person working in Madrid with its more than 6 million inhabitants is nearly 15 per cent more productive, on average, than he or she would have been working in Toledo with its 120,000 inhabitants. It also means that roughly half of the productivity benefit of larger cities comes through agglomeration economies.

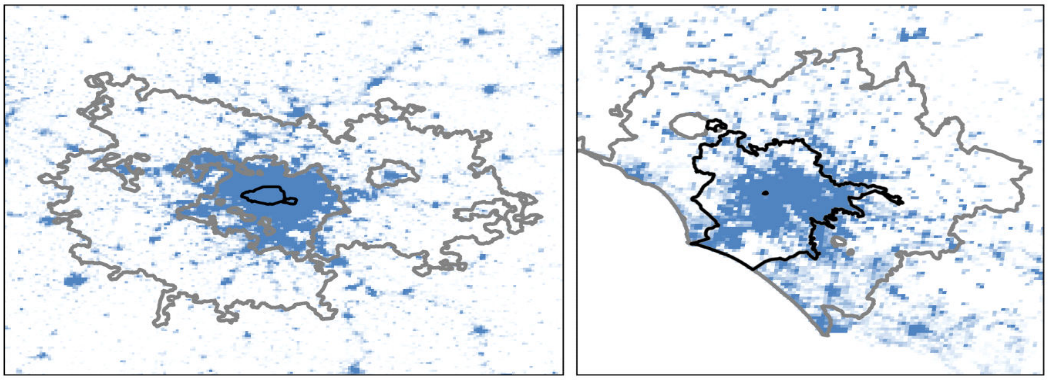
For cities that are close to other urban areas, there seems to be some room to "borrow" agglomeration economies, even net of selection. A 10 per cent larger number of urban dwellers living in a 300 kilometre radius around the city is associated with about 0.1-0.2 per cent higher productivity.

The remainder of the article is structured as follows. Section 2 provides an overview of the data and statistical definitions used, as well as descriptive evidence on productivity levels in cities, and shows that larger functional urban

7 The actual difference is even larger with Paris producing more than 30 per cent more GDP per worker than Lyon in 2014 (http://measuringurban.oecd.org/, accessed 9 November 2016).

8 Keeping with the French example, the per centage of university graduates in the working age population in Paris is larger than in Lyon. The diversity and amenities of cities were widely popularized in the early 2000s as an argument for the attractiveness and success of cities. See Florida (2002), for one of the most well-known studies on this topic.

Chart 1: Administrative Boundaries and EU-OECD Metropolitan Areas for Paris and Rome



Notes: Shades of blue denote population density (dark blue: 1,500 inhabitants/km² or more; light blue: 500-1,500 inhabitants/km²), black lines delineate the administrative city, grey lines the urban centre(s) and commuting zone.

Source: Adapted from OECD (2012).

areas are more productive on a per capita basis with positive spillovers to surrounding and connected regions. Section 3 uses micro-level data to distinguish the contribution of agglomeration economies from effects caused by differences in (observable) worker characteristics, e.g. education levels, due to sorting. Section 4 concludes.

Data and Definitions

The work summarized in this contribution combines different data sources and definitions of spatial units. For regions, the OECD defines subnational territorial units at two different levels; the higher Territorial Level 2 (TL2) and the lower Territorial Level 3 (TL3). In total there are 362 TL2 regions and 1792 TL3 regions in OECD countries. As there is very little data on the TL3 level available outside of Europe, all analysis using regional data focuses on approximately 600 European TL3 regions from 18 countries for which GDP growth rates and other data is available from 1995 to 2010.[9]

The study uses travel time and travel distance to urban centres in Europe as explanatory variables for economic growth. Travel time is measured as the number of minutes required to travel by car from the geometric center of a TL3 region to the centre of the closest functional urban area (FUA) above the respective population threshold. Travel distance indicates the distance in kilometres between those two points using the fastest road connection. Travel time assumes normal road conditions without congestion. The data are based on route planning information from Google Maps that has been collected using Google Maps' Application Programming Interface (API). When centroids of regions do not lie exactly on a road, the closest point on a road has been used as start or end point of a route, respectively.

The median travel distance to the centre of the closest FUA with at least 500,000 inhabitants is 105 kilometres. Due to a small number of very remote regions, the mean distance is larger at 127 kilometres. Median and mean travel times are 76 and 105 minutes, respectively. Across all observations, the average travel speed as predicted by Google Maps is 78 kilometres per hour. The correlation between travel time and travel distance is 0.86. This relatively high cor-

9 Excluded from the analysis are those regions that are not part of the mainland of a country, such as exclaves and oversea territories.

relation indicates a fairly homogenous quality of road infrastructure across Europe.

In the EU-OECD definition, functional urban areas are densely populated urban centres with a surrounding commuting zone.[10] Based on gridded population density data, high density population clusters with more than 50,000 inhabitants are identified (100,000 inhabitants in Japan, Korea and Mexico). All municipalities who have at least 50 per cent of their inhabitants living in the high density cluster are considered part of the urban centre of the functional urban area. If there are two high density clusters and at least 15 per cent of the working population of one high density cluster commutes into the other, they are considered part of the same functional urban area. Finally, the commuting zone is defined as those municipalities from which at least 15 per cent of the working population commute into the municipalities in the urban centre.

