

Transport investment, agglomeration and urban productivity.

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Abstract. This paper is concerned with the links between city size, productivity and infrastructure provision. The role of transport infrastructure in sustaining productivity is notoriously hard to isolate empirically due to the inter-dependent nature of the relationship which create problems of simultaneity bias. In this paper we show that transport investment can have an important influence on productivity by increasing the effective density of people and jobs within a given distance. We estimate elasticities of productivity with respect to city size for different industrial sectors. Empirical work is based on the estimation of translog production functions for detailed sectors of the UK economy using data on UK firms.

I. Introduction

This paper is concerned with the link between city size and productivity. It provides a quantitative assessment of this relationship for different sectors of the UK economy. The motivation for exploring this theme is to identify if there might be any external benefits that arise from the provision of transport infrastructure that are not included in standard transport appraisals. Specifically, we investigate whether there is an association between the density of urban and industrial activity, or in other words the density of people and jobs, and levels of productivity. This theme is important in assessing the benefits of transport investment for two reasons. First, because ultimately transport investment is crucial in sustaining cities and supporting urban agglomerations and these in turn may provide external benefits to the economy; second, because it is clear that a change in the level of transport infrastructure in any area of Britain will typically change the effective density of people and jobs that are accessible to the economy of that area with associated implications for productivity and efficiency.

Venables (2003) has shown that estimates of the elasticity of productivity with respect to city size can be used to shed light on the external benefits of transport improvements. He develops a computational model of an urban economy that links productivity to transport investment via effects on city size. His objective is to distinguish the real income changes that result from transport investment due to a productivity-city size effect, from those economic benefits that are captured in standard transport appraisal and which arise from resources saved in commuting and from an increase in urban output.

An outline of Venables' model is given in figures 1 to 3. Figure 1 shows an urban equilibrium in which the size of the city is determined at point E , where the wage gap between

city workers and non-city workers is entirely dissipated in the travel costs of the city worker who is most distant from the CBD.

Figure 2 shows that when a transport improvement is made commuting costs are shifted downwards and consequently the city expands to point E^* . The increase in the output of the urban economy is area $\beta + \gamma$. Note that since productivity is higher in the city by an amount equal to the height of the wage gap (WW), if workers transfer from outside the city to inside they are more productive. The total change in the resources used in commuting is $\gamma - \alpha$, which combined with the change in output ($\beta + \gamma$), yields a benefit (real income gain) from the transport improvement of $\alpha + \beta$.

In figure 3 Venables considers the implications of the existence of a city size - productivity gradient. If, as the literature suggests, larger cities have higher productivity the productivity gap is now expressed as a concave curve that increases with city size. Equilibrium is found at the intersection of the commuting cost and wage gap curves. The fact that productivity is non-constant with respect to city size means that the real income gain from a transport improvement is $\alpha + \beta + \delta$, where δ measures the increase in productivity experienced by city workers and is akin to a measure of the elasticity of productivity with respect to city size.

As Venables points out, the additional benefit δ is the effect that would be missed by a standard transport appraisal. Estimates of δ do exist, but they tend to be exclusively for manufacturing industries. The purpose of this paper is to quantify δ for detailed sectors of the economy to show the extent to which the city size productivity effect is prevalent. Specifically, we estimate elasticities of productivity with respect to a measure of the effective density of jobs and people. We estimate the magnitude of these values for different industrial sectors.

The paper is structured as follows. Section two discusses the literature on agglomeration productivity and transport investment. Sources of data used in the analysis are described in section three. The estimation model is next discussed in section 4. Estimation results are presented in section five. Conclusions are drawn in the final section.

II. Agglomeration productivity and transport investment.

Agglomeration and productivity

The tendency towards concentration or agglomeration is perhaps the most widely observed feature of the spatial organisation of economic activity. It can be discerned across the Globe at a variety of different geographical levels. Agglomeration is evident, for instance, in the existence and growth of cities, in the formation of industrial regions and districts, and in the clustering of like activities within the same neighbourhood of a town or city. The theory of agglomeration economies is based on the premise that the tendency towards spatial concentration is caused by the existence of positive externalities that are generated through close spatial proximity and that serve to raise the efficiency of firms.

The externalities generated through agglomeration are traditionally categorised under three headings.

Internal scale economies describe efficiency gains that occur as the overall scale of production is increased. With respect to agglomeration, the crucial assumption regarding internal scale economies is that they are internal at the plant level and therefore imply production at a single location rather than being spread across a number of locations.

Localisation economies describe efficiency gains generated through the increased scale of a particular industry operating in close spatial proximity. Benefits are thought to be generated in three ways: through ‘technological spillovers’ between firms within the same industry, through the efficient provision of intermediate inputs to firms in greater variety and at lower cost due to the growth of subsidiary trades, and through the sharing of larger markets for inputs and outputs and in particular they can share a local skilled labour pool. Localisation economies are intra-industry; they are external to firms but internal to the industry.

