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Transport-Induced Agglomeration Effects: Evidence for US Metropolitan Areas

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Abstract

While the interaction between transport and agglomeration economies is widely accepted, there is insufficient research attempting at a direct empirical quantification. Using a balanced panel dataset for US metropolitan areas, we estimate a system of simultaneous equations to measure the indirect effect of urban agglomeration economies which arises through transport provision. Our findings suggest that public transit reinforces the effect of urban agglomeration, whereas road lane miles appear to weaken it. The results highlight the importance of public transit in supporting positive urban agglomeration externalities.

JEL Classification: R11, R12, R41

Keywords: Transport-induced agglomeration effects, productivity, system of simultaneous equations, metropolitan areas

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1. Introduction

The relationship between transport and agglomeration economies has been formally described by Venables (2007), who showed that there are productivity gains from urban transport improvements that arise through city size. By facilitating the connectivity between people and economic activities, transport networks can reinforce the productivity effects arising due to agglomeration externalities, namely, those relating to knowledge spillovers, labour market pooling, and input-output sharing (e.g. Henderson, 2003, Rosenthal and Strange, 2004). Surprisingly, and in spite of the abundant research on the relationship between productivity and agglomeration economies (see Rosenthal and Strange, 2004, Melo et al., 2009 for recent reviews of the literature), there is limited research on the nature of transport-induced agglomeration effects on productivity.

Accessibility type measures of agglomeration economies such as *market potential* and *effective density* have increasingly been used in the literature to establish a clearer link between transport and agglomeration economies. This improves on previously used measures of agglomeration economies (i.e. total population, employment density, etc.) by providing a better representation of proximity to economic activities. However, the majority of these studies measure accessibility in terms of physical distance (e.g. Mion and Naticchioni, 2005, Graham, 2007a, Graham and Kim, 2008, Combes et al., 2008, Rosenthal and Strange, 2008, Di Addario and Patacchini, 2008, Fally et al., 2010, Hering and Poncet, 2010, Fallah et al., 2011).

Only a few studies have used transport-based measures of agglomeration economies. Lall et al. (2004), Rice et al. (2006), Graham (2007b), Holl (2012) and Le Néchet et al. (2012) used accessibility type measures based on travel times derived from the road network to measure agglomeration economies. While these studies allow for a direct role of (road) transport in the measurement of agglomeration, they cannot inform about the extent to which agglomeration effects are reinforced or weakened through transport systems. Existing literature on transport and urbanisation suggests that the provision of road transport has led to the decentralisation of employment and suburbanization (e.g. Baum-Snow, 2007a, Baum-Snow, 2007b), while public transit is associated with spatial concentration and increased urban densities. There is extensive research on the relation between urban form (and more generally the built environment) and travel demand, much of which supports a positive link between higher densities and public transit (Leck, 2006, Ewing and Cervero, 2010). The prevailing view is that urban spatial structures based on private road transport tend to encourage sprawling and dispersal of activities, reducing the scope and reach of agglomeration economies (e.g. Burchfield et al., 2006, Baum-Snow, 2007a). In contrast, public transit networks tend to be more compatible with higher densities and hence possibly also stronger agglomeration effects.

To the best of our knowledge the only study on the indirect productivity effects of transport is Chatman and Noland (2014), who find significant indirect productivity effects of public transit provision for US metropolitan areas. They also find that higher rates of road transport infrastructure reduce central city employment density, but do not derive its indirect effect on productivity (that is, whether it is positive or negative). In this paper we develop a system of simultaneous equations based on panel data for Metropolitan Statistical Areas (MSA) in the United States to investigate the component of urban agglomeration effects on productivity which arises through transport investment (i.e. transport-induced urban agglomeration effects), and distinguish between road transport and public transit effects.

The most interesting finding of this research is that public transit reinforces urban agglomeration economies, while road lane miles appear to weaken it. This suggests that transport-induced urban agglomeration effects are positive for public transit but negative for road transport, and highlights the importance of transit services in supporting productivity gains from urban agglomeration. The direct effect of doubling employment density (i.e. urban agglomeration) on labour productivity is 3%, while the overall net effect is approximately 2%. These values fall within the range of values (2%-5%) identified by Glaeser and Mare (2001) for the US for the wage elasticity of employment density, and are also broadly consistent with the values reported in existing surveys of the literature typically ranging between 3%-8%.

