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AGGLOMERATION BENEFITS AND COSTS OF INVESTING IN URBAN TRANSPORT INFRASTRUCTURE*

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Abstract. Theory and evidence suggest that a city owes its existence to an agglomeration benefit. An investment in urban transportation infrastructure may increase this benefit. While some years ago the agglomeration benefit of urban transportation was just a vague idea, recently its size has been estimated and the idea has gained concreteness and respectability. However, the theoretical literature has emphasized the agglomeration benefit that arises through immigration and higher population, while the empirical literature has emphasized the benefit that arises from effective density at constant population. A third strand of the literature has discussed transportation of goods. We bring together these theoretical and empirical literatures, and discuss which agglomeration benefits and costs are relevant for major categories of urban passenger and freight transport investment.

Keywords: transport; agglomeration; effective density; cost-benefit analysis

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1. Introduction

A city exists because it offers economic advantages. It provides specialized inputs and sustains specialized industries. It inspires entrepreneurs and is a magnet for talent. It supports increasing returns to scale industries and allows sharing of public goods. Up to a point, the advantages of cities are greater than the well-known disadvantages of e.g., congestion, pollution, crime and the cost of housing.

Urban transport infrastructure is an essential part of a city. Transport infrastructure increases the proximity between people, businesses and goods, and contributes to the city's advantages and disadvantages. Transport makes an urban area more "city-like". Yet, a transport planner may find the contribution of an investment in transport infrastructure to be elusive. How does traditional cost-benefit analysis internalize agglomeration

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benefits? Do all transport investments generate equal effects? Are agglomeration benefits more important than the contribution to congestion and pollution?

In the literature on urban economics one distinguishes between agglomeration benefits (sometimes called 'wider economic benefits') associated with market imperfections, and user benefits. However, there are gaps in our understanding of how urban transport investments engage with these ideas. The theoretical literature uses concepts and indicators that are not entirely satisfactory from a practical point of view, and the empirical literatures uses concepts that are not clearly based in theory.

In this paper we aim to bring together the theoretical and empirical analysis of these issues. In particular, we provide a micro-foundation for the concept of effective density, or market potential, which is often used in empirical work. The micro-foundation allows us to distinguish between agglomeration benefits in a stable population as opposed to those that depend on migration to a city. The previous literature on impacts of transportation investments has only emphasized agglomeration benefits arising from immigration. We show that these are in fact smaller than immigration's external costs.

In a modern city there are several forms of physical transport: Commuters travel to work in the morning, and back in the afternoon. Business travellers go back and forth on errands and to meetings during work hours. Leisure travel is for shopping and football practice and all the other things that households do in their spare time. Then there is transport of goods, freight, of which we will recognize two kinds: Transport of final goods that are consumed and transport of intermediate goods used to make final goods. To the extent that investments targets specific purposes of transport, there are different constituents of benefits and costs that come into play. We demonstrate how agglomeration benefits and user benefits enter and exit as we consider transport of different kinds.

2. Previous literature

The theoretical literature on benefits of urban transport infrastructure is derived from the literature on urban areas and cities. Existing models treat transport modes and transport costs differently. Some emphasize transport of commuters. Agglomeration benefits enter these models through migration and higher population. Others emphasize transport of goods, often modelled in terms of iceberg costs. In these models, agglomeration benefits sometimes do not arise at all.

An important early contribution is Duranton and Puga (2004), see also Duranton and Puga (2014). Building on Abdel-Rahman and Fujita (1990), they present a model of a city economy with market imperfections. Migration to the city provides for a bigger city with more talent that interacts with the market imperfections and generate agglomeration benefits. The model also emphasizes costly commuting costs. Commuting costs provides a dispersion force. The size of the city hangs in the balance between agglomeration benefits, user benefits and commuting costs. Transport of people enters the picture through commutes. Transport of goods is limited: The intermediates of the model cannot be transported out of the city, while final goods can be transported at zero cost.