A minimum threshold for the population size of the functional urban areas is set at 50,000 persons. The definition is applied to 30 OECD countries (Iceland, Israel, Latvia, New Zealand and Turkey are not included). It identifies 1,197 urban areas of different sizes (small urban areas with population below 200,0000, medium-sized urban areas with a population between 200,000 and 500,000 people, and metropolitan areas with population higher than 500,000.

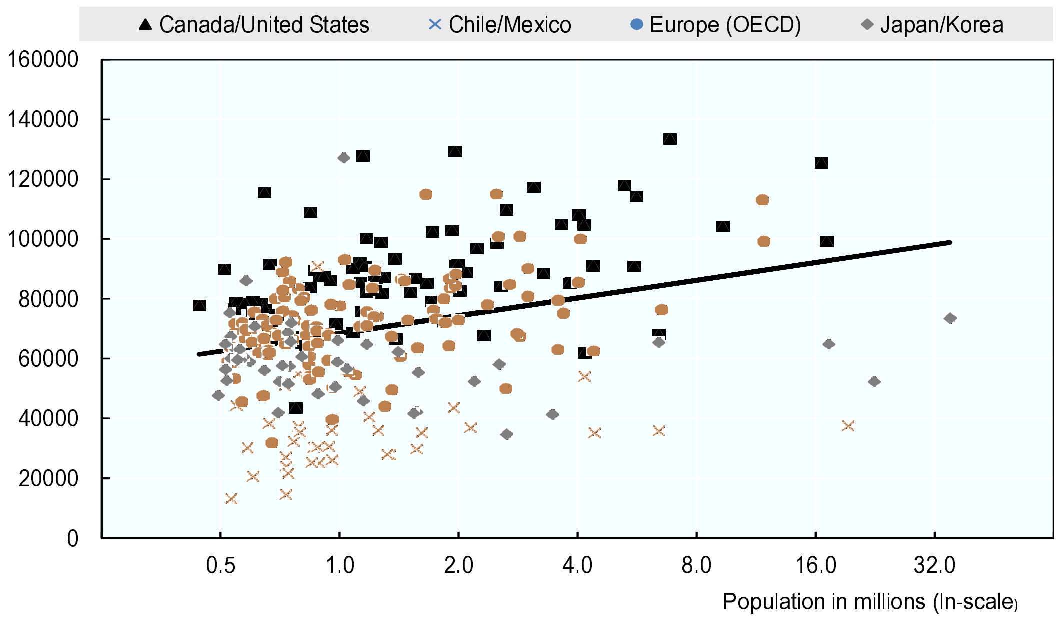
This definition overcomes previous limitations for international comparability of urban areas. Traditional definitions based on administrative boundaries are often not comparable across countries, because the shape and size of administrative areas varies from country to country. The boundaries of the city of Paris, for example, cover only a fraction of the urban centre of the metropolitan area, while, the urban centre of the metropolitan area of Rome coincides with the administrative city, but both exclude the substantial commuting zones surrounding the urban centres (Chart 1). The aim of the OECD approach to functional urban areas is to create a methodology that can be applied in all countries, thus increasing comparability across countries. The OECD definition may not correspond to national definitions. Therefore, the resulting functional urban areas may differ from the ones derived from national definitions.[11]

For Germany and Spain, social security data was used. Employment surveys for Mexico and the United Kingdom and the American Community Survey for the United States. For Germany, the data cover 2 per cent of all social security contribution paying employees and are based on the Employment Panel of the German Federal Employment Agency, with the data hosted at the Research Data Centre of the Institute for Employment Research. For Spain, a 4 per cent sample of workers, pensioners and unemployment benefit recipients, the Continuous Sample of Working Histories, was used. Mexico's employment survey (National Occupation and Employment Survey) covers 0.4 per cent of the population per quarter and the UK Annual Survey of Hours and Earnings is a 1 per cent sample of national insurance paying workers. For the United States, the public use file of the American Community Survey, a 1 per cent ample of the population, was used. For Germany, Mexico, Spain and the United Kingdom the data allowed a match to functional urban

10 Adapted from the Reader's guide in OECD (2016b) and OECD (2012).

11 For five OECD countries, Germany, Mexico, Spain, the United Kingdom and the United States, the definition of functional urban areas is matched with large scale microdata sets that include worker wages and (some) characteristics. As the match requires geographic information on residence at small spatial scales, e.g. municipalities, these data are typically confidential and not directly accessible. The selection therefore aimed to cover large OECD countries across several continents, which had suitable datasets that could be accessed directly or in collaboration with local partners.

Chart 2: City Size and Labour Productivity, 2010



Notes: Labour Productivity is measured as GDP (USD in constant PPP and constant prices, reference year is 2005) divided by the total employment in a Functional Urban Area. Data refer to 2010 or the closest available year.
Source: OECD Metropolitan Explorer.