The structure of the paper is as follows. Section 2 describes the research approach, estimation strategy, data and model specification. Section 3 presents and discusses the results, and Section 4 summarises the main conclusions.

2. Empirical methodology and data

2.1. Research approach

The empirical methodology follows the approach developed by Charlot and Duranton (2004) to measure the role of communication externalities on agglomeration effects in French cities. The authors estimated separate wage and communication models to quantify how much of the effect of agglomeration economies arises through communication externalities. Our approach combines the estimation of labour productivity models to measure urban agglomeration economies with the estimation of transport models to measure the link between urban agglomeration, transport, and productivity. The models are estimated in a system of simultaneous equations to allow for joint causality and dependence, according to equations (1) to (3) respectively.

Productivity-urban agglomeration effects

Wage equations can be used to model labour productivity under the assumption that input factors are paid the value of their marginal products (i.e. wage rates should reflect, even if partially, labour productivity). The literature offers several explanations for the presence spatial disparities in labour productivity, including both exogenous and endogenous factors. These include differences in human capital (e.g. Rauch, 1993, Glaeser and Mare, 2001, Moretti, 2004), in the cost of living (mainly housing) and the quality of local amenities (e.g. Roback, 1982, Glaeser and Gottlieb, 2009), and agglomeration externalities (Fujita and Thisse, 2002).

We define a wage model where labour productivity, measured by average metropolitan area wage, is as a function of urbanisation economies represented by employment density (*DENS*), human capital measured in terms of educational attainment (*EDU*), a series of variables that control for the industrial and occupational distribution of local employment in industry *k* (E_k/E) and occupation *o* (E_o/E), the availability of transport - both road lane miles (*RLM*) and transit vehicle miles (TVM), and the local cost of living measured by a housing price index (HPI). Equation (1) provides a general description of the wage model, from which it is possible to estimate the direct effects of urban agglomeration and transport investment (by type of transport system) on labour productivity.

$$W = f_1(DENS, EDU, \frac{E_k}{E}, \frac{E_o}{E}, RLM, TVM, HPI) \qquad (1)$$

Transport-agglomeration effects

Transport investment is simultaneously determined with urban agglomeration: it is a function of urban size (i.e. larger urban areas require more transport) but at the same time facilitates additional interactions (i.e. movements) and hence increased urban size. To separate between the effects of road transport and public transit on urban agglomeration (as discussed in the introduction), we estimate two transport models defined in equations 2 and 3 respectively. The specification of the models follows the literature on induced travel demand and transport investment (e.g. Noland and Cowart, 2000, Noland and Lem, 2002, Cervero and Hansen, 2002, Cervero, 2002). The provision of road lane miles (*RLM*) is a function of traffic demand measured by road vehicle miles travelled (*VMT*), previous congestion levels measured in terms of total hours of delay (*HDELAY*), the size of the metropolitan area measured both in terms of total population (POP) and employment density (DENS), and economic output measured by GDP per capita (*GDPpc*). Similarly, the provision of transit vehicle miles (TVM) is defined as a function of transit passenger miles travelled (*PMT*), the size of the metropolitan area measured both in terms of total population (POP) and employment density (DENS), and economic output (*GDPpc*).

$$RLM = f_2(VMT, POP, DENS, GDPpc, HDELAY) \qquad (2)$$

$$TVM = f_3(PMT, POP, DENS, GDPpc) \qquad (3)$$

Transport-induced agglomeration effects on productivity

The wage model in equation (1) allows us to estimate the direct effect of urban agglomeration and transport infrastructure on labour productivity. The two transport models in equations (2) and (3) allow us to identify the relation between transport provision and urban agglomeration. By combining the coefficients obtained from the wage and transport models we can determine how much of the productivity effects from urban agglomeration arise through the provision of roads and public transit respectively (see detailed explanation in section 2.3. below).

