

# **When simplifying assumptions are too simple: developing a 'catalogue' of agglomeration economies and other spatial impacts of infrastructure**

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## **Abstract**

Traditional program evaluation of transport investment tends to focus on relatively narrow measures of market benefit (e.g. a transport project's reductions in travel-times that will be generated for travellers). In many cases benefit measures such as these are more than sufficient, especially when considering increments to existing transport and other infrastructure networks. However, transport infrastructure can have significant spatial effects such as expansion in effective access to markets for goods and services and an ability to achieve agglomeration and other spatial economies across those markets. Agglomeration economies in particular are inconsistently understood and often incompletely specified. This paper develops a template which categorises agglomeration effects, indicating how they arise from real-world characteristics which are counter to standard simplifying assumptions which are the basis of most traditional evaluation methods.

## 1. Introduction

Transport investments (and infrastructure investments more generally) have many potential economic benefits. One of these is the ability to configure and reconfigure locations of people and activities, ideally in ways that allow a given set of resources to yield a greater output than would be the case otherwise.

Sounds simple, but how does such 'mere' spatial reconfiguration accomplish such an economic outcome? And how does a transport investment facilitate such a reconfiguration? A huge amount has been written on these two questions but the exact nature of these dynamics is still surprisingly obscure in many cases.

The objective of this paper is to take a step back to fundamental concepts and build an initial template for sorting through the potential relationships that location in space has to economic productivity, focusing in particular on 'agglomeration economies'. Starting from the first principles of economic theory, this paper develops a framework which categorises agglomeration effects, indicating how they arise from real-world characteristics which are counter to standard simplifying assumptions which are the basis of most traditional understanding.

## 2. Human beings do agglomerate

Before getting into this, though, let's state the obvious: human beings do agglomerate. This occurs at varying degrees of spatial scales, to be sure, from marketplaces to cities to cluster regions to neighbourhoods. But it does happen widely.

Evidence of this sort is widespread and includes many sorts of data, qualitative and otherwise.

### 2.1 Urbanisation

At its simplest level more and more people worldwide are concentrating in urban agglomerations. The 2005 Revision of the UN World Urbanization Prospects report indicates that the global proportion of urban population rose dramatically from 13% (220 million) in 1900, to 29% (732 million) in 1950, to 49% (3.2 billion) in 2005. The same report projected that the figure is likely to rise to 60% (4.9 billion) by 2030 (United Nations 2005).

This trend is nothing new: cities are as old as human civilisation. The first cities discovered archeologically are in Sumeria circa 3500 BCE, with sites in ancient Egypt following shortly thereafter. Urban concentrations are universal as well for ancient cities have been discovered all over the world, in places as diverse as Mexico, (Mayan and Aztec), China, and East Africa (Yoruba) (Mumford 1961; Smith 2009).

### 2.2 High-rise building

Related to the first point has been the increasing use of high-rise building. Technologies, such as the Otis Safety Elevator and the development of steel beams, and design strategies such as those pioneered by Chicago architect Louis Sullivan at the turn of the 20th century, enabled cities to vastly expand upwards as well as outwards. The full-embrace of this technological advance indicates that there is something about concentration that is attractive to human beings vertically as well as horizontally (as is the continued push, somewhat blunted by 9/11, to build ever higher structures) (Douglas 1996).

### 2.2 Clustering by industries and specialties

Alfred Marshall's most intuitive example of spatial economies (one part of his famous 'trinity', discussed more below) referred to "thickly populated industrial districts" (Marshall 1890). Marshall was referring to what is commonly observed both within cities and outside of them,

namely concentrations of specific economic activities which cluster in a particular area. This pattern perhaps even predates cities. Neolithic peoples clustered in communities in what might in some cases be very primitive patterns of spatial specialisation (Grantham 1997).

### **2.3 Marketplaces**

The existence of marketplaces predates industrial history, or even significant commercial history, by perhaps 60,000 years by some estimates [6]. Certainly dedicated areas where people gathered to buy and sell goods and services has been a dominant feature of human trade, with some markets being quite large in size and often leading to creation of urban centres (Polanyi 1944, Kohn 2003).

### **2.4 Other contexts**

To this list could be added findings from literature on social psychology, socio-biology and organisational behaviour which indicate that human beings have marked tendencies to group and congregate together at various scales. John Donne's famous quote that "No man is an island" clearly has support in the empirical data regarding agglomerations.

## **3. Agglomeration does have economic benefits**

There are, no doubt, many reasons why human beings agglomerate, some of them having little to do with economics. Of special interest here is the narrower question: is this sort of agglomerating economically productive? And is all agglomeration 'optimal' in this economic sense?