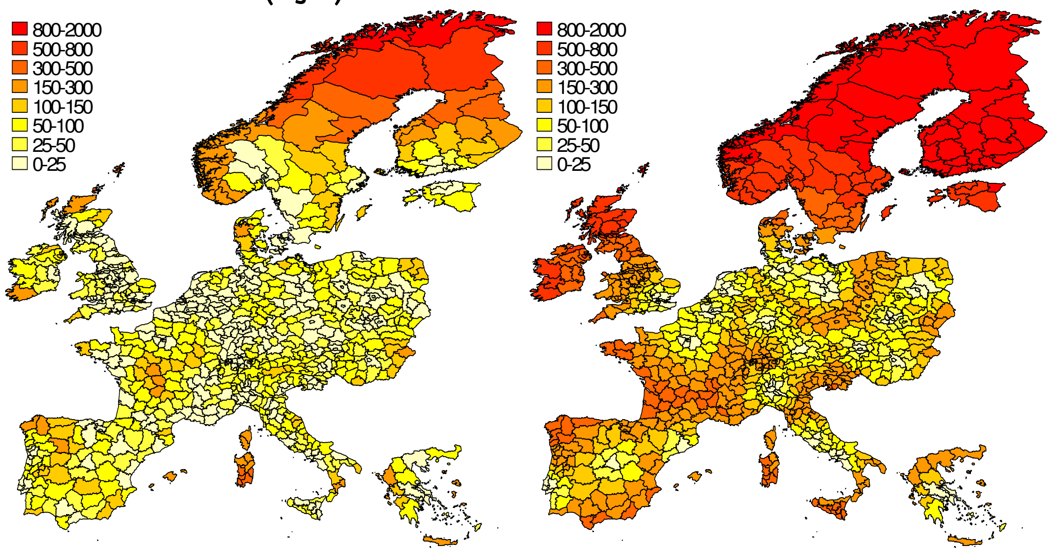
areas of all sizes, for the United States the analysis was restricted to metropolitan areas with more than 500,000 inhabitants.

Descriptive evidence

Per capita GDP increases with city size. On average across all functional urban areas with more than 500,000 inhabitants in the OECD, a 1 per cent increase in population is associated with an increase in per capita GDP of approximately 0.1 per cent. In some countries, such as France, the effect is significantly larger. There, a 1 per cent increase in population is associated with a 0.2 per cent increase in per capita GDP (Bettencourt and Lobo, 2016). Studies that focus on productivity tend to find smaller but still substantial effects, with estimates ranging between 3-8 per cent higher productivity for a doubling, i.e. 100% increase, in population (Rosenthal and Strange, 2004).

A similar pattern is noticeable if productivity levels are analysed rather than GDP. Chart 2 presents the average level of productivity measured in US dollars per worker on the vertical axis and plots these against the size of the city — as measured by its resident population. It becomes obvious that larger cities benefit from a productivity premium. In per centage terms, a 1 per cent increase in the population in a metro area is associated with, on average, 0.12 per cent higher labour productivity. But this does not necessarily imply that relocating people into larger cities will raise productivity. As outlined above, a significant part of this productivity premium can be attributed to the characteristics of the workforce in larger cities, i.e. these workers would be more productive wherever they chose to work. In section 3 the analysis aims to disentangle this "selection" effect from the agglomeration benefits that a larger city confers by virtue of its size.

Chart 3: Distance to Closest Functional Urban Area with 500,000 Inhabitants (left) and 2 Million Inhabitants (right)



Note: The chart shows the distance in kilometres to the closest functional urban area (FUA) with at least 500,000 inhabitants (left), and 2 million inhabitants (right). Darker colours indicate larger distances. With the exception of northern Europe, most regions are relatively close to FUAs with 500,000 inhabitants, but distances to large FUAs vary greatly.

Regional economic growth and distance to cities

This section describes the role of cities for the economic growth of surrounding regions, focusing on the relation between growth and distance to urban centres in Europe. It shows that there are important spillovers from cities to surrounding regions. Regions containing large cities have been growing faster than regions that do not contain large cities. Likewise, regions that do not contain large cities, but are located close to them have been growing faster than regions that are far away from large cities. Since 2000, travel time from a region to the closest large city has been negatively correlated with per capita GDP growth.

The empirical strategy is based on cross-section regressions of the average annual regional per capita GDP growth rate between 1995 and 2010 on an outcome variable of interest. Most specifications include initial log-per capita GDP in 1995 and a set of country dummies as control variables. The baseline regression is given by:

$$\Delta pcGDP_i^{95-10} = \alpha + \beta_1 x_i + \beta_2 log(pcGDP_i^{95}) + \sum_{c=1}^{C} \gamma_c dum_i^c + \varepsilon_i \quad (1)$$

where $\Delta pcGDP_i^{95-10}$ indicates the average annual growth rate of per capita GDP between 1995 and 2010 in region i, x_i is the respective explanatory variable, $\log(pcGDP_i^{95})$ is a control variable for log per capita GDP at the beginning of the observation period, and $\sum_{c=1}^{C} \gamma_c dum_i^c$ is a set of dummy variables for country c. The set of country-dummies implies that, generally, within-country effects are estimated. This ensures that the estimates are not affected by country-wide developments that are unrelated to regional characteristics. It is furthermore a way of dealing with the problem of shocks that are clustered on the country-level and which could lead to a severe underestimation of the estimated standard errors. Control-

Table 1: Average annual per capita GDP Growth and Size of the Largest FUA within a Region

	(1)	(2)
Agglomeration >500,000	0.23*** (0.10)	
Agglomeration >2,000,000		0.54** (0.26)
Agglomeration 500,000-2,000,000		0.28*** (0.10)
Agglomeration 200,000-500,000	0.16** (0.07)	0.16** (0.07)
Per Capita GDP in 1995	-0.65** (0.24)	-0.67*** (0.24)
Constant	9.25*** (2.60)	9.43*** (2.61)
Country-FE	YES	YES
N	603	603

Note: ***/**/* indicates a statistically significant coefficient at the 1%/5%/10% level

ling for initial GDP is required in many cases to avoid that estimates are biased by regression to the mean.