2.2. Data

The data used in our analysis consist of a balanced panel of 84 Metropolitan Statistical Areas for the period 2001-2008. We collated data from different sources for socio-economic and transport related variables, as defined in equations (1) to (3) above. Table 1 provides basic descriptive statistics for these variables, which are summarised below, while Table 2 provides pairwise correlation coefficients for the explanatory variables included in the wage and transport models.

Socio-economic data contain the variables used to measure metropolitan area labour productivity and economic output, educational attainment, urban agglomeration, industrial and occupational composition, and local cost of living:

- Labour productivity is represented by average real wages (*W*), available from the Regional Economic Information System (REIS) of the Bureau of Economic Analysis (BEA). To calculate real average earnings we use the GDP deflator with base year for 2001.
- Data for economic output measured by GDP per capita (*GDPpc*) in 2001 USD were also obtained from the Bureau of Economic Analysis.
- To account for differences in the industrial and occupational structure across the metropolitan areas, we use a set of covariates for the proportion of local employment in manufacturing

(*MANU*), finance and insurance (*FINS*), professional and technical services (*PTSERV*) and the management of companies and enterprises (*MANG*). These data were obtained from the BEA's REIS database.

- Urban agglomeration economies are measured by employment density (*DENS*), where employment data were obtained from the BEA's REIS database.
- Data for MSA population were obtained from US Census Bureau, Population Division.
- Human capital is measured by the level of educational attainment and consists of the percentage of people aged 25 years and over holding a bachelor's or higher degree (*EDU*). Data for educational attainment were obtained from the American Community Survey.
- Data for the local housing price index (*HPI*) were obtained from the Federal Housing Finance Agency (FHFA).

Transport-related data contain the variables used to measure road transport supply, public transit supply, traffic demand, transit demand, and road congestion.

- Road transport supply is measured in terms of lane miles (*RLM*) for both freeways and arterial streets, and road travel demand is measured by vehicle-miles travelled (*VMT*). Data for road transport and road travel are obtained from the Texas Transportation Institute Urban Mobility Reports.
- Public transit supply is measured by the number of revenue vehicle miles (*TVM*) for rail modes (commuter rail, light rail and heavy rail) and buses. Public transit demand is measured by passenger miles travelled (*PMT*) by rail modes and bus. Data for public transit supply and demand are obtained from the National Transit Database (NTD) for the urbanized areas contained in the metropolitan areas considered in our study.
- We also account for road congestion in the main urbanized areas of each metropolitan area, measured in terms of annual hours of total delay (*HDELAY*). Data for road congestion are obtained from the Texas Transportation Institute Urban Mobility Reports.

Table 1: Descriptive statistics

Variable	Label	Unit	Min	Mean	Median	SD	Max
Average wage	W	2001 USD	14,857	31,438	31,456	5,474	53,617
GDP per capita	GDPpc	2001 USD	13,629	38,400	38,012	9,079	68,230
Employment density	DENS	People per km2	10	108	100	67	404
Population	POP	000 people	200	2,330	1,200	3,360	22,200
Educational attainment	EDU	%	12	29	28	7	53
Employment in manufacturing	MANU	%	0.00	7.86	7.00	3.21	20.00
Employment in finance and insurance	FINS	%	3.00	4.91	5.00	1.33	11.00
Employment in professional and technical services	PTSERV	%	0.00	6.04	6.00	2.21	15.00
Employment in management of companies	MANG	%	0.00	1.14	1.00	0.77	4.00
Housing price index	HPI	Integer	0.90	1.28	1.17	0.28	2.44
Road lane miles	RLM	Miles	2,670	28,445	20,174	26,636	165,141
Road vehicle miles travelled	VMT	000 miles	2,060	34,300	18,829	46,655	300,274
Transit vehicle miles	TVM	000 miles	118	19,200	7,200	34,000	213,000
Transit passenger miles travelled	PMT	000 miles	98	281,000	57,400	715,000	5,400,000
Hours of delay	HDELAY	000 hours	201	35,861	14,762	52,529	380,578

Notes:
Min=minimum, SD=standard deviation, Max=maximum.
Total number of observations is 672 for all variables with the exception of the public transit related variables for which it is 664 observations.