Urbanisation economies describe the productive advantages that accrue to firms through location in large population centres such as cities. Firms derive benefits from the scale of markets, from the proximity of market areas for inputs and outputs, and from good infrastructure and public service provision. These spatial external economies are cross-industry; they are external to the firm and the industry but internal to cities.

The empirical literature on the link between agglomeration and productivity has been comprehensively reviewed in previous surveys by Rosenthal and Strange (2004), Eberts and McMillen (1999), Henderson (1988), Gerking (1994), and Moomaw (1983a). Here we briefly summarise some of the main results on the magnitude of estimated values of the effects of agglomerate economies on productivity

Econometric studies of the effects of agglomeration on productivity have been conducted almost exclusively for manufacturing industries. Table 1 provides a summary of results from the literature relating to the effects of agglomeration on productivity. We summarise here those studies that have produced an actual elasticity estimate of the effects of agglomeration rather than those that have detected agglomeration effects through the use of dummy variables or other limited variable methods.

Table 1: Estimates of agglomeration economies from production function analyses.

Author	unit of analysis	dependent variable	independent variable	elasticity
Aaberg (1973)	Swedish cities	productivity	city size (population)	0.02
Shefer (1973)	US MSAs	productivity	RTS at MSA aggregation	0.20
Sveikauskas (1975)	US MSAs	productivity	city size (population)	0.06
Kawashima (1975)	US MSAs	productivity	city size (population)	0.20
Fogarty and Garofalo (1978)	US MSAs	productivity	city size (population)	0.10
Moomaw (1981)	US MSAs	productivity	city size (population)	0.03
Moomaw (1985)	US MSAs	productivity	city size (population)	0.07
Nakamura (1985)	Japanese Cities	productivity	city size (population)	0.03 ^a
Tabuchi (1986)	Japanese Cities	productivity	city size (population)	0.04
Louri (1988)	Greek Regions	productivity	city size (population)	0.05
Sveikauskas et al (1988)	US MSAs	productivity	city size (population)	0.01 ^b
Nakamura (1985)	Japanese Cities	productivity	industry size (employment)	0.05
Henderson (1986)	Brazilian Cities	productivity	industry size (employment)	0.11 ^c
Henderson (1986)	US MSAs	productivity	industry size (employment)	0.19 ^d
Henderson (2003)	US MSAs	plant output	industry size (no. of plants)	0.03 ^e
Ciccone and Hall (1996)	US States	productivity	employment density	0.06
Ciccone (2002)	EU regions	productivity	employment density	0.05

Notes: a - mean value for 14 industries, b - mean value from 5 model specifications, c - mean value for ten industries, d - mean value for 9 industries, e - mean value for 4 model specifications.

With the exception of Shefer (1973) regressions use metropolitan population as a proxy for city size within a basic production function framework. The availability of capital stock data at the metropolitan level has exerted a big influence on the functional form used for estimation¹. Early studies were typically based on either the Constant Elasticity

¹ The studies by Aaberg (1973), Kawashima (1975), and Moomaw (1981) proxy capital using measure of non-labour income, those by Fogarty and Garofalo (1978) and Sveikauskas et al (1988) create capital data through the perpetual inventory method, while those by Sveikauskas (1975), Moomaw (1985) and Louri (1988) derive estimating equations which avoid the need for capital data altogether.

of Substitution (CES) function (e.g. Shefer 1973, Sveikauskas 1975, Moomaw 1981) or the Cobb-Douglas (CD) (e.g. Aaberg 1973, Kawashima 1975, Fogarty and Garofalo 1978). More recent estimates are based on flexible functional forms such as the translog (e.g. Nakamura 1985, Henderson 1986, Tabuchi 1986, Louri 1988, Sveikauskas et al 1988).

The estimates of urbanisation economies range from 0.01 to 0.20, but the majority of values are under 0.10. This indicates that a doubling of city size is typically associated with an increase in productivity of somewhere between 1% and 10%. The estimates given in the table above are all positive although Henderson (1986, 2003a) does report difficulties in identifying urbanisation effects on productivity.

It is worth pointing out that of the studies shown in table 1 only those by Henderson (1986, 2003a) and Nakamura (1985) treat urbanisation and localisation economies within the same estimating equation. They are able to do this by estimating an industry level production function for some particular industrial sector in contrast to the other studies of urbanisation where estimation is based on an aggregate function for all manufacturing.

Table 1 shows four estimates of localisation economies. Nakamura (1985) estimates the effect of localisation economies on the productivity of 20 manufacturing industries. He quotes unweighted average elasticity of productivity with respect to industry size of 0.05. This compare to an average city size elasticity of 0.03 and thus Nakamura concludes that the effects of localisation tend to be more significant than those of urbanisation.