To briefly consider a very large body of evidence, overall there is a definite positive connection on average between agglomeration and productivity.

### **3.1 Broad findings of the literature**

(1) Rappaport and Sachs (2003) found that 57 per cent of the income in the US was generated within 80 km from the coast and only 13 per cent of the landmass (Rappaport and Sachs 2003);

(2) Rosenthal and Strange (2004) survey the literature on agglomeration economies and very roughly find that a doubling of city size increases productivity by an amount that ranges from 2 to 8 per cent. This has been confirmed in later studies;

(3) Glaeser and Mare (2001) find that workers in cities over a million earn a wage premium over those living in cities under 100,000, even after adjusting for the selection bias of more productive workers locating in larger cities. This is consistent with more general findings of core-periphery 'gradients' in rents, wages, and land prices, all of which suggest that there must be returns to locating close to centres since people are willing to pay a premium for being there.

(4) Graham (2005, 2006) uses measures based on 'effective density' or employment potential and aggregate up the employment counts in a circular region centred on each individual firm, with higher weights. Others look at the effects of employment within several preset distance or travel time bands. Using this latter approach, Rosenthal and Strange (2003) find for the US that new firms within a given industry are most attracted to zones within 1 mile of existing employment centres within that industry with effects diminishing rapidly with distance. Rice et al (2004) use travel-time bands and find that most of the productivity benefits of agglomeration are related to population within 80 minutes travel time.

(5) Swinburn et. al. (2008) estimate forecast productivity changes to worker density in London as a way of estimating the productivity returns of high buildings and find that by 2026 the resulting "agglomeration benefit" is equal to 17% of the rent paid in those buildings. This builds on work by Graham (2005, 2006) which estimates that a 10 per cent increase in

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effective density, controlled for other changes, yields a 1.25 per cent increase in productivity for firms in that area [12, 13]. Ciccone and Hall (1996) estimate that doubling of employment density, all other things constant, increased average labour productivity in the US by 6% and in Europe by 5%.

The general drift of most studies, and these are only a few, is that density and concentration do have positive productivity and other economic returns.

### **3.2 Patterns of agglomeration and economic productivity**

A few points should be made about this finding. First, there is not one obvious scale over which these returns can be realised. In other words, returns can be found across all sorts of different spatial areas, from regions to cities to neighbourhoods to individual sites and they are often found at one scale, but not at another in the same overall location.

Second there will typically be some scale beyond which such economic returns are exhausted (and below which there will be still be returns to be had) or there could be discontinuities in scale. A clear reason for this fact is that there are costs as well as benefits to agglomeration and concentration. The scale at which these marginal benefits equal marginal costs (and by economic logic thus be 'optimal' from a unit productivity point of view) will vary by industry, location, and firm, amongst other things so there will be no 'magic scale' which will hold for all activities or regions.

Third there may well be multiple spatial optima (and hence equilibria) from an efficiency point of view and no guarantee that the agglomerations that are observed are in fact optimal in and of themselves.

Fourth, agglomeration economies are also clearly dynamic and can be reversible. Urban 'sprawl' and suburbanisation are evidentiary realities as clear and compelling as agglomerations indicating that while human beings have clear tendencies to concentrate, this tendency has its limits and people stand ready to disperse when those limits are reached. Agglomeration does appear to be strongly correlated with economic development, with phenomena such as urban primacy and general urbanisation being especially strong in the developing world and suburbanisation trends being strongest in the developed world (World Bank 2009). Of course a balancing of agglomeration benefits with agglomeration costs is also undoubtedly taking place in many instances.

Finally regarding the estimates themselves, the productivity impacts observed could be said to be 'modest' or 'small', especially in the lower ranges. Thus if a doubling of city size 'only' increases labour productivity by 2% then perhaps it is not all that much to shout about. A counter-point to this is that at the margin even a figure as low as 2% might be very important, especially when compounded over time. Also these are averages and economies for particular projects or locations may be much smaller (or negative) as well as much larger.

## **4. A theoretical template for agglomeration economies**

### **4.1 The 'ideal' world of economic theory: a world without space**

All of this evidence still does not clarify what the economic basis of agglomerations is (and noting that surely there are noneconomic drivers as well). There is certainly no shortage of explanations even within neoclassical economic theory. This section does not add to this stock of narratives but instead seeks to put a bit of frame around this thinking to put some salient points into greater focus. This is particularly important from a policy standpoint in which the natural question is what types of agglomeration should government encourage and how should they encourage it?