Models of a single city are similar in design to small open economy. By contrast, models of urban and sometimes rural systems are like models of the global economy. Important early contributions include Krugman (1991, Fuijita and Krugman (1995) and Helpman (1998). These models exclude transport of individuals, but they include iceberg costs of transporting differentiated goods. Transport of goods gives rise to an agglomeration force. Krugman (1991) combines iceberg costs of differentiated goods with costless transport of homogenous goods, Helpman (1998) assumes that the homogenous good cannot be transported, while Fujita and Krugman (1995) assume positive costs of transporting the homogenous good. The transport or non-transport of homogenous goods gives a dispersion force.

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The early models of cities and urban systems have recently been elaborated e.g., by Behrens et al. (2014), Redding and Turner (2015) and Redding and Rossi-Hansberg (2017). These authors solve a general equilibrium system of n locations that each produce differentiated goods. In Redding and Turner (2015) and Redding and Rossi-Hansberg (2017) there are iceberg costs of transporting differentiated goods to other cities. In Behrens et al. differentiated goods cannot be exported, but individuals (the input factor) can migrate at zero cost.

The empirical literature on transport and agglomeration makes heavy use of the concept "effective density" or "market potential" (the two are used interchangeably), see e.g., the survey of Ahlfeldt and Pietrostefani (2019). In the empirical literature effective density refers to the synergies of ideas and human capital along the lines of Marshall (1890) and endogenous growth models (Lucas, 1988; Romer, 1990). Graham (2007) and Graham et al., (2010a) are two examples of empirical work that postulates an index of effective density as a sum of employment in adjacent locations, with distance from "our location" as weights. Instead of geographical distance as weights one may use generalized cost of transport including time and pecuniary cost, as in Graham et al., (2010b).

In the theoretical literature the concept is often attributed to Harris (1954). Harris defines it as "an abstract index of the intensity of possible contacts in markets". Contemporary models of urban systems have interpreted the concept in the form of market access of goods (Krugman, 1993, Eaton and Kortum, 1993), particularly associated with foreign trade (Donaldson and Hornbeck, 2016). Hence, although the name may be the same the connotations are different in the empirical and theoretical literatures: The theoretical literature emphasizes market access of goods, while the empirical literature emphasizes density of ideas. The theory papers on market potential are not really helpful in explaining the empirical models.

Analyzing the impact of a transport investment on agglomeration is like analyzing a perturbation of the city or urban system. A small number of previous papers have done this. Venables (2007) has a model containing an increasing returns to scale production function, a cost of commuting, and an income tax. He finds that a transport investment that lowers the cost of commuting has a direct impact on the aggregate cost of commuting plus an external agglomeration benefit and cost to the extent that the investment induces migration to the city. Venables also shows how an income tax interacts with the other market imperfections.

Kanemoto (2013) also considers the impact of an investment to lower the cost of commutes. Kanemoto has an explicit microeconomic underpinning of the aggregate production function, and he has several cities. However, like Venables, Kanemoto does not discuss agglomeration benefits in a given population, nor does he discuss different transportation aims and modes.

Our paper makes three contributions to the literature on transport and agglomeration. First, we show how transport investment may generate agglomeration benefits in a given population and that this is the proper channel since agglomeration benefits of immigration are dwarfed by agglomeration costs. Second, we provide a satisfactory theoretical underpinning for the concept of effective density. Third, we discuss agglomeration benefits of all relevant transportation aims and modes, including recreational travel and freight.

3. The model

We present here a model of a city economy that features agglomeration. We use upper case letters for aggregate variables, lower-case letters for individual level variables, and (where necessary) lower-case letters with a bar for average variables. For parameters we use lower case Greek letters.