Regions that contain an urban agglomeration above 500,000 inhabitants had a per capita income that was approximately 21 per cent larger than the respective country average in 1995. Nevertheless, regions that contain such agglomerations had a much higher per capita GDP growth over the subsequent 15 years. Table 1 shows how the presence of a large urban agglomeration affects regional per capita GDP growth. The explanatory variables are specified as dummy variables that take on the value 1 if a region contains a FUA with the respective size and 0 otherwise. Regions that contain urban agglomerations 200,000 - 500,000 inhabitants grew 0.16 per centage points faster than regions without such urban agglomerations. For regions with urban agglomerations above 500,000 inhabitants, the difference in annual per capita growth rates is approximately 0.2 per centage points (column 1) and for those with urban agglomerations above 2 million inhabitants it is more than 0.5 per centage points (column 2).

The previous estimates have shown that regions containing large urban agglomerations have been growing faster between 1995 and 2010. This section estimates whether a correlation between economic growth and proximity to large urban agglomerations also exists. It is in spirit similar to Veneri and Ruiz (2013) who analyse the effects of proximity between rural and urban regions, but differs from their analysis by using a larger set of distance measures and considering only large urban agglomerations.

Table 2 presents the results of a series of regressions that show the effect of travel times and geographical distance on economic growth. Column (1) shows the estimate for the following specification:

$$\Delta pcGDP_i^{95-10} = \alpha + \beta_1 I_i^{45-90} + \beta_2 I_i^{90-180} + \beta_3 I_i^{180-300} + \beta_4 I_i^{>300} + \beta_5 log(pcGDP_i^{95}) + \sum_{c=1}^{C} \gamma_c dum_i^c + \varepsilon_i \quad (2)$$

It includes four dummy variables that indicate whether a region is within the given number of minutes by car from the nearest urban agglom-

Table 2: Distance to Urban Agglomerations with at Least 2 Million Inhabitants

	Full Sample			Restricted Sample		
	(1)	(2)	(3)	(4)	(5)	(6)
45-90 Min	-0.50* (0.29)					
90-180 Min	-0.62** (0.29)					
180-300 Min	-0.79** (0.31)					
>300 Min	-0.87*** (0.32)					
Log Travel Time		-0.02 (0.08)		-0.22** (0.097)		-0.17* (0.10)
Log Distance			-0.07 (0.05)		-0.14** (0.06)	-0.08 (0.06)
Log p.c. GDP 95	-0.81*** (0.21)	-0.00** (0.00)	-0.80*** (0.22)	0.000 (0.000)	-0.61** (0.29)	-0.64** (0.29)
Constant	11.63*** (2.05)	3.86*** (0.505)	11.17***(2.08)	4.122*** (0.868)	9.71*** (3.30)	10.66*** (3.47)
Cut-off Time	--	--	--	0-480 Min	0-480 Min	0-480 Min
Country FE	YES	YES	YES	YES	YES	YES
N	545	545	545	385	385	385

Note: ***/**/* indicates a statistically significant coefficient at the 1%/5%/10% level

eration with at least 2 million inhabitants. The base category is regions that are within less than 45 minutes of such urban agglomerations. It shows that cities that are within 45 to 90 minutes of such agglomerations have been growing approximately half a per centage point slower per year than those that are within less than 45 minutes. For regions that are further away from large urban agglomerations, the negative difference in growth is even larger.

Specification (2) also estimates a relation between travel time and economic growth but uses a log-linear specification of travel time instead of a set of dummy variables to model the relation between the two variables. The estimated coefficient on travel time is small and insignificant. The reason behind this result is that the negative relationship between travel time and economic growth breaks down at more than roughly 400 minutes travel time. Specification (4) takes this into account by restricting the sample to regions that are within 8 hours (a day's drive) by car to an urban agglomeration with 2 million inhabitants. It shows that for distances below that threshold a robust negative relationship between distance and economic growth exists. A doubling in travel time is associated with an annual per capita GDP growth rate that is approximately 0.2 per centage points lower.

Specifications (3) and (5) repeat the exercise but use the natural logarithm of geographic distance to the next urban agglomeration of more than 2 million inhabitants as explanatory variable. Although less pronounced, the emerging pattern is similar: while there is an overall negative relationship, a statistically significant result can only be found for regions that are not too far away from the next large urban agglomeration.