The first point to note is the existence of physical space. This may seem an obvious point but in fact much of economic theory does not admit of activity or agents that take up or exist

in such space. Agglomerations are by definition spatial. But can economic theorists nonetheless abstract away from this key element to get a simple predictive and explanatory model that is useful in the real world?

Arrow and Debreu attempted to build such a world in their 1954 work laying out the possibility of 'complete contracting' in which all transactions between agents contain all attributes necessary to allow the drawing up of contracts between buyers and sellers and reach an ironclad general equilibrium across an entire economy. Physical space was added to this construct in the Theory of Value, by Debreu (1959). There he tries to incorporate this element by extending the Arrow-Debreu world by adding location to the commodity being traded, defining each commodity by all its characteristics including its location. This means that the same good traded in different locations must be treated as different commodities.

This approach of defining commodities as bundles of attributes has been used widely in economics (if not completely uncontroversially), for example, with Gary Becker's incorporation of time into commodities. However, applying this method to space doesn't work theoretically. Starrett's Impossibility Theorem shows (1978) shows that, even keeping the very restrictive and artificial assumptions needed to make an Arrow-Debreu and Debreu-extended world work, any finite number of economic agents and transactions will result in equilibria that avoid transportation costs entirely (Starrett 1978). Put another way, an economy with a finite number of locations and positive, resource-using transport costs cannot possess a competitive equilibrium. All this makes sense in a world where all locations are identical and activities are perfectly divisible: agents will of course be autarkic to eliminate transport costs (and trade). But the real world we observe obviously does not look this way.

#### **4.2 Violating assumptions**

So what to do? The argument of this paper is that it is both theoretically and practically fruitful to return to the underlying assumptions of the neoclassical paradigm and see how violations of one or more of these leads to (a) agglomeration economies and then (b) how transport investments might facilitate the particular type of agglomeration effect that results.

The major assumptions of the neoclassical model posit the following key working beliefs (having relaxed already the assumption of no physical space, a working hypothesis that is used in many economic arenas):

- (1) There are no transport costs
- (2) All space is 'homogeneous' (or to put it another way, space consists of a 'featureless plain')
- (3) Everyone has the same information and that information is 'complete' (and related: all agents have perfect foresight)
- (4) There is no interdependence in production and consumption (in other words, no externality); all goods are purely private in the economic theory sense
- (5) Capital and labour are perfectly divisible ('putty-clay')
- (6) Returns to production and consumption are constant and continuous
- (7) There is perfect competition in all markets
- (8) The primary unit of analysis consists of atomistic actors
- (9) All actors are rational, maximising and self-interested

The agglomeration economy implications of real world conditions that do not conform to each one of these assumptions will be considered below, touching upon each of the following aspects: (a) how agents will seek to take advantage of the condition in terms of their

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agglomeration/location choices); (b) the potential transport investments that might facilitate or enhance agglomeration economies under these conditions; and (c) the potential limiting factors to agglomeration economies strategies of both agents and transport investment authorities.

Of course there are interrelationships between these conditions but the simple thrust of the exercise below is to focus on a *ceteris paribus* relaxation of single assumptions in which all others are assumed to be holding. Some comments will be made later about multiple violations of assumptions, a circumstance that is likely the factual norm.

## **5. The implications of violating assumptions**

### **5.1 Positive transport costs**

Mainstream transport economics rests on the existence of positive transport costs and it also is a direct outgrowth of the Starrett Impossibility Theorem discussed above. Relaxing this assumption alone necessarily creates a situation where some locations are economically preferable to others because transport costs are minimised at those points. Assuming positive transport costs is the basis of the oldest of explicit spatial theories, namely Central Place theories, starting with von Thunen (1850, 1996) and Christaller (Rossler 1989) , who work with featureless plains, and, in theory, undifferentiated space, but nonetheless posit locations that are not identical to one another, simply because some areas have better market access than others. (Hotelling also works in this sort of logic, but with very different implications, as discussed more below).

Once one posits costs of moving about, then agents will find an incentive to be as close as possible to economic activity they desire to engage in (for consumers, to find employment and consumer goods, and for producers, to find workers and sell to consumers) and to do so in locations with lowest possible transport cost.

This model's equilibrium is conceptually quite simple: locate where marginal benefit of market access is equal to marginal transport cost (as yielded by a given transport infrastructure).