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3.1 *Commuting cost and land rent*

Our modeling of commuting costs and land rent follows Duranton and Puga (2004) and is by now fairly standard. A short summary is offered. Commuting cost and land rent determine the spatial extent of the city. The individual commuting cost *c* is a function of distance traveled, *x*, and a parameter τ that summarizes the quality of infrastructure service:

$$c = c(x,\tau), \frac{\partial c}{\partial \tau} < 0, \frac{\partial c}{\partial x} > 0 \qquad (1)$$

A longer distance (high *x*) increases costs, while improved infrastructure service (high τ) decreases cost. All workplaces are located at the same location in the city, the Central Business District (CBD).

Everybody is equal and therefore, in equilibrium the sum of commuting cost and land rental cost will be the same for all. Land rent at the border is zero and there is no congestion immediately outside the border.

There are *N* individuals in the city. Everybody lives somewhere on a disk of area *N* and radius $\sqrt{N/\pi}$ from the CBD. Subsuming the square root into the function *c(x,τ)* this gives the following relation between commuting cost and rental cost of land:

$$r(x) + c(x,\tau) = c(N,\tau) + 0 = c(N,\tau) \qquad (2)$$

Equation (2) says that the sum of commuting cost and rental cost of land is the same everywhere in the city, including at the border where land rent is zero. In particular, the equation holds for an individual experiencing average commuting costs ($\bar{c}$) and average land rent ($\bar{r}$), which we state as equation (3):

$$\bar{c} = c(N,\tau) - \bar{r} = \bar{c}(N,\tau) \qquad (3)$$

3.2 *Production technology of the final good*

Production of the final good and intermediates again follows the standard model, which is a love of variety production function and fixed costs of making intermediates. The city produces a final good *Y* by means of a mass *m* of intermediates *y(s)*:

$$Y = \left\{ \int_0^m y(s)^{\frac{1}{1+\sigma}} ds \right\}^{1+\sigma} \qquad (4)$$

The parameter *σ* determines the curvature of the production function, the elasticity of substitution.

3.3 *Production technology of intermediates*

Intermediates are produced by increasing returns to scale technologies:

$$y(s) = \beta l(s) - \alpha \qquad (5)$$

β indicates variable cost, *α* indicates fixed cost, and *l(s)* is input of human capital in production of the intermediate. To begin with we assume that intermediates are not exported. Intermediate producers then face downward sloping demand curves from the local final goods sector, and profit maximization implies:

$$q = \frac{w(1+\sigma)}{\beta} \qquad (6)$$

Intermediates use identical production technologies where *q* is the common price of intermediates and *w* is the common wage of human capital in the city. A common wage and no other primitive inputs imply that there is one

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final goods sector in equilibrium. Free entry into production of intermediates implies zero profits, which determine a common production level of intermediates *y* by means of equations (5), (6) and (7):

$$qy(s) - wl(s) = 0 \tag{7}$$

$$y = \frac{\alpha}{\sigma} \tag{8}$$

Equation (5) determines the common level of human capital *l* in each intermediate:

$$l = \frac{\alpha(1+\sigma)}{\beta\sigma} \tag{9}$$

With a fixed level of human capital *H* in the city, the mass of intermediates can be found:

$$m = \frac{H}{l} = \frac{\beta\sigma}{\alpha(1+\sigma)}H \tag{10}$$

3.4 *Effective density*

We depart from the standard model and assume that each individual is endowed with *h* units of human capital. We let $g(i,j)$ denote the intellectual influence of individual *j* on individual *i*. $g(i,j)$ is a scalar between 0 and 1. The network literature (e.g., Topa and Zenou, 2015) usually assumes that $g(i,j)$ is either 0 if there is no contact between *i* and *j*, or 1 if there is unhindered contact. These are extreme outcomes. Most links between people face transaction costs in the form of culture, distance, frequency of interaction etc that suggest that an intermediate value between 0 and 1 is appropriate.