Henderson (1986) also finds weak evidence of urbanisation economies using industry level data for US MSAs and Brazilian cities but does find substantial evidence of localisation economies. His estimates of localisation economies for Brazil vary by industry, with a maximum elasticity estimate of 0.20 and a minimum of 0.03, the mean value over 10 industries is 0.11. For US MSAs Henderson (1986) again finds substantial evidence of localisation with a range in estimated elasticities of 0.09 to 0.45 for selected industries and a mean value of 0.19. He concludes that economies of agglomeration tend to be ones of localisation not urbanisation and that localisation economies tended to be strongest in the sectors in which cities specialise but that they diminish as city size increases. Henderson (2003a) finds similar results. He estimates plant level production functions for high-tech and machinery industries in the US using a variable recording the number of own industry plants to test for localisation economies. He finds that localisation effects are strong for high tech industries but not for machinery.

In addition to studies using MSA population and employment to construct variables representing city and industry size there are those that have incorporated some measures of distance or density into the specification of agglomeration effects. Two recent papers are particularly interesting in this respect.

First, is the study of state level labour productivity and the density of economic activity by Ciccone and Hall (1996). They develop two spatial economic models; one based on the neo-classical conception that density can affect productivity through local geographi-

cal externalities, another which emphasises diversity of intermediate services where spatial density gives rise to aggregate increasing returns. From these models they derive an equation to estimate the effects of county-level employment density on aggregate state productivity. They find that over 50% of the variance in aggregate labour productivity across states can be explained by variance in the density of employment and that a doubling of employment density is associated with a 6% increase in average labour productivity. Ciccone (2002) extends the analysis to European data and estimates an elasticity of labour productivity with respect to employment density of 0.045.

Second, is the paper by Rosenthal and Strange (2003) which used distance based measures at the establishment level to test for the extent of geographical externalities. Using the zipcode of the establishment as a centroid they construct distance rings at 1 mile, 5 miles, 10 miles and 15 miles. For the six industries they study that find that localisation economies are present but that the strength of these decreases rapidly across space and substantially even within a five mile radius of the plant. Regarding urbanisation economies they identify relatively small and inconsistent effects.

Density and distance based measures have been used by other researchers. Fogarty and Garofalo (1988) estimate a production function with a vector of agglomeration effects that includes manufacturing employment density. They show that density has a strong positive non linear effect on productivity and that a change in spatial distribution of the density of industry may affect productivity substantially. Henderson et al (1995) estimate a growth model which finds externalities positively associated with own industry employment concentration. Hansen (1990) estimates a production function with distance based agglomeration measures to explore the trade off between factor costs and productivity in the Sao Paulo region of Brazil. He finds that productivity is enhanced by agglomeration as represented by distance to the centre of Sao Paulo but that there is a trade off because costs diminish with distance. Hanson (1996a, 1996b, 1997) explores relationships between agglomeration, productivity and wages for the garment sector of Mexico City. His data support the existence of localisation economies and show that regional wages decrease by distance from the centre of Mexico City. Duranton and Overman (2002) develop distance based tests of localisation for the UK. They find that 51% of 4 digit industries are genuinely localised at an acceptable statistical level and that localisation takes place at small scales, mostly below 50 kilometres.

The role of transport investment.

In terms of agglomeration public infrastructure can be treated as an unpaid factor of production. Positive spatial externalities exist when an urban area provides an input that lowers costs for firms. If costs are lowered for only one industry we have localisation economies. If costs are lowered for all firms we have urbanisation economies.

Eberts and McMillen (1999) cite two bodies of literature; one that is concerned with the impact of agglomeration on productivity, and one that is concerned with the impact of infrastructure provision on productivity. Analytically these two topics have remained largely distinct, due in part to difficulties in constructing adequate data on public infrastructure at the metropolitan level.

A number of studies have estimated the impact of infrastructure investment on productivity at the national or state levels. (see Gramlich 1994, Holtz-Eakin 1994, Fernald 1999, Rovolis and Spence 2002 for reviews of this literature). Some authors have found positive effects on productivity from public infrastructure provision (e.g. Aschauer 1987, 1988, 1989, 1990, Munnell 1990a, 1990b, Lynde and Richmond 1992, 1993a, 1993b, Seitz 1993a, 1994, 1995), other are more sceptical (e.g. Hulten and Schwab 1991, Holtz-Eakin 1993a, 1993b, 1994, Garcia-Mila et al 1996).

In fact disagreement within the literature tends to focus on methodological approaches and particularly on the treatment of endogeneity. Holtz-Eakin (1993a, 1993b, 1994), for instance, contends that studies by Aschauer (1987, 1988, 1989, 1990) and Munnell (1990a, 1990b), which found positive effects on productivity from public infrastructure provision, have not dealt effectively with simultaneity bias arising from the fact that more productive regions tend to have larger output and greater income and consequently spend more on public infrastructure. In other words, Holtz-Eakin believes that the direction of causality is unclear and finds that with the use of methods to circumvent the simultaneity bias, public sector capital is found to have no effect on output (Holtz-Eakin 1994). In contrast, a recent paper, Fernald (1999) finds that changes in roads are associated with larger changes in productivity growth in US industries that are more vehicle intensive. Fernald (1999) rejects the hypothesis that causation runs from prosperity to roads on the basis that this would not leave any particular relationship between an industry's vehicle intensity and its productivity performance.