Finally, specification (6) compares the explanatory power of travel time and distance for per capita economic growth by including both variables. When controlling for distance, the interpretation of the travel time coefficient changes somewhat. Conditional on distance, travel time becomes a measure of road connectivity. In this specification, the coefficient on log-travel time remains significant at the 10 per cent level and is exactly twice as large as the coefficient on log-distance, which turns insignificant. Both point estimates on the two coefficients are directly comparable in their magnitude because both variables are in logarithmic terms. Therefore, the coefficients can be interpreted as the effect of a per centage change of the explanatory variable on the outcome. As both variables also have similar standard deviations, a fixed per centage change has a comparable importance for both variables. Therefore, the difference in the estimated coefficients implies that actual distance is of lower importance than travel time for economic growth.

Although travel time between regions and large urban agglomerations is strongly correlated with economic growth, the picture is less clear with respect to smaller urban agglomerations. While some specifications (not shown) suggest that closeness to small and medium-sized urban agglomerations had a positive effect on economic growth between 1995 and 2010, coefficients are imprecisely estimated and typically not statistically significant.

Several issues potentially bias the estimates above. One potential source of bias is attenuation bias, since expected travel time from regional centroid to centroid of the FUA is only an imperfect measure of actual travel times. Another source of bias is related to reverse causality. Travel time was measured in 2013, after the end of the observation period. If policy makers respond to expected or actual growth rates by investing in infrastructure, it is possible that the differences in travel time are at least partly caused by per capita GDP growth. If fast growing regions receive more infrastructure investments, the estimate on travel time would be negatively biased (i.e. its effect would be overestimated). Correspondingly, if slow growing regions receive more infrastructure investments, the effects would be underestimated.

Furthermore, travel time might be correlated to other factors that affect growth rates over the observation period. Such factors would introduce omitted variable bias in the estimates. Especially in sparsely populated regions, for example, the actual investment into road construction can have a sizable impact on per capita GDP. It might therefore be the case that part of the higher growth in better connected regions comes from the investment that made them better connected in the first place. In this case, the coefficient on travel time would be positively biased.

Agglomeration Economies in Functional Urban Areas

To understand the role of agglomeration economies and the importance of cities for the production in a country, the productivity premium needs to be separated into two parts. The first part is productivity that is attributable to the worker. For example, larger cities have a larger per centage of highly educated workers. If these workers were to move to another city, this city would become more productive, not because of agglomeration economies, but because inherently more productive workers "sorted" into the city. This sorting is not random. Typically, inherently more productive workers sort into larger cities. This part of the productivity premium therefore needs to be separated from the second part, the agglomeration economies that arise through a larger population being concentrated in an area. These economies appear as an externality to the worker, something they cannot take with them when they move to a smaller city.[12]

12 Several recent papers highlight that workers actually do retain some of the benefits when moving from a larger to a smaller city, in line with arguments that highlight the importance of networks and experience they can gain during the time they live in the larger city (e.g. de la Roca and Puga, 2016, for Spain).

Methodology

Empirical work attempting to quantify agglomeration economies, while accounting for selective sorting, has followed two paths. The first is based on the equilibrium location decisions of firms — under the assumption that firms will locate where they are most productive (e.g. Ellison and Glaeser, 1997; Rosenthal and Strange, 2003). The second strand of empirical work, the one followed in this article, focuses instead on the productivity of workers. Empirical work along these lines has found a relation between urban density and productivity — proxied by wages — that continues to hold after controlling for both observable and (permanent) unobservable individual characteristics (e.g. Glaeser and Maré, 2001 or Combes, Duranton and Gobillon, 2008).[13]

In our research, the analysis follows a common empirical strategy applied across five OECD countries. This not only ensures that the individual country results are comparable, but allows for pooled regressions on the full sample of cities from five countries. The latter aspect is of critical importance, given the limited number of cities in each country. Pooling helps create a sample with mass not only among small and medium-sized cities or administratively congruent cites, but also among large or very fragmented cities. The harmonized approach is made possible through the use of an internationally comparable definition of "city" that is based on economic linkages, rather than administrative boundaries.

Administrative and functional definitions of cities do not always coincide. Many people who work in central London, for example, commute to work from London's surrounding municipalities. Likewise, manufacturing plants that are located on the outskirts of a city could require workers to commute out. According to an administrative definition, such commuting workers would not live and work in the same urban area, whereas a functional definition avoids this bias. More generally, a sole focus on the central administrative unit of a city will underestimate the population size of an urban area, overestimate the density, and might over- or underestimate its productivity. The empirical analysis of this article therefore employs the Functional Urban Area (FUA) definition of cities (see section 2).

While it is possible to consider aggregate productivity at the FUA level, e.g. per worker GDP (Chart 2), the evident positive slope combines agglomeration economies with other sources of higher productivity in larger cities. Crucially, productivity in larger cities is higher because they tend to attract more skilled and productive workers. To disentangle the agglomeration component and this non-random sorting of skilled individuals, a two-step empirical approach is applied separately to national microdata surveys for the five countries in the study.[14] While it is possible to estimate agglomeration benefits directly in the microdata, the confidential nature of the datasets used would not allow pooling all 5 samples. Instead, the estimation is split into two parts, estimating productivity differences across cities in each country and then explaining these differences in a pooled sample based on city characteristics. An important caveat that remains despite the two-step estimation is that the sorting that can be taken into account is only the sorting of individ-

13 Much of the literature uses wages as a proxy for productivity. Under standard wage setting mechanisms, the marginal product of labour should be reflected in wages. Even if higher wages are offset by larger commuting and housing costs (from the perspective of the worker), if there were no productivity advantages in urban areas firms would move to low-wage locations.