We assume that the links between people can be improved by better communication technologies:

$$g(i,j) = g(i,j;c_1 \ldots c_n) \qquad \frac{\partial g}{\partial c_k} < 0\ \forall\, k \tag{11}$$

$c_1 \ldots c_n$ are the costs of communication technologies between *i* and *j*. Individuals in the city may also receive influence from outside the city. Such influence is incorporated into equation (11).

We are concerned with ordinary physical transportation, whether business travel where people meet professionally in meetings and seminars and professional dinners, or leisure travel where ideas may be shared on the sidelines of a football field or during a chance meeting at a café, or commutes where people of common interests may end up talking at the subway station. Suppress other explanatory variables and let τ be an indicator of infrastructure quality that decreases the cost of transportation in the manner of equation (1).

Adding over all influencers gives aggregate influence on individual *i*:

$$g(i) = \int_0^N g(i,j;\tau)h(j)dj \tag{12}$$

Equation (12) is our expression for effective density. It is an index, or weighted sum of human capital elsewhere in the urban area that one considers a city. The index allows significant flexibility. If the influence from employees, say, to entrepreneurs is a priori zero, the relevant *g(i,j)* are always zero and *g* is lower than it would have been otherwise. If *g(i,j)* of some *j* are equal, e.g., because these *j* share the same location, equation (12) will cluster the relevant *h(j)* into groups. Such a clustering is common in empirical formulations.

In equation (13), $\frac{\int_0^N g(i,j;\tau)dj}{N}$ is average influence on individual *i*. In general, the average influence depends on the cost of communication *vis-à-vis* everybody else, and this cost will differ depending on one's location in the city. We suppress this locational difference and assume that the average influence on all individuals is the same and denoted *g*. Total influence on each individual is *gH*:

$$g(i) = g = \int_0^N g(i,j;\tau)h(j)dj = Nh\frac{\int_0^N g(i,j;\tau)dj}{N} = g(\tau)H, \quad \frac{\partial g}{\partial \tau} > 0 \tag{13}$$

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In equation (13) we ignore any influence of population (*N*) on effective density (*g*). The interpretation is that population growth is accompanied by proportional spatial growth.[†]

Stronger intellectual influences increase productivity among intermediate producers. For instance, among the self-employed influence and inspiration from others may spur innovation to develop new processes that reduce cost and improve productivity. Among employees the influence from others may inspire to improve work procedures and product lines, again improving productivity. We propose a formulation for productivity improvement as follows:

$$\alpha = \overline{\alpha}(gH)^{\theta} \tag{14}$$

$$\beta = \overline{\beta}(gH)^{\theta} \tag{15}$$

$\bar{\alpha}$ and $\bar{\beta}$ are benchmark parameters of productivity when there is no influence from others. $\theta > 0$ is the elasticity on productivity when intellectual influence increases (i.e. learning), or better: the externality of effective density.

3.5 *Aggregate production*

Pulling together equations (4), (8), (10), (14) and (15), we obtain the aggregate production function of the final good:

$$Y = g^{\theta} H^{1+\sigma+\theta} \tag{16}$$

A complicated function of constants have been subsumed into *Y* by an appropriate choice of units. The price of the final good is the numeraire. We assume that our city is an island in a sea of cities and that the final good sector participates in a large market subject to free entry, and zero profits prevail. Zero profits imply a wage rate equal to *Y/N*, or

$$w = hg^{\theta} H^{\sigma+\theta} \tag{17}$$

3.6 *Utility and welfare*

We assume that income from land rent is divided equally between the individuals of the city. Since the price of the final good is the numeraire it is straightforward to calculate indirect utility of each individual in the city (*v*) as wage income plus the average share of land rents, less rental cost, less commuting cost. In other words, indirect utility equals net income in this economy of one final good.
Inserting equations (3) and (17) we obtain:

$$v = w + \bar{r} - c(N,\tau) = w - \bar{c} = hg(\tau)^{\theta}(Nh)^{\sigma+\theta} - \bar{c}(N,\tau) \tag{18}$$

Equation (18) is a key equation for what follows. It states that a city is a trade-off between positive learning externalities (indicated by the exponent θ) and sharing externalities (the exponent σ) on the one hand, and congestion costs $(\bar{c})$ on the other. The city population generates learning (θ) and sharing (σ) externalities, which reinforce each other $((Nh)^{\sigma+\theta})$, but city size also influences average congestion costs $\bar{c}$. Infrastructure (τ) influences agglomeration directly in the term $g(\tau)^{\theta}$. Previous models have included this impact only through growth in population (*N*).