At the national and regional level it is fair to say that the empirical findings on the role of infrastructure from the production and costs function analyses are inconclusive.

There are some studies that have analysed the productivity effect of infrastructure at the urban level, but have not incorporated the influence of agglomeration economies. Eberts (1986) estimates public capital stock data for US MSAs using the perpetual inventory method. He then analyses the effect of public capital stock on the manufacturing output of US MSAs. He estimates an elasticity of output with respect to public capital stock of 0.03. Dalenberg (1987) using the same MSA capital stock data finds that a 10% increase in capital stock is associated with a 2% decrease in manufacturing costs. Deno (1988) again using the same data, finds that manufacturing output responds strongly to public capital: the output elasticities of water, sewer and highway infrastructure are 0.08, 0.30 and 0.31.

Thus, it would seem that infrastructure provision is associated with positive spatial externalities. However, as Eberts and Mcmillen (1999) point out, there are at least two good reasons for analysing agglomeration effects on productivity together with infrastructure in a single analysis. First, if it is the case that public infrastructure per capita is higher in larger cities then the omission of an infrastructure variable from an estimating equation could bias estimates of agglomeration economies upwards, and vice versa. Second, without adequate public infrastructure the benefits of agglomeration could be entirely offset by diseconomies of congestion, and consequently, cities of identical size could experi-

ence different effects on productivity from agglomeration due to the level of provision and quality of public infrastructure.

There are a small number of studies that have included measures of both agglomeration and public infrastructure simultaneously in an analysis of productivity. Moomaw (1983b) includes variables measuring transportation infrastructure in his analysis of the effects of agglomeration on productivity. He finds that public infrastructure has a positive effect on productivity and that its addition to the estimating equation only marginally reduces the magnitude of the agglomeration effect. Seitz (1993b) estimates the effects of agglomeration economies and public infrastructure investment on productivity. He estimates a cost elasticity of public infrastructure of -0.127.

More recently, Holl (2004a, 2004b) has looked at the effects of agglomeration economies and the provision of transport infrastructure on the location of new firms and firm birth. Using data on Spanish municipalities she finds that new firms do prefer location close to motorways but that effects on the spatial distribution of manufacturing differs across sectors and space. Using Portuguese firm birth data for 13 manufacturing and 9 service sectors she finds locations near motorways are associated with higher geographic firm birth concentrations, but that again this varies by sector. Regarding agglomeration, she finds firm birth encouraged by a diversified local economy but no evidence of agglomeration economies stemming from sectoral specialisation at the local level.

Haughwout (1999) takes a different view about the effects of infrastructure on agglomeration. He argues that the provision of public infrastructure outside of dense economic areas can serve to reduce the agglomeration economies available there because it can induce the decentralisation of employment. His empirical work supports this hypothesis showing that the provision of new infrastructure tends to redistribute employment growth from areas of dense employment to other parts of the state. On this basis he asserts that public infrastructure provision in decentralised locations can diminish the agglomeration benefits offered by cities. But this argument uses a restrictive definition of density based on geographical area rather than travel times. An alternative view would be that the provision of public infrastructure increases the temporal proximity of a larger scale of economic activity. In effect, it increases the size of the city, and if city size counts for productivity, then it also increases the agglomeration benefits available at the locations connected by the infrastructure.

III. Data.

For the research undertaken here we need data with detailed geographical and sectoral disaggregation and in particular we need a good coverage of the service industries. The only data we have found that matches these requirements are the firm level data of registered UK companies. Under UK legislation each registered company is required to provide accounting and other data about their operations to an executive agency of the Department of Trade and Industry know as Companies House. These data are made available in a commercial software package called Financial Analysis Made Easy (FAME), which is produced jointly by Jordans and Bureau Van Dijk. The FAME data record ex-

tensive financial information for each company including information on the production and costs characteristics of companies that will allow us to empirically estimate a production function.

The FAME data are concerned with companies not plants, and consequently any one company reporting can have plants at a number of different locations. For our purposes we want to have a sample of companies that only produce from one location since it is the effect of location on productivity that is of primary interest. For each company the FAME data do provide information both on the registered office address and on a variety of addresses that the firm trade from.

To isolate single plants firms from the FAME data we have take the following steps. First, we remove firms that record more than one UK trading address. Second, we remove firms that have a registered office address that is different from their main trading address. Third, we keep only those firms that do not have a UK or foreign holding or subsidiary company. Fourth, as a further precaution, we have removed large firms from the data because these could record all of their information from one UK registered office address, typically their headquarters, but not provide information about other plants they may have located in different areas of the UK or the World. Our sample is based on firms that have less than 100 employees.

In addition to the firm level commercial data we make use of official government data to represent urbanisation and localisation effects. The Annual Business Inquiry (ABI) provides information on the number of jobs by industry for a variety of geographical bases including wards. These data can be used to represent city size and industry scale. The ABI data are the most detailed industrial and geographical economic data available for Britain. These data give the number of employees in employment broken down by the 1992 SIC (defining up to 504 industrial sectors). We also use population data provided by the Office for National Statistics (ONS) to represent the density of people within Britain.