### **5.2. Nonhomogenous space**

Adding an assumption of non-homogeneity in space is the basis of probably the oldest economic explanation for location decisions. This could be as simple as the fact that some locations have natural geographic advantages (a port, for example) or, a little more sophisticated, some natural resource endowments (such as oil or coal or gold). This sort of locational difference is observed widely in actual fact and is the basis for Ricardian theories of trade based on absolute and comparative advantage. Later theories of trade, such as Hecksher/Ohlin provide more elaborated models but work with the same basic logic (Leamer 1995). These would be 'first nature' advantages. It also is possible to build up 'second nature' advantages over time in which case historical patterns of investment build up a locational 'edge' (such as a stock of parks or cultural institutions); this dynamic is considered in more detail later.

These trade theories imply that it pays, up to a point, to 'agglomerate' in areas with comparative advantage. The existence of positive transport costs reinforces this dynamic though it is possible to imagine a natural feature imposing a non-transport 'friction' cost all its own (e.g. an impassable mountain range). Unlike Central Place notions, theories such as this have the advantage of at least potentially making location choice endogenous (although closely based on an exogenous assumption of location-based advantage).

### **5.3. Incomplete information (imperfect foresight)**

Classical location theory has its roots in Hotelling's 1929 paper in which he assumes consumers are continuously distributed along a linear and bounded segment. He posits two

firms and consumers that pick between the two based on each one's respective price and their travel costs to reach each one relative to the location they currently occupy (Hotelling 1929). There are actually a number of dimensions to Hotelling's analysis including an element of imperfect competition (each store has a locational monopoly power of sorts relative to closeness of consumers) but incomplete information is a key element of this approach because the location advantage fundamentally derives from search minimisation: consumers find it costly to search for optimal price-quantity bundles and stores capitalise on that by locating strategically to minimise that search cost.

Using a sequential game process, Hotelling solves for optimal location and price and his innovation is to show the 'spatial competition is inherently strategic'. His analysis also shows the optimal location to be at the centre of the line. However, there is an analytical error in Hotelling's logic and later authors show that firms will seek to differentiate products and then locate at extremities. Nonetheless a strong force leading to clustering of particular stores remains minimisation of search costs (once consumers get to a location, their costs of travel there are 'sunk' and they are more likely to visit one area over another if there is a cluster of stores to search amongst and increase the probability of a good price-quality match). If one starts relaxing other assumptions, results become more varied. Schulz and Stahl (1996) for example show that competition from outside firms may be welcomed by existing firms within a cluster if such entry increases the size of the market by making it more attractive to consumers to visit that location (because of the increased cluster or increased variety of goods on offer).

#### **5.4. Externalities; Publicness in goods**

What causes clusters? The classic explanation is the so-called Marshallian Trinity developed by Alfred Marshall: input sharing (dense concentrations drive down prices and increase availability of specialised inputs due to pooling); labour market pooling (efficiencies in finding and hiring labour due to 'thick' labour pools); and knowledge spillovers (sharing of knowledge and ideas arising from proximity). The first two of these will be considered below under non-constant returns to scale. The last of these is clearly a non-market externality. 'Publicness' is closely related to externality, of course, which is why these two are being considered together. Infrastructure itself can become a quasi-public 'club' good, e.g. cultural amenities, or a good transport or communications network. It is also possible to consider 'knowledge' pools as a public good rather than an external effect. In both these cases agglomerations are encouraged by 'free riding' made possible by proximity.

The agent response to publicness or externality is clear: locate close enough to derive unpriced benefit until that benefit is exhausted relative to agglomeration costs.

#### **5.5. Indivisibilities in capital and labour**

Koopman saw indivisibilities as the key to agglomerations. He argued that perfectly divisible economic agents working with perfectly divisible capital could locate anywhere and geography would not matter in the least in that case. "While increasing returns are essential to understand why there are cities, it is hard to think of any single activity or facility subject to large-enough indivisibilities to justify the existence of cities. Thus, one of the main challenges for urban economists is to uncover mechanisms by which small-scale indivisibilities (or any other small-scale non-convexities) aggregate up to localised aggregate increasing returns capable of sustaining cities." [Garretson p. 430]. One could argue that this is the basic driver of the conditions discussed next: increasing returns to scale, imperfect competition and non-atomistic agents.

Indivisibilities of capital in particular by definition limit location choices. The classic 'putty-clay' capital of neoclassical growth theory makes location modelling tractable but not realistic and agents must live with minimum scales of activity and investment even if the 'indivisible' optimum is below that level. Indivisibilities can be across time as well as physical space and

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indeed most facilities, production or otherwise, are 'lumpy' in both senses. That is, they take time to build, have a set operating life and take time and resources to decommission as well as having minimum physical scales.