Table 2: Pairwise correlation coefficients

Variables	W	GDPpc	DENS	POP	EDU	MANU	FINS	PTSERV	MANG	HPI	RLM	VMT	TVM	PMT	HDELAY
W	1.00														
GDPpc	0.78	1.00													
DENS	0.35	0.28	1.00												
POP	0.47	0.35	0.22	1.00											
EDU	0.69	0.61	0.15	0.21	1.00										
MANU	0.14	0.21	0.08	0.06	0.04	1.00									
FINS	0.47	0.49	0.39	0.21	0.34	0.00	1.00								
PTSERV	0.65	0.54	0.19	0.37	0.65	-0.09	0.29	1.00							
MANG	0.41	0.34	0.17	0.22	0.28	0.28	0.30	0.23	1.00						
HPI	0.17	-0.16	0.13	0.15	-0.01	-0.37	-0.01	0.07	0.00	1.00					
RLM	0.55	0.45	0.22	0.95	0.31	0.09	0.28	0.45	0.30	0.09	1.00				
VMT	0.48	0.38	0.18	0.97	0.24	0.06	0.19	0.37	0.19	0.16	0.93	1.00			
TVM	0.50	0.39	0.42	0.83	0.28	-0.01	0.23	0.44	0.18	0.13	0.80	0.73	1.00		
PMT	0.45	0.32	0.33	0.83	0.24	-0.01	0.19	0.37	0.16	0.12	0.78	0.71	0.98	1.00	
HDELAY	0.48	0.43	0.52	0.71	0.27	-0.01	0.22	0.43	0.10	0.14	0.74	0.72	0.85	0.75	1.00

2.3. Detailed model specification

The fully specified models estimated simultaneously are described in equations (4) to (6).

$$\begin{aligned}\ln W_{it} = \beta_0 + \beta_1 \ln DENS_{it} + \beta_2 \ln EDU_{it} + \beta_3 MANU_{it} + \beta_4 FINS_{it} + \beta_5 PTSERV_{it} + \beta_6 MANG_{it} \\ + \beta_7 \ln RLM_{it} + \beta_8 \ln TVM_{it} + \beta_9 HPI_{it-1} + \lambda_t + \gamma_r + \varepsilon_{it}\end{aligned} \quad (4)$$

$$\ln RLM_{it} = \alpha_0 + \alpha_1 \ln VMT_{it-1} + \alpha_2 \ln POP_{it} + \alpha_3 \ln DENS_{it} + \alpha_4 \ln GDPpc_{it-1} + \alpha_5 \ln HDELAY_{it-1} + \omega_t + \eta_r + \upsilon_{it} \quad (5)$$

$$\ln TVM_{it} = \delta_0 + \delta_1 \ln PMT_{it-1} + \delta_2 \ln POP_{it} + \delta_3 \ln DENS_{it} + \delta_4 \ln GDPpc_{it-1} + \psi_t + \sigma_r + \nu_{it} \quad (6)$$

where the subscripts *i* and *t* identify the MSA and year respectively, and the variables are as defined in section 2.2 above. Besides the main explanatory variables, we also include a set of temporal (λ_t, ω_t, ψ_t) and regional (γ_r, η_r, σ_r) control variables in each equation to capture potential unobserved heterogeneity.[1] ε_{it}, υ_{it} and ν_{it} are the residual error terms and are assumed to be normally distributed while allowing for heteroskedasticity and clustering on metropolitan areas. The indirect effect of urban agglomeration economies that arises through the provision of road lane miles and public transit vehicle miles is ($\beta_7 * \alpha_3$) and ($\beta_8 * \delta_3$) respectively, which can be compared with the direct (β_1) and overall net effect ($\beta_1 + \beta_7 * \alpha_3 + \beta_8 * \delta_3$) of urban agglomeration on labour productivity.

2.4. Estimation strategy

The disturbance terms in equations (4) to (6) are likely to be contemporaneously correlated because some unobserved factors that influence the error term in one equation may also influence the error term in the other equation. Not accounting for this correlation and estimating the equations separately would lead to inefficient estimates of the model parameters. Therefore, we adopt the estimation procedure known as *seemingly unrelated regression* (SUR) (Roback, 1982).