IV. The model

The translog production function

We model the effects of agglomeration economies within the framework of a production function. The production function for the firm is

$$Y = g(z)f(X) , \tag{1}$$

where Y is the output level of the firm, X is a vector of factor inputs with elements X_i ($i = 1, \dots, n$), and $g(z)$ is a vector of influences on production which are Hicks' neutral in nature including those that arise from the firm's 'environment' such as agglomeration economies.

If inputs are rented in competitive markets then the first-order conditions for output maximisation subject to an expenditure constraint are

$$\frac{\partial Y}{\partial X_i} = \lambda W_i, \quad (2)$$

where W_i is the price of the i^{th} input, and λ is a Lagrange multiplier which is the reciprocal of marginal cost $\partial C / \partial Y$. The expenditure constraint is given by,

$$\sum_i W_i X_i = C, \quad (3)$$

where C is total cost.

From (2) and (3)

$$\lambda = \frac{\sum_i (\partial Y / \partial X_i) X_i}{C} \quad (4)$$

and substituting (4) back into (2) after rearrangement yields the inverse input demand equations

$$\frac{W_i}{C} = \frac{\partial Y / \partial X_i}{\sum_i (\partial Y / \partial X_i) X_i} \equiv g_i(X). \quad (5)$$

Note that these inverse input demand functions determine prices as functions of quantities as opposed to ordinary demand functions which determine quantities in terms of prices.

Equation (5) can be written in cost share form (S_i^C) as

$$S_i^C = \frac{W_i X_i}{C} = \frac{\partial \ln Y / \partial \ln X_i}{\sum_i \partial \ln Y / \partial \ln X_i}. \quad (6)$$

The production function described in equation (1) can be represented by a translog approximation.

$$\ln Y = \alpha_0 + \sum_{i=1}^i \alpha_i \ln X_i + \frac{1}{2} \sum_{i=1}^i \sum_{j=1}^i \gamma_{ij} \ln X_i \ln X_j. \quad (7)$$

Given (6) appropriate differentiation of (7) yields the cost share equations.

$$S_i^C = \frac{\alpha_i + \sum_j \gamma_{ij} \ln X_j}{\sum_i \alpha_i + \sum_i \sum_j \gamma_{ij} \ln X_j}. \quad (8)$$

The translog parameters can be efficiently estimated by simultaneously estimating (7) and (8) as a nonlinear multivariate regression system.

The specification of agglomeration economies

As discussed in the literature survey chapter of this report, previous research has typically used total metropolitan population or employment to provide an empirical measure of city size and total metropolitan employment in some industry i to represent the size of that industry.

Such simple measures of agglomeration are not available for Britain. As noted above, there are no good sources of data for British metropolitan areas and the aggregate data that do exist are for administrative areas that do not readily correspond to ‘cities’. Perhaps more importantly it could be argued that in a small island country such as Britain it is hard to define distinct metropolitan areas. For instance, while Greater Manchester and Liverpool are nominally two separate cities, there is interaction between the two over relatively small distances that arguably prevents them from being truly distinct. Likewise it is conceivable that a firm located outside the London conurbation can still enjoy agglomeration benefits through proximity that arise from the scale of London and its industries. The point is that in a small country like Britain we can legitimately ask where the actual influences from urban centres ends.

For this reason we model agglomeration economies using measures that incorporate both proximity and the scale of economic activity and that can be calculated for very small areas throughout the country. Specifically, we use ward level employment and population data to construct a measure of accessibility experienced by each firm in the FAME data.

The urbanisation experienced by any firm in industry o located in ward i is given by

$$g(\cdot) = \beta_a \log \left(\frac{P_i + E_i}{\left[\sqrt{(A_i/\pi)} \right]^{\alpha_o}} + \sum_j^{i \neq j} \left([P_j + E_j] \cdot d_{ij}^{-\alpha_o} \right) \right), \quad (9)$$

where P_i is total population in ward i , A_i is the area of ward i , P_j is total population in ward j , and d_{ij} is the distance between i and j . The value of α^o determines the effect of distance on the strength of externalities for each industry o .

V. Results.

The translog estimations are conducted for 20 industry groups consisting of 8 service activities and 12 manufacturing activities. The service activities investigated are

1. Finance & insurance (SICs 65, 66 and 67)
2. Real estate activities (SIC 70)
3. Computer and related activities (SIC 72)
4. Business and management consultancy activities (SIC 7414)

5. Architecture and engineering activities (SIC 742)
6. Advertising (SIC 744)
7. Labour recruitment and provision of personnel (SIC 745)
8. Motion picture and video activities, radio and television (SICs 921 and 922).