People are free to migrate between our city and the outside world, and equilibrium city size obtains when individual utility inside the city equals individual utility outside. Individual utility outside the city is fixed at $\bar{v}$, hence $v = \bar{v}$ in equilibrium. Viewed as a function of city size N the model admits two equilibria, of which one is stable and the other is unstable (Duranton and Puga (2004, 2014)). A stable equilibrium requires $\frac{dv}{dN} < 0$. This requirement states that the equilibrium city is bigger than what would have been optimal. Intuitively, migration to

[†] Recall that everybody lives on a disk of size N. Here we deviate from a recent paper by Davis and Dingel (2019). Davis and Dingel argue that a larger N encourages learning. There are some other differences between our paper and Davis and Dingel (2019) as well. In particular, learning is optimal in their model, there is no external agglomeration benefit.

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the city eats away at the surplus of the city until the point where the congestion cost equals the positive externalities.

4. Cost-benefit test for investment in transport

We use the model to set up a cost-benefit test of an investment in transport infrastructure. The test comprises agglomeration benefits, external costs, and user benefits.

4.1 Preliminaries

There are altogether $\bar{N}$ members of the economy inside and outside the city, and to measure the benefit of a transport project we use a simple welfare function:

$$V = vN + \bar{v}(\bar{N} - N) \quad (19)$$

We submit that an investment to improve transport infrastructure should pass the cost-benefit test

$$\frac{dV}{d\tau} = \frac{dv}{d\tau}N + (v - \bar{v})\frac{dN}{d\tau} = \frac{dv}{d\tau}N > 0 \quad (20)$$

For simplicity we disregard the investment cost of constructing τ. Adding a non-zero investment cost would only change the hurdle of the cost-benefit test. In (20) $(v - \bar{v})\frac{dN}{d\tau}$ is the displacement effect, the effect of people migrating between the city and the outside world. To the first order, the displacement effect generates zero utility. What remains as a potential benefit is the impact on individual utility, multiplied by city population.

To indicate the impact on individual utility we make the standard assumption in cost-benefit analysis that the economy is initially in equilibrium and the project under consideration will benefit the economy if $\frac{dv}{d\tau}$ is positive. The effect on individual utility can generally be written as

$$\frac{dv}{d\tau} = \frac{\partial v}{\partial N}\frac{\partial N}{\partial \tau} + \frac{\partial v}{\partial \tau} \quad (21)$$

It is useful to sign the terms of (21). In equilibrium we know that $\frac{\partial v}{\partial N}$ is negative. Further, τ is optimally arranged prior to any project that is new to the economy. This means $\frac{dv}{d\tau} = 0$ initially. It follows that $\frac{\partial N}{\partial \tau}$ is positive when $\frac{\partial v}{\partial \tau}$ is positive. In plain words: Transport infrastructure that improves individual utility directly ($\frac{\partial v}{\partial \tau} > 0$) will attract migrants to the city ($\frac{\partial N}{\partial \tau} > 0$). This seems a reasonable feature of the model.

Armed with these preliminaries we are ready to work out the cost-benefit test of specific, new transportation aims and modes.