The main estimation issues that need to be taken into consideration to ensure that we obtain consistent and unbiased parameter estimates relate to unobserved heterogeneity, omitted variable

[1] Regional controls based on appropriate combination of Census regions and divisions (East North Central, East South Central, Mountain, Pacific, South Atlantic, West North Central, West South Central).

bias, and reverse causality. All three are potential sources of endogeneity bias and inconsistent parameter estimates. In the context of panel data, unobserved heterogeneity and omitted variable bias can be addressed through the use of subject-specific effects, which can be assumed to be fixed or random. The choice of estimator depends on whether there is correlation between the model covariates and subject unobserved heterogeneity. To address the issues relating to reverse causality, instrumental variable (IV) techniques can be combined with SUR, resulting in a simultaneously estimation of the system of equations generally called *three-stage-least squares* (3SLS) (Zellner and Theil, 1962).

We suspect of reverse causality between labour productivity, educational attainment, and urban agglomeration. Metropolitan areas with higher worker productivity (and wages) are likely to attract workers with higher educational levels (i.e. sorting of higher skills), and generally more workers and firms; this in turn increases the level of human capital and urban agglomeration. We construct a set of instruments using a method similar to that used by Fingleton (2003, 2006), who instrumented agglomeration economies using a three-group rank method. Variations of this method can be used to get a better differentiation (i.e. more groups) of values for the instrumental variable. We use a five-group method which ranks the endogenous variable into one of five quintiles according to its size and then defines the instrumental variable as the rank order (Kennedy, 2003, p.162-163). Instruments are constructed in this fashion for employment density (*DENS*) and educational attainment (*EDU*). The pairwise correlation between the instruments and the endogenous variables is 0.88 for employment density and 0.89 for human capital, suggesting strong relevance in both cases.

There may also be issues of reverse causality between transport provision, travel demand, traffic congestion, and economic output in equations (5) and (6). To avoid simultaneity bias in the transport models, we use the first lag of road traffic and transit demand (VMT_{t-1}, PMT_{t-1}), road traffic congestion ($HDELAY_{t-1}$), and economic output ($GDPpc_{t-1}$). The underlying idea is that current levels of transport provision cannot determine past levels of travel demand, past levels of traffic congestion and past levels of economic output. Similarly, we use a time lag for the local housing price index (HPI_{t-1}) in the wage model in equation (4) to avoid potential simultaneity bias.

4. Results and discussion

The main findings obtained from the system of simultaneous equations are reported in Table 3. Overall, the explanatory power of the models is high. The value of the coefficient of determination (R^2) is 0.74 for the wage model and 0.95 for the road and transit supply models. Moreover, the sign of the coefficients is generally what we would expect from theory and previous studies.

We first discuss the results for the relationship between productivity, urban agglomeration, and transport provision. The results show that the direct effect of urban agglomeration on average metropolitan area labour productivity is 0.032, while the overall net effect is 0.019. This indicates that the net effect (i.e. after we account for transport provision) of urban agglomeration economies is 60% of its direct effect. The difference between the net effect and the direct effect results from the interaction between urban agglomeration and transport, which differs according to the type of transport system. The relationship is positive for public transit and negative for road transport. That is, the provision of public transit services appears to strengthen the effect of urban agglomeration economies, while the provision of road lane miles appears to weaken the effect of urban agglomeration economies. The provision of public transit increases the direct effect of urban agglomeration by 7%, while the provision of road lane miles reduces the direct effect of urban agglomeration by nearly 48%. We discuss these results in greater detail in the following paragraphs.

Higher employment densities are associated with lower provision of road transport (-0.294), while larger population bases are positively associated with the provision of road transport (+0.170). An increase of 10% in the level of metropolitan area employment density and total population is associated with a reduction of 2.9% and an increase of 1.7% in road lane miles respectively. The key point here is that overall population size is positively associated with road transport, while actual urban densities (i.e. employment density) are not. One possible reason for the latter might be the positive relation between higher employment densities and scarcity of land, and the fact that road transport is space intensive. On the other hand, both employment density and overall population are positively associated with the provision of public transit. An increase of 10% in metropolitan area employment density and population is associated with an increase of 2.1% and 2.7% in transit vehicle miles respectively. The main finding for the relation between urban agglomeration and transport provision is that higher employment densities support the provision of public transit services, but are negatively associated with the provision of roads.