The manufacturing industries are

1. Manufacture of food products and beverages (SIC 15)
2. Manufacture of textiles, wearing apparel, dyeing and dressing of fur (SICs 17 and 18)
3. Manufacture of wood and wood products (SIC 20)
4. Manufacture of pulp, paper and paper products (SIC 21)
5. Publishing, printing and reproduction of recorded media (SIC 22)
6. Manufacture of chemical and chemical products (SIC 24)
7. Manufacture of rubber and plastic products (SIC 25)
8. Manufacture of basic metals and fabricated metal products (SICs 27 and 28)
9. Manufacture of office machinery and computers (SIC 30)
10. Manufacture of radio, television and communication equipment (SIC 32)
11. Manufacture of medical, precision and optical instruments, watches and clocks (SIC 33)
12. Manufacture of motor vehicles and transport equipment (SICs 34 and 35)

The choice of manufacturing industries has been made largely on the basis of data availability; we have excluded industries for which we have an insufficient number of firms for estimation. For services, we have excluded sectors such as retail, education, health, and public administration which are less interesting from the point of view of agglomeration.

Results for service industries are shown in table 1 below. For brevity we here present only the elasticity results relating to the agglomeration term (β_a). The full set of production estimates are reported in Graham (2005).

Table 1: Estimates of the elasticity of output with respect to agglomeration externalities for service sectors from translog functions.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
β_a	0.294** (0.021)	0.084** (0.033)	0.072** (0.023)	0.176** (0.033)	0.244** (0.061)	0.353** (0.045)	0.125* (0.063)	0.477** (0.172)

The estimates shown in table 1 indicate strongly that there is a positive association between proximity to agglomeration of people and jobs and higher productivity. Estimates range from 0.072 to 0.477. The strongest effects are found in motion picture video & TV activities (8), advertising (6), finance and insurance (1), and architecture and engineering (5). Weaker, but still positive and significant effects are found in real estate activities (2), computer activities (3), and labour recruitment (7).

It may be that the services with smaller accessibility coefficients tend to be those that have broadly homogenous functions across different types of locations. It is worth noting that since we have no information on the particular function of firms, or on the skill characteristics of the labour inputs of firms, it is not unreasonable to suppose that service activities in more urbanised locations tend to have higher productivity simply because they are specialised in higher value added functions which tend to be more productive. For instance, we can compare the global financial activities that take place in the City of London with the type of high street banking activities that will take place in any small town. In fact a general characteristic of service sector agglomeration in Britain is that it tends to feature most strongly amongst non-basic service activities, or those services that are traded, while those that are consumed locally will tend to be spatially dispersed. These tradeable services also tend to be unevenly distributed across the urban hierarchy, existing disproportionately in and around large cities of Britain.

For manufacturing sectors we found that the accessibility index performs poorly. For many sectors sample are relatively small and this may mean that there is inadequate variance to detect agglomeration effects. For this reason, we decide to pool the industry data and estimate a Cobb-Douglas equation using dummy variables to distinguish our separate industry groups. We hypothesise that these dummy variables will capture a variety of industry specific differences that give rise to variation in productivity including differences in RTS. We use the Cobb-Douglas form here because for some sectors we have insufficient cost data to estimate the full translog system. The estimating equation is

$$\ln \frac{Y}{L} = D + \beta_a \log \left(\frac{P_i + E_i}{[\sqrt{(A_i/\pi)}]^{a_0}} + \sum_j^{i \neq j} ([P_j + E_j] \cdot d_{ij}^{-a_0}) \right) + \beta_K \ln \left(\frac{K}{L} \right) + (\beta_K + \beta_L - 1) \ln L + \varepsilon. \quad (10)$$

where in addition to variables already defined D is a matrix of dummy variables that differentiates by industry type, K is capital input and L is labour input..

Results are presented in table 2 below.

Table 2: Cobb-Douglas estimates for manufacturing firms with a single accessibility measure of agglomeration.

<i>SIC15</i>	3.701**	(0.445)
<i>SIC1718</i>	3.376**	(0.453)
<i>SIC20</i>	3.564**	(0.448)
<i>SIC21</i>	3.291**	(0.451)
<i>SIC22</i>	3.292**	(0.455)
<i>SIC24</i>	3.457**	(0.450)
<i>SIC25</i>	3.249**	(0.451)
<i>SIC2728</i>	3.249**	(0.447)
<i>SIC30</i>	3.366**	(0.452)
<i>SIC32</i>	3.401**	(0.452)
<i>SIC33</i>	3.148**	(0.449)
<i>SIC3435</i>	3.473**	(0.449)
β_k	0.609**	(0.011)
$(\beta_k + \beta_L - 1)$	-0.005**	(0.011)
β_a	0.105**	(0.031)
R^2	0.581	
n	2331	

The dummy variables for industry group are all significant at 1% confirming the need to differentiate the data in this way. The estimate of $(\beta_k + \beta_L - 1)$ is statistically insignificant indicating that we cannot reject the hypothesis that there are CRS. Thus, the elasticity of output with respect to capital is 0.609 and the elasticity of output with respect to labour is 0.391. The coefficient associated with the accessibility agglomeration variable is positive and significant at the 1% level. Across our sample, holding factor inputs and industry specific effects constant, we find that a 10% increase in the effective density of people and jobs available to the firm is associated with a 1.05% increase in productivity. Thus, even for the manufacturing sectors, using a single accessibility measure, we find evidence of agglomeration or density externalities.