14 See Combes *et al*. (2011) for a theoretical discussion of this methodology and Combes *et al*. (2008) for earlier implementations of the empirical methodology.

uals based on observable factors such as education or age.

In the first step, the functional EU-OECD definition of cities is matched with large-scale administrative or survey-based microdata of workers from each of the five countries. The resulting data sets are then used to estimate productivity differentials — net of individual skill differences and other individual level observables — across cities using an OLS regression of the natural logarithm of wages on individual level characteristics and a set of fixed effects for each city-year combination.[15]

$$y_{ia(c)t} = \beta X_{ia(c)t} + \gamma_{a(c)t} d_{ia(c)t} + \varepsilon_{ia(c)t} \quad (3)$$

$y_{ia(c)t}$ denotes the natural logarithm of wages for individual i in city a in country c at time t, X a vector of individual characteristics, d a vector of dummy variables (one for each city and year) that take the value 1 if the individual resides in city a at time t, and ε denotes an error term. The coefficient vector of interest, γ, captures the productivity differential across cities, net of (observable) skill differences.

Since the primary concern in this study is to create comparable estimates for all five countries (Germany, Mexico, Spain, United Kingdom, and United States), the specific controls that can be included are limited to the controls available in all five data sets. Not all variables are available in all countries and the different data sources include both panel data and repeated cross-sections. The common set of controls selected includes age (and its square to allow for decreasing returns to experience), education (dummies for degree categories), occupation (dummies for occupational categories), gender (dummy) and an indicator for part-time work (dummy) to account for possible level differences in wages of part time and full time workers, in addition to the city-year fixed effects.[16]

The city-year fixed effects obtained in the first step capture city productivity differentials, net of the observable skill-relevant characteristics of the urban workforce for each of the five countries (c). The estimated productivity differentials $\hat{\gamma}_{a(c)t}$ are used as the dependent variable in the second step, in which they are regressed on indicators for structural and organisational determinants of city productivity — both time varying $Q_{a(c)t}$ and non-time varying $Z_{a(c)}$. Additional country-year fixed effects d_{ct} control for time-fixed differences across countries, national business cycles and country specific inflation (the first step estimates nominal productivity differentials).

$$\hat{\gamma}_{a(c)t} = \delta Q_{a(c)t} + \mu Z_{a(c)} + \theta d_{ct} + \upsilon_{a(c)t} \quad (4)$$

The estimates are based on a balanced panel of all cities for the three years that are available for all five countries (2005-2007). The standard errors in the OLS estimations are clustered at the city level to allow for heteroscedasticity and arbitrary autocorrelation over time (for each city) in the error term.[17]

15 This model follows the seminal work by Mincer (1974) and the large body of empirical literature that followed it. The German data is right-censored, which introduces a bias in OLS estimation. However, comparing the results from a Tobit model, which accounts for censoring, and the OLS model shows that the bias is negligible (Ahrend and Lembcke, 2016).

16 Panel data are only available for three countries (Germany, Spain, and United Kingdom). The common specification can therefore not account for individual specific unobserved skill differences in the first step. While this would be an important improvement, it comes at a cost: identification of productivity differentials would only rely on individuals who move between cities, a group that is likely highly selected as mobility is costly (Combes *et al.*, 2011). In addition if agglomeration benefits are persistent (de la Roca and Puga, 2016), recent movers will have lower/higher productivity than the average comparable worker in the FUA if they moved from a smaller/larger FUA.

The two-step estimation accounts for selective sorting based on observable characteristics, but other aspects might influence productivity in cities, resulting in biased estimates. One concern is reverse causation, which could result in either upward or downward bias. For example, a positive productivity shock can result in increased job opportunities, attracting new residents to a city, which would result in an upward bias in the estimated agglomeration economies. One small step to reduce the possibility of reverse causality is a definition for Functional Urban Areas that is based an earlier time period (2001) than the estimated city-year productivity differentials (2005-2007), which ensures that potential changes in the boundaries of successful cities are not influencing the results.

To further reduce the potential confounding factors additional controls are introduced to the specification. These include a capital city and port city dummies[18] and indicators that capture the industrial and skill structure of cities, calculated from the five estimation samples. To capture the industrial structure, the indicators are the share of employees working in 1-digit industries, with manufacturing split into four categories based on technology intensity, and the Herfindahl index of employment shares at the 2-digit industry. The Herfindahl index is defined for each city as the sum of the squared employment shares in each industry.[19] For human capital, the share of university degree holders among the 25-64 year old workforce in the city is used. Summary statistics for each of the indicators are presented in Ahrend *et al.* (2014), which also includes further descriptions of the data sets.[20]

Results

As a benchmark, it is useful to put numbers to the suggestive trends for agglomeration economies in the descriptive graph of Section 2. Country-by-country regressions show productivity to be higher in larger cities across all five countries in this study. When city productivity differentials are regressed on city population, the estimated elasticities range from 0.015 (United Kingdom) to 0.063 (United States). That is, a worker in an U.S. city with a population that is 10 per cent larger than that of another comparable U.S. city is, on average, about 0.63 per cent more productive.[21] The main results from the pooled regression,

17 As the specifications include country fixed effects the standard errors should ideally be clustered at the country level. With 5 countries in the sample this is not feasible and spatial autocorrelation in the error could be a source of bias in the standard errors. In order to affect the statistical significance of the estimates, unobserved shocks to the productivity level in a city would have to be strongly correlated with shocks to nearby cities. While some correlation is undoubtedly present and possibly sizeable in some cases (e.g. the smaller FUAs surrounding London are benefitting from the capital's pull), the effect would need to be large in general to create concerns for the statistical significance of the key results presented here.