4.2 Cost-benefit test for commutes

We find the impact on welfare of an increase in τ that affects the average cost of commutes, $\bar{c}$:

$$\frac{dV}{d\tau} = \frac{dv}{d\tau}N = \left\{\frac{dg}{d\tau}\theta h g^{\theta-1}H^{\sigma+\theta} + \left[h^2 g^{\theta}(\sigma+\theta)H^{\sigma+\theta-1} - \frac{\partial \bar{c}}{\partial N}\right]\frac{\partial N}{\partial \tau} - \frac{\partial \bar{c}}{\partial \tau}\right\}N$$

$$= \theta\frac{dg}{g}Y - \frac{\partial \bar{c}}{\partial \tau}N + \left((\sigma+\theta)hw - \frac{\partial \bar{c}}{\partial N}N\right)\frac{\partial N}{\partial \tau} \quad (22)$$

We spell out the terms of (22). When τ increases the first term in (22) is the percentage increase in effective density (dg/g) times the elasticity of productivity with respect to effective density (θ), times production. This term is the external agglomeration benefit of much empirical work. In empirical work θ is often found to be around 0.04 (Ahlfeldt and Pietrostefani, 2019).

The second term in (22), $\frac{\partial \bar{c}}{\partial \tau}N$, is the decrease in average transportation and congestion cost for commutes that the improvement brings about, times the number of inhabitants in the city. This term is the user benefit of the investment and the only term of this model that would be included in a traditional cost-benefit appraisal.

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The third term in equation (22), $\left((\sigma+\theta)hw - \frac{\partial \bar{c}}{\partial N}N\right)\frac{\partial N}{\partial \tau}$, collects the effects of a larger population. Inside the brackets the first term, $(\sigma+\theta)hw$, combines the sharing and learning externalities of a larger population, where the sharing externality implies that more intermediate varieties can be supported, and the learning externality implies that a higher human capital base generates more synergies, more learning. The second impact inside the brackets, $\frac{\partial \bar{c}}{\partial N}N$, is the increase in average congestion cost when new inhabitants arrive, multiplied by population.

The bracketed term in the second line of equation (22) equals $\frac{\partial v}{\partial N}$, which we know is negative in an economy that starts out from equilibrium. The cost increase in congestion is more important than the benefit increase through sharing and learning. Hence there is no external benefit of the bracketed terms in total, rather the expression points to an external cost. Still, the previous literature has emphasized the agglomeration benefit inherent in the expression and not the overall sign (Venables, 2007).

4.3 Cost-benefit test for recreational travel

Commutes are carried out in order to generate income and production. Residential travel, by contrast, is done to increase utility. In the model so far, all one does in ones spare time is to consume *Y*. We now assume there are two goods for citizens to choose from, namely the consumption good *Y* and time *T* spent on recreation in the form of contact with friends and family etc. Labor supply stays the same. Individual consumption of recreation is *t* and *T=tN*.

Y has a price of 1 as before. The unit cost of recreation is p_t. More precisely, p_t is the cost of travelling to gain access to the recreational service (i.e. friends, family). We integrate recreational travel into the analysis by inserting its price into the indirect utility function of households, see equation (23).

$$v = v(p_t, w-\bar{c}) = v\left(p_t(\tau,N), hg^{\theta}H^{\sigma+\theta} - \bar{c}(N,\tau)\right) \qquad (23)$$

Similarly to the cost of commutes we assume that improvements in infrastructure τ lower the price of recreational travel, and that a larger population *N* increases the price of recreational travel (average length of time spent travelling, congestion) hence $\frac{\partial p_t}{\partial \tau} < 0, \frac{\partial p_t}{\partial N} > 0$. Let $\frac{\partial N}{\partial \tau} < 0$ as before, and consider a project that increases the indicator τ. In this setup the indicator τ allows for more convenient recreational travel *and* commutes, since both travels occur on the same roads, railways etc. We obtain

$$\frac{dV}{d\tau} = \frac{\partial v}{\partial p_t}\left(\frac{\partial p_t}{\partial \tau} + \frac{\partial p_t}{\partial N}\frac{\partial N}{\partial \tau}\right)N + \frac{\partial v}{\partial(w-\bar{c})}\left[\theta\frac{dg}{g}Y - \frac{\partial \bar{c}}{\partial \tau}N + \frac{\partial(w-\bar{c})}{\partial N}\frac{\partial N}{\partial \tau}\right] \qquad (24)$$