From the wage model, it is also possible to estimate the direct effect of transport on productivity, which is positive for both road (+0.052) and public transit (+0.011) provision. However, the coefficient for transit services is not statistically significant. Turning to the other covariates in the wage model, the results are in line with expectations and previous studies and indicate positive returns to education, partial compensation of higher local housing cost, and higher wage rates for finance and insurance compared to other employment sectors.

As for the remaining covariates in the transport models, we find that in both cases previous levels of travel demand determine future levels of road lane miles and public transit services. The elasticity value is 0.44 for road traffic and 0.54 for public transit demand. Similarly, road traffic congestion helps predict future levels of road transport infrastructure: on average, a 10% increase in the total hours of delay is associated with an increase of 1.4% in road lane miles on the following year. Finally, the results also indicate that increased economic activity, measured by GDP per capita, also determines future levels of transport provision, with an elasticity value equal to 0.31 for road lane miles and 0.41 for public transit vehicle miles.

Table 3: Results from the wage and transport provision models

Variables	**Wage equation**	**Road supply equation**	**Transit supply equation**
Log of employment density ($DENS_{it}$)	0.032***	-0.294***	0.214***
Log of educational attainment (EDU_{it})	0.010***		
Employment in manufacturing ($MANU_{it}$)	0.010***		
Employment in finance and insurance ($FINS_{it}$)	0.017***		
Employment in professional and technical services ($PTSERV_{it}$)	0.010***		
Employment in management of companies ($MANG_{it}$)	0.013**		
Log of road lane miles (RVM_{it})	0.052***		
Log of transit vehicle miles (TVM_{it})	0.011		
Lag of Housing Price Index (HPI_{it-1})	0.124***		
Lag of log of road vehicle miles travelled (VMT_{it-1})		0.436***	
Lag of log of transit vehicle miles travelled (PMT_{it-1})			0.538***
Log of population (POP_{it})		0.170*	0.270***
Lag of log of GDP per capita ($GDPpc_{it-1}$)		0.307***	0.409***
Lag of log of number of hours of delay ($HDELAY_{it-1}$)		0.140***	
Year controls	yes	yes	yes
Regional controls	yes	yes	yes
Joint significance of regional dummies			
Joint significance of time dummies			
R^2	0.74	0.95	0.95
Observations	581	581	581

Notes:
***, **, * indicate significance at 1%, 5%, and 10%, respectively.
Endogenous regressors: Wage model: educational attainment, employment density, road lane miles, transit vehicle miles; Road supply model: population, employment density; Transit supply model: population, employment density.
Instruments: five-group method instrumental variables for employment density, educational attainment, and population.
Due to inclusion of lagged values of some variables, and also missing data for public transit variables, reduces the total number of observations from 672 (8 years and 84 regions) to 581.

5. Conclusions

It has been shown by Venables (2007) that there are productivity gains from urban transport improvements which arise through agglomeration economies. Despite this interaction between transport and agglomeration economies is widely accepted by the community of researchers interested in the productivity-agglomeration relationship, there is insufficient research attempting to empirically quantify this interaction.

This paper contributes to the literature by measuring the indirect effects of urban agglomeration economies which arise through the provision of road transport and public transit. The most important finding of our analysis is that although road transport has a direct positive impact on labour productivity, it appears to reduce the scope for productivity gains derived from urban agglomeration. These findings are in line with existing evidence that private road transport tends to encourage sprawling and dispersal of activities, reducing the scope and reach of agglomeration economies (e.g. Burchfield et al., 2006, Baum-Snow, 2007a). On the other hand, public transit services are found to support the productivity gains from urban agglomeration economies. This indicates that transport-induced urban agglomeration effects can be reinforced by public transit but weakened by road transport.

In drawing conclusions for policy implications, one needs to distinguish between the different spatial scales at which agglomeration externalities may operate. Our study focused on intra-metropolitan area interactions but there may be scope for inter-metropolitan area effects which may rely more on road networks than public transit. As a result, we posit that our findings of a more efficient effect of public transit services in maximising the opportunity for interactions (and hence urban agglomeration externalities) in urban environments is a plausible result.

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