18 Port cities based on Lloyd's List "Ports" (http://directories.lloydslist.com/, accessed 01.07.2013).

19 Spain and Germany are exceptions. For Spain, internal OECD estimates for city population are used. For Germany, only total employment can be observed; after the results from the last German census, municipality level population data became unavailable. To estimate population in German FUAs the ratio of employment to population for 2000 (OECD estimates) is used to rescale the observed employment levels for all years.

20 Despite the additional controls, the specification remains the estimation of a partial equilibrium. In a general equilibrium, residents might be willing to accept lower productivity (and therefore wages) if they are compensated by lower cost of living or higher amenities (e.g. in the Rosen-Roback model; Roback, 1982). This might create a bias if larger cities are associated with higher (dis)amenities, resulting in (upward) downward biased estimates.

21 Interpreting the elasticity multiplied by 100 as the per cent increase in productivity associated with a "doubling in city size" is commonly used in the literature to give an idea of the size of the impact. The interpretation is not exact as the log-approximation error is only negligible for small changes. The exact marginal effect for a doubling in city size is the product of the estimated coefficient and the natural log of 2 (approximately equal to 0.693).

Table 3: Agglomeration Economies in Five OECD countries, 2005-07

	(1)	(2)	(3)	(4)	(5)	(6)
ln(population)	0.038***					
	(0.005)					
ln(density)		0.037***	0.048***	0.037***	0.034***	0.016**
		(0.006)	(0.006)	(0.007)	(0.007)	(0.007)
ln(area)		0.038***	0.064***	0.062***	0.058***	0.036***
		(0.006)	(0.008)	(0.009)	(0.010)	(0.008)
ln(number of municipalities)			-0.032***	-0.036***	-0.036***	-0.029***
			(0.006)	(0.006)	(0.006)	(0.005)
ln(pop. in catchment area)				0.018**	0.017**	0.012*
				(0.008)	(0.008)	(0.007)
% University Graduates				0.283***	0.258***	0.275***
				(0.077)	(0.075)	(0.073)
Capital				-0.011	-0.000	0.028
				(0.037)	(0.038)	(0.030)
Port				0.027**	0.027**	0.039***
				(0.011)	(0.011)	(0.010)
Herfindahl Index					-0.698*	-0.704***
					(0.358)	(0.266)
Agriculture						0.0808
						(0.257)
High-tech Manufacturing						1.104***
						(0.234)
Med. High-tech Manufacturing						0.840***
						(0.135)
Med. Low-tech Manufacturing						0.494***
						(0.146)
Low-tech Manufacturing						0.082
						(0.149)
Electricity						-0.931**
						(0.463)
Trade						0.223
						(0.171)
Catering						0.472**
						(0.230)
Transport & Communication						-0.126
						(0.200)
Finance						0.878***
						(0.181)
Real Estate & Business						0.410**
						(0.176)
Public Administration						0.057
						(0.261)
Educ., Health & Social Work						-0.120
						(0.154)
Other Services						0.535*
						(0.275)
R-Squared	0.760	0.760	0.779	0.791	0.794	0.854
Observations	1,290	1,290	1,290	1,290	1,290	1,290
FUAs	430	430	430	430	430	430

Note: Includes an interaction control of country and year fixed effects (Country x Year FE). ***/**/* indicates a statistically significant coefficient at the 1%/5%/10% level reported in Table 3, present equally strong evidence for sizeable agglomeration benefits.[22] They indicate that, a city with 10 per cent more residents is associated with 0.38 per cent higher productivity (specification 1).

The source of agglomeration economies can be further disentangled by a specification that uses both population density and surface area of the city. The coefficient of (the natural logarithm of) population density gives the elasticity of city productivity with respect to its population size, holding constant the surface area covered by the city. The coefficient on (the natural logarithm of) city surface area captures the impact of an expansion of city limits while population density remains constant; that is, when population and area expand at the same rate. Finally, the difference between the area and the density coefficients gives the estimated impact of increasing the surface area covered by a city while holding the total population constant (i.e. decreasing density with the given population spreading out over a larger surface).

Interestingly, coefficients for population density and area are similar (Table 3, specification 2), indicating that both an increased population for a given surface area, and an increased spatial extent, while population density remains constant, have similar productivity effects. However, an increase in the surface area — for a given population — does not increase productivity, as suggested by the difference of the two coefficients that comes to zero. The introduction of additional city characteristics as controls leads to estimated agglomeration elasticities ranging from 0.02 to 0.05, with highly statistically significant coefficients in all specifications (Table 3, remaining specifications). The number of municipalities within a city, a measure of administrative fragmentation, is negatively correlated with productivity. It indicates that between two cities of the same size, in the same country, if one has twice the number of municipalities within its functional boundaries it is on average about 2-4 per cent less productive.