From Roy's identity we have $\frac{\partial v/\partial p_t}{\partial v/\partial(w-\bar{c})} = -t$. Hence, equation (24) is positive if and only if:

$$-T\frac{\partial p_t}{\partial \tau} + \theta\frac{dg}{g}Y - \frac{\partial \bar{c}}{\partial \tau}N + \left(\frac{\partial(w-\bar{c})}{\partial N} - T\frac{\partial p_t}{\partial N}\right)\frac{\partial N}{\partial \tau} > 0 \qquad (25)$$

From equation (25) a project that promotes recreational travel gives a user benefit that is proportional to recreational transport consumption, $-T\frac{\partial p_t}{\partial \tau}$. Furthermore it increases effective density as an external benefit, $\theta\frac{dg}{g}Y$. The impact on effective density may be further disentangled using (11), since we now have two items, commutes and recreational travel, that contribute (through a higher τ) to higher effective density. In plain terms recreational contact may transfer knowledge and influence, adding to the impact of commutes. Most empirical analysis does not distinguish travel by purpose when calculating external agglomeration impacts of higher effective density. Implicitly, recreational travel is treated on par with commutes, highlighting the relevance of including recreational travel in the theory model.

The project may also reduce travel costs for commuters, $\frac{\partial \bar{c}}{\partial \tau}N$.

These improvements in welfare set in motion migration to the city. Population increases, which gives rise to positive learning and sharing externalities, but also further congestion and impediments to recreational services.

Around a stable equilibrium the congestion and impediments dominate, the net impact of immigration is an external cost.
Compared to commutes the difference when assessing recreational travel is the a) the stronger economic benefit of increased density $\frac{dg}{g}$, b) the user benefit $-T\frac{\partial p_t}{\partial \tau}$ and c) the additional external economic cost associated with population growth, $-T\frac{\partial p_t}{\partial N}$.

4.4 Cost-benefit test for transport of final goods

As noted earlier in the paper, there is a strand in the literature on market access, effective density and agglomeration benefits that is concerned with trade in goods and transport of goods. We now extend our model to trade in goods. First, we consider trade in the final good. We ignore recreation (the previous section).

To model trade in goods we assume that the economy has access to a final good *X* that can be imported for consumption at price p_x. Consumption of the final good that is domestically produced, is *Z*. From equation (18) the budget constraint of the economy is

$$p_x X + Z = (w - \vec{c})N \tag{26}$$

For each consumer, equation (26) modifies indirect utility as follows:

$$v = v(p_x, w - \vec{c}) \tag{27}$$

We assume iceberg costs in transporting good *X* to our city. An investment to reduce iceberg costs will reduce p_x.

Similarly to above, we have that $\partial N/\partial p_x < 0$ in a stable equilibrium.

By means of equation (27) and Roy's identity we obtain

$$\frac{dV}{dp_x} = \frac{\partial v}{\partial p_x}N + \frac{\partial v}{\partial(w-\vec{c})}\frac{\partial(w-\vec{c})}{\partial N}\frac{\partial N}{\partial p_x} \tag{28}$$

Since the investment to reduce iceberg costs will reduce p_x the cost-benefit test is formulated in the negative. Equation (28) is negative if and only if

$$-X + \frac{\partial(w-\vec{c})}{\partial N}\frac{\partial N}{\partial p_x} < 0 \tag{29}$$

The equation tells us that a decrease in iceberg freight cost produces a user benefit in proportion to imports of the final good, plus a net external cost of migration to the city. The net external cost consists of a gross external benefit and a larger gross external cost, like in the other cases we have examined. The reason, of course, is that lower freight costs improve transport lines of goods, lower prices and increase the standard of living in the city. People realize this and move to the city in response. There is a beneficial impact of sharing and learning, but in the neighborhood of equilibrium this benefit is dominated by costs of congestion. In contrast to improvements in commuting costs or recreational costs within the city, lower freight costs do not bring people closer together and has no consequence for effective density of a given population.