The accessibility measure we have used here is a composite of population and employment; it measures the density of people working and living in proximity to each firm. In theory we could attempt to identify the separate effects that employment and population have simultaneously on firm productivity but we found that the variables are so highly correlated that it is not possible to accurately estimate the individual elasticities.

Instead, we re-ran the regressions twice using, first, a single accessibility measure based only on employment, and second, a single accessibility measure based only on population. The results shown in tables 3 and 4.

Table 3: Estimates of the elasticity of output with respect to agglomeration externalities for service sectors from translog functions with:

a) a single employment based accessibility measure of agglomeration

b) a single population based accessibility measure of agglomeration.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
β_E	0.235** (0.016)	0.076** (0.027)	0.050** (0.019)	0.160** (0.027)	0.202** (0.049)	0.285** (0.036)	0.107* (0.050)	0.404** (0.136)
β_P	0.337** (0.027)	0.085* (0.039)	0.092** (0.026)	0.176** (0.039)	0.269** (0.071)	0.404** (0.053)	0.140 (0.077)	0.503** (0.200)

Table 4: Cobb-Douglas estimates for manufacturing firms with:

a) a single employment based accessibility measure of agglomeration

b) a single population based accessibility measure of agglomeration.

<i>SIC15</i>	3.960**	(0.360)	3.680**	(0.470)
<i>SIC1718</i>	3.636**	(0.367)	3.355**	(0.478)
<i>SIC20</i>	3.825**	(0.363)	3.544**	(0.473)
<i>SIC21</i>	3.552**	(0.365)	3.269**	(0.476)
<i>SIC22</i>	3.549**	(0.370)	3.276**	(0.480)
<i>SIC24</i>	3.719**	(0.365)	3.435**	(0.476)
<i>SIC25</i>	3.511**	(0.365)	3.228**	(0.476)
<i>SIC2728</i>	3.511**	(0.361)	3.228**	(0.473)
<i>SIC30</i>	3.627**	(0.367)	3.346**	(0.477)
<i>SIC32</i>	3.662**	(0.367)	3.380**	(0.477)
<i>SIC33</i>	3.409**	(0.364)	3.127**	(0.475)
<i>SIC3435</i>	3.734**	(0.363)	3.452**	(0.474)
β_k	0.608**	(0.011)	0.609**	(0.011)
$(\beta_k + \beta_L - 1)$	-0.005	(0.011)	-0.006	(0.011)
β_E	0.094**	(0.027)	-	-
β_P	-	-	0.109**	(0.034)
R^2	0.581		0.581	
n	2331		2331	

The results for both services and manufacturing show consistently higher elasticities for all industries when we based our accessibility measure on population rather than on jobs. Estimates based on a composite measure given in tables 1 and 2 are midway between the employment and population based estimates given in tables 3 and 4. Ward population tends to be more dispersed across the wards than employment. The standard deviation of ward values for employment is twice the mean value while the standard deviation of ward values for population is only three quarters of the mean value. Therefore, it may be that ward population is able to capture a broader measure of ‘activity’ and for that reason can produce a more general accessibility index.

We have seen from estimates based on our single accessibility measures that there appear to be positive agglomeration, or density, externalities for service sector and manufacturing firms. One important issue that is that we have not able to control for the particular function of firms or for the skill characteristics of the labour inputs of firms. We have classified our firms according to the SIC, but yet we know that data classified by industry may not contain homogenous activities. Firms differ in the functions they perform, even within the same detailed SIC, and there is evidence to show that this ‘functional specialisation’ is related to city size For instance, Duranton and Puga (forthcoming), show that while the largest cities tend to specialise in functions related to business services and management, smaller cities tend to specialise in production based activities. Rice and Venables (2004), analysing earnings in relation to productivity at the NUTS3 level, find that occupational structure is positively correlated with productivity and therefore that areas with higher productivity also tend to have employment structures in high paying occupations².

Therefore, it is legitimate to ask whether we have identified real productivity differences between homogenous firms due to agglomeration externalities, or whether instead we have found a kind of ‘functional gradient’ with firms in the most urbanised locations performing different and more productive types of activities. This is, however, a very difficult question to address empirically. We do not have information on the functions our firms perform or on the occupational structure of their workforces. What we do know is that if there is a ‘functional gradient’ it is likely to be at a maximum in London. It may therefore be informative to extract London firms from our sample and see how estimates change with London excluded.

Tables 5 and 6 show results for service and manufacturing firms, excluding those with a London location based on the single accessibility measure of agglomeration (equation 9).