Aggregate human capital, measured by the share of university graduates in the city, increases productivity. A 10 per centage point increase in the share of university graduates is associated with a 2.8 per cent increase in productivity. It is important to note that this result does not indicate the direct impact of human capital on productivity, but only the externality associated with working in a city with a large share of university graduates in the workforce. And, while port cities exhibit higher productivity — on average port cities are 2.7-3.9 per cent more productive than comparable cities without a port — there appears to be no evidence that capitals differ systematically from other cities.

Industrial specialization, measured by the normalized Herfindahl Index of employment shares at the 2 digit industry level, has a negative and weakly significant impact. This suggests that a diversified industrial structure has a positive impact on productivity. However, variation in estimates across specifications suggests that this finding is not overly robust.

Moreover, clear evidence can be found that cities with a large share of employees in specific industries exhibit higher productivity. The base category in the regressions is the share of employees in construction, such that when an increase in an industry share is considered, the share of employees in construction is reduced by the same amount. The results (specification 6 in Table 3) indicate that a 1 per centage point increase in the share of high-tech manufacturing workers (and a concomitant 1 per centage point decrease in the share of construction workers) is,

22 Pooling estimates has the advantage of creating a sizeable sample that allows the introduction of additional controls, the price for this advantage is that the estimated elasticity is assumed to be the same in each country.

on average, associated with 1.1 per cent higher productivity in the city. This productivity premium gradually reduces with the technological intensity of the manufacturing industry: it is 0.8 and 0.5 per cent for medium-high-tech and medium-low-tech manufacturing, respectively, while it becomes insignificant for low-tech manufacturing.

The productivity premium for financial intermediation is estimated at 0.9 per cent for a 1 per centage point increase in the employment share, while that of business services and real estate activity is 0.4 per cent. Interestingly, it is not only the knowledge-intensive services that yield a productivity premium, but also technology-intensive manufacturing.

The final variable considered to determine productivity is the proximity of a Functional Urban Area to other cities (population in the catchment areas). The variable aims to incorporate the idea that the exchange of people, ideas and goods is greatly simplified by close connections between places. The indicator measures the number of people that residents of a given city can directly interact with, within a "reasonable" amount of time, the idea being that a meeting of several hours can take place going back and forth within a day. It is defined as (the natural logarithm) of all inhabitants in other Functional Urban Areas within a 300 kilometre radius around a city, divided by the distance.

For the sample of all cities the estimates in Table 3 indicate that, ceteris paribus, a 10 per cent increase in the (distance weighted) number of city residents within 300km is associated with 0.1-0.2 per cent higher productivity. While this effect suggests that cities benefit from proximity to other urban agglomerations, it is unlikely to capture the full impact of the position of a city within its local network of cities and rural areas. For example, estimates by Partridge *et al.* (2009b) for the United States show that the impact on earnings differs for counties with cities of different sizes and that it is the distance to large agglomerations that create the strongest benefits, rather than general market potential.

Conclusion

This article provides cross-country estimates of agglomeration economies for functional urban areas that are independent of administrative boundaries. Using an internationally harmonized definition developed by the EU and the OECD allows pooling comparable FUAs from five OECD countries. We find strong support for the presence of agglomeration economies. Estimates indicate that for two comparable workers living in functional urban areas that differ by 10 per cent in terms of population size, productivity is, on average, between 0.2 per cent and 0.5 per cent higher for the worker living in the larger city. This effect is sizeable; it implies that a worker in the metropolitan area of Hamburg with 3 million inhabitants is expected to be 6-14 per cent more productive than a comparable worker in the functional urban area of Bayreuth which has less than 200 thousand inhabitants. Thus, the article provides an important addition to the existing literature on agglomeration economies, which generally provides estimates of similar magnitudes but study much narrower contexts.

Furthermore, the article highlights that the presence of large cities translated into higher regional growth over the 1995 to 2010 period. Regions that contain a city of at least 500,000 inhabitants experienced annual per capita growth rates that were approximately 0.2 per centage points higher than those of regions without cities of this size. Regions that contained cities of more than 2 million inhabitants even grew by 0.3 to 0.5 per centage points per capita and year more than those without cities of this size. The presence of big cities plays a role for regional growth even if cities are some distance away. Among regions that do not contain a large functional urban area with more than 2 million inhabitants, those that are closest to one (typically within 45 to 60 minutes by car) grew the fastest. Each doubling of travel time reduces average regional per capita GDP growth by 0.2 per centage points per year.

More generally, the article demonstrates the important role that cities play in determining productivity and economic prosperity not just for their own residents, but also far beyond their boundaries. By concentrating economic activity in space, cities increase the productivity of their residents and make it possible to provide specialized services that would not be economically viable otherwise. Surrounding regions benefit from these services. Due to this influence, cities matter for the economic performance of large regions and helping cities to achieve strong economic performances can benefit the entire country.

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