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4.5 Cost-benefit test for transport of intermediates

To conclude the taxonomy of transport modes and aims we consider transport of intermediate goods. In addition to domestic intermediate goods we assume that it is possible to purchase from other regions *n* intermediate goods $x_1 \dots x_n$ at fixed prices $q_1 \dots q_n$. The purchase is financed by sales of the final good Y. The production function (4) is modified to.

$$Y = F\left(x_1 \dots x_n, \left\{\int_0^m y(z)^{\frac{1}{1+\sigma}}\right\}^{1+\sigma}\right) = F\left(x_1 \dots x_n; g^{\theta} H^{1+\sigma+\theta}\right) \tag{30}$$

The regional budget constraint is modified to

$$V = Y - \sum_{i=1}^{n} q_i x_i - \bar{c}N \tag{31}$$

The budget constraint equals city utility. Assume freight costs decrease and q_i goes down. (31) is a money metric utility function and Hotelling's lemma immediately gives $\frac{d(S - q_i x_i)}{d q_i} = -x_i$. The cost-benefit test is again formulated in the negative:

$$\frac{dV}{dq_i} = -x_i + \frac{\partial V}{\partial N}\frac{\partial N}{\partial q_i} < 0 \tag{32}$$

(32) bears similarities to (29). (32) tells us that a decrease in the cost of an intermediate gives a user benefit in proportion to consumption of that intermediate, plus an external economic cost as the primary benefit is eaten away by migration to the city. External economic benefits are absent in the aggregate despite the sharing and learning externalities.

Discussion and conclusion

The previous theoretical literature on costs and benefits of urban transportation has associated agglomeration benefits with immigration. We have developed a simple model that allows agglomeration benefits in a city structure of a given population size. This is the maintained assumption in much empirical work. Along the way we have shown that in the neighborhood of equilibrium the external agglomeration benefit of immigration actually is dominated by an external congestion cost. Further, we have shown that investments to improve transport facilities for people in cities will entail agglomeration benefits to a given population, while investments to improve the transportation of goods influence population size. While these investments bring agglomeration benefits, they entail larger external costs and the net external effect is negative.

External benefits and costs, and traditional user benefits, associated with different transport purposes are summarized in Table 1.

Table 1. Types of transport, types of benefit

	External economic benefits and costs		*User benefits*			
Type of transport	Benefit (through effective density)	Cost (net effect of congestion, productivity)	Recreation	Transport accessibility	Consump-tion	Lower cost of production
Recreational travel	X	X	X	X		
Commutes	X	X		X		
Freight, final goods		X			X	
Freight, intermediate goods		X				X

Table 1 reiterates that only transport projects that increase transportation of people produce agglomeration benefits at given population size. The agglomeration benefits at given population size are positive in nature.

All urban transport projects – whether passenger or freight – facilitate a response in terms of immigration. With immigration a number of benefits and costs are set into motion. Learning and sharing externalities are enhanced, commuting costs rise, and environmental amenities may be strained. However, to the first order the costs of immigration are larger than the benefits. The reason is that immigration is a response to the benefit of a transport project. The benefit implies that city life is more attractive and immigration results. Immigration eats away at the surplus until it is eliminated. If it were never eliminated marginal utility would remain higher in cities, and city growth would be a runaway process (unstable equilibrium). Hence, the agglomeration benefits requiring migration are arguably less interesting than those at given population. By implication improving transport of goods is less likely to bring about agglomeration benefits than transport of people, and projects that improve both commutes and recreational travel could be the most fruitful of all.

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