Table 5: Estimates of the elasticity of output with respect to agglomeration externalities for service sector firms outside London from translog functions with a single accessibility measure of agglomeration.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
β_a	0.216** (0.047)	-0.007 (0.069)	0.166** (0.047)	-0.037 (0.071)	0.269* (0.136)	0.351** (0.099)	0.256* (0.130)	-0.023 (0.228)
n	1165	882	1590	413	224	208	187	59

For five of our eight service sectors we are still able to identify a positive density externality in the data having excluded London from the sample. For sector (1), financial and business services, the estimate is smaller than that obtained using the full sample, 0.22 compared to 0.29, but still relatively large. For industries (3) and (7), which are computer

² Rice and Venables (2004) go on to analyse relationships between proximity to economic mass and the productivity and occupational components of variation in average earnings. Interestingly they find a robust relationship between productivity and proximity to economic mass but not between occupational composition and proximity to economic mass.

activities and labour recruitment and personnel, we actually obtain higher estimates using the sample that excludes London. The large difference for computer activities, 0.17 compared to 0.07, is surprising, but possibly reflects the agglomeration of this industry in the South East region (excluding London) which has the highest location quotient for this sector of all British regions (LQ = 1.78). The difference for labour recruitment is also high, 0.256 compared to 0.125, but the data do not give any indication as to why this may be the case. Industries (5) and (6), architecture and engineering and advertising, have estimates of roughly the same order of magnitude using either the full sample or that excluding London.

Estimates for industries (2), (4), and (8) - real estate, business and management services, and motion picture and TV - are insignificant when London is excluded from the sample. In the case of industry (8) the sample is so small when London is excluded that we it becomes difficult to treat this estimate seriously. It is perfectly conceivable, given the value of property in London, that London based firms should have substantially higher productivity given that output is measured in financial units. Furthermore, we may suppose that there is little functional distinction between real estate firms located in other parts of the country and this may be significant in our failure to identify a productivity gradient. Likewise, we find that accessibility counts less for business and management service firms that are located outside of London, and again this may be indicative of roughly similar levels of productivity across more or less homogenous firms.

Table 6 presents the estimates for manufacturing firms based outside London.

Table 6: Cobb-Douglas estimates for manufacturing firms outside London with a single accessibility measure of agglomeration.

<i>SIC15</i>	3.870	0.560
<i>SIC1718</i>	3.426	0.570
<i>SIC20</i>	3.690	0.563
<i>SIC21</i>	3.422	0.569
<i>SIC22</i>	3.448	0.566
<i>SIC24</i>	3.605	0.568
<i>SIC25</i>	3.458	0.569
<i>SIC2728</i>	3.385	0.568
<i>SIC30</i>	3.478	0.569
<i>SIC32</i>	3.544	0.570
<i>SIC33</i>	3.405	0.568
<i>SIC3435</i>	3.599	0.568
β_k	0.608	0.011
$(\beta_k + \beta_L - 1)$	-0.017	0.010
β_a	0.099	0.041
R^2	0.632	
n	1986	

The estimate of the elasticity of output with respect to our accessibility index is almost identical for manufacturing firms using either the sample including or excluding London, approximately 0.1. Thus, for manufacturing firms outside London we still find evidence of positive agglomeration or density externalities.

It is hard to reach any firm conclusions comparing estimates obtained using the full sample of firms to those based on data that excludes London firms. The evidence is mixed and in many cases the number of observations is insufficient for us to draw any meaningful comparisons between the two samples. What we can say, however, is that for many of our sectors positive density externalities can still be identified when London is excluded and that there does therefore appear to be a productivity-density gradient for the rest of the country.

In conclusion to this brief treatment of functional specialisation we must stress that simply excluding London from the sample does not constitute a serious attempt to empirically address this problem. What it does allow us to do is compare estimates from samples in which the 'functional gradient', if such a gradient exists, is likely to be rather different. Elasticity estimates of output with respect to density derived from the sample excluding London are not systematically smaller than those derived from the full sample.

VI. Conclusions

In this paper we have estimated the effects of 'city size' on productivity for different sectors of the UK economy. Our specification of 'city size' is based on a measure of accessibility which recognises the importance of both the scale and proximity of population and economic activity. It is a measure that contains an implicit transport dimension by capturing the *effective density* that is available to firms. Our results provide compelling evidence of a strong association between our measure of city size and productivity for both service and manufacturing sectors of the UK economy. Thus, if transport investment increases the effective density of locations there could be an effect on productivity which can be quantified for economic appraisal in the way suggested by Venables (2003).

On the other hand, our results also indicate that there may be a gradient of functional specialisation at work in creating productivity differentials and that this gradient may be correlated with city size. If so, we have to caution a simplistic view which would imagine productivity differences amongst homogenous activities distributed across the urban hierarchy with those in the largest cities being the most efficient. Unfortunately, the limitations of the SIC do not allow us to analyse this issue in great depth. What we can say, is that even if the productivity differences are based on functional specialisation, we may still expect external benefits from transport improvements if they assist the process of functional specialisation by improving the effective densities of people and jobs.

For nations in the process of rapid urbanisation one clear implication is that urban growth and the expansion of city size offers tremendous opportunities in terms of productivity. Transport investments can help to foster the conditions for city size to make an impact on

the efficiency of firms. Understanding the relationships between city size, transport improvements and productivity can also be helpful in making the economic case for transport investment.

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