## **5.6. Nonconstant returns to scale**

The first two parts of the 'Marshallian Trinity' are essentially scale economies: (a) input sharing (dense concentrations drive down prices and up availability of specialised inputs due to pooling); and (b) labour market pooling (efficiencies in finding and hiring labour due to 'thick' labour pools). Less often referred to but related are economies of scope which refer to lowering of unit costs through joint production of two or more different goods than would be achieved by production individually by separate firms. Like scale economies these too may or may not be spatially driven. When either is spatial then we can speak of agglomeration effects (Parr 2002).

Lack of Constant Returns to Scale has been a centrepiece of the New Economic Geography (NEG). From an agent point of view NEG posits three centripetal forces based on Marshall: (1) market-size effects (linkages); (2) thick labour markets; (3) pure external economies; and three centrifugal forces: (1) immobile factors (2) land rents and (3) pure external diseconomies. Scale is a key decision and is both cause and effect of some of these forces: returns do vary with scale and this has various causes and does lead to agglomerations. This, of course, is not the only framework to consider returns to scale but it is one of the most formally elaborated ones.

## **5.7. Imperfect competition**

Market structure is a subtle feature. For example, there can be a reasonable assumption of competition in tradable goods, but lowered degrees of competition in nontradable sectors (such as differentiated local goods). There can also be differences in market structures of input and output markets. Theoretical models built along these lines yield a remarkable conclusion: diversity and variety in consumer goods or in producer inputs can yield external scale economies, even though all individual competitors and firms earn normal profits. And, ala the NEG, it can be the other way round: in imperfectly competitive settings there are market access effects in which monopolistic firms locate in big markets and export to small markets and market crowding effects in which imperfectly competitive firms locate in areas with fewer competitors.

In fact imperfect competition is widespread and, as seen in Hotelling and others, often spatially based. Producers will want to gain some sort of monopoly location advantage while consumers will want to gain monopsonistic advantage.

## **5.8 Non-atomistic agents**

For Oliver Williamson (1985), taking a neoclassical transactions costs stance, the transaction is the basic unit of analysis, something consistent with atomistic agents. But for business historian Alfred Chandler (1977), the firm is the basic unit of analysis. Just in this pair of different agents, there are significant differences in economic choices and agglomeration dynamics.

Changing the unit level of analysis goes to a fundamental question: who in fact is the relevant decision agent? The limiting factors will depend upon the agents. Assuming all are rational and maximising, nonetheless if firms are driving economic decisions, for example, their optimum decisions may work out differently than those for developers, governments, or consumers taken as a fundamental actors.

## **5.9. Non-rational, non-maximising agents**

A final frontier challenges the holy grail of economics: that all agents are rational and maximising. This violation goes beyond limits to rational decisionmaking (such as imperfect



information). In fact there could be 'anomalies' in spatial location such as 'altruism' or 'herd' effects. The implications for agent response are wide-ranging but unclear. Much depends on the actual nature of decision agents.

## 6. Conclusions and suggestions for further research

Where does this lead future and hopefully improved transport investment analysis? A few points are salient.

First, proving optimality is difficult because by definition one is looking at a 'theoretical' state. The theory on spatial optimality is far from conclusive and suggests that agglomerations, while natural, may not be always be the best scale from an economic point of view and will in any case come in many flavours. Thus while it is useful to have the 'first-best' as a benchmark for project analysis, such analysis might also more explicitly need to consider 'second-best' possibilities given actual complications on the ground.

Second, induction of at least a basic sort may be appropriate. Not least is an explicit consideration given to fundamental questions often taken for granted such as: who is the likely to be the key decision agent? What are their objectives? What is market structure in this area? And so forth. If these are nailed down with some certainty or at least certitude, then the consequent investment analysis can be adjusted accordingly.

Third, borrowing a page from the NEG, analysts should at least keep in mind that dynamics are relevant. Thus even if locations are ex ante identical, ex post they can be very different and this can be affected by investment decisions themselves interacting with other factors. 'Cumulative causation' forces may operate so that very small differences in initial conditions can translate into large differences in outcomes, and there are also path dependence and 'lock-in' effects.

Finally there are likely to be multiple violations of assumptions and interactions between these. Rather than opt for complex multivariate modelling it might be fruitful to keep things simple. Again, NEG provides some guidance. A key aspect of NEG from a modelling perspective is pair-wise comparison of key dispersive and concentration forces rather than a look at all interacting together [38]. If one has identified these forces already for a particular situation as suggested in the second point above then one could conduct relatively simple scenarios of opposing forces to get a better handle on potential outcomes and, perhaps most importantly, the way these outcomes will actually play out rather than just the end